ARTICLE | Article in Press

Color matching ability of single-shade resin-based composites: an in vitro study

Meltem Akbaba · Çağatay Barutçugil

Received: 17 July 2026 / Accepted: 22 October 2026
© The Author(s) 2026

Abstract

Single-shade resin-based composites (RBCs) are marketed as matching a wide range of tooth shades, although supporting evidence remains limited. This in vitro study evaluated the color-matching ability of Omnichroma (OMN), Vittra APS Unique (VTR), and Charisma Diamond One (DIA) against four shade backgrounds. Molds were fabricated from a conventional composite in A1, B1, JE, and BW shades, and standardized cavities were restored with each RBC (n = 15; 180 specimens). Color was measured using a clinical spectrophotometer. Two CIEDE2000 (ΔE_{00}) outcomes were calculated: polymerization-induced color change and the difference between the background mold and restored specimen. Data were analyzed using two-way ANOVA, followed by Welch's ANOVA and Games–Howell tests. Polymerization-induced ΔE_{00} ranged from 3.31 to 10.18, differed among materials in three of the four shade backgrounds ($p < 0.001$), and exceeded the perceptibility (0.8) and acceptability (1.8) thresholds in all groups. Only VTR against JE produced clinically acceptable matching (1.29 ± 0.24), although the difference remained perceptible. All other combinations exceeded the acceptability threshold. Color matching was material- and background-dependent and poorest against the most chromatic backgrounds, indicating that universal color matching should not be assumed under the tested conditions.

Keywords Single-shade composite · Color matching · Individual mold · Esthetic dentistry

Introduction

Shade selection and color matching are among the most technically demanding aspects of direct composite resin restorations. Achieving a visually imperceptible match between restorative material and the surrounding tooth structure requires careful consideration of hue, chroma, value, and translucency—parameters that vary not only between patients but across different regions of the same tooth[1,2]. Conventional multi-shade composite systems address this complexity by offering a broad palette of shades, but this approach introduces procedural burden and the risk of shade selection error, particularly under variable clinical lighting conditions[3].

Single-shade composite systems have emerged as an innovative solution to these challenges. These materials are engineered to achieve color adaptation across a range of tooth shades through structural coloration mechanisms rather than conventional pigmentation. Most notably, Omnichroma (Tokuyama Dental Corp.) incorporates

This Article in Press is shared early to give you faster access to new research. It is citable and carries a permanent DOI. The final edited version will replace it automatically.

Published online: 27 October 2026

scientific reports

monodisperse 260 nm spherical filler particles that produce structural color in the red-to-yellow spectral range through light scattering, enabling optical adaptation to the surrounding tooth substrate[4]. Other systems, such as Vittra APS Unique (FGM Dental Group) and Charisma Diamond One (Kulzer GmbH), employ related but distinct proprietary optical modification strategies.

Despite the commercial appeal and rapid clinical adoption of single-shade systems, the scientific evidence base regarding their actual color matching performance remains limited and heterogeneous[5,6]. Several in vitro studies have demonstrated that the color matching ability of these materials is influenced by multiple variables, including background shade, cavity dimensions, restoration depth, and the type of color metric applied[7,8]. A recent systematic review with meta-analysis confirmed that single-shade composites do not universally outperform multi-shade systems in color matching ability, and that performance varies substantially across shade backgrounds[9].

A further underexplored area is the polymerization-induced color shift in single-shade composites. Photopolymerization alters the optical properties of resin-based materials through changes in refractive index, filler-matrix interaction geometry, and degree of monomer conversion—all of which affect how the material appears to the eye and to measurement instruments[10]. For materials relying on structural coloration, these changes may be especially significant, as the Tyndall effect is highly sensitive to the size, distribution, and arrangement of filler particles[4].

The CIEDE2000 (ΔE_{00}) color difference formula is currently the recommended standard for dental colorimetric research[11]. Two clinically meaningful thresholds have been established for this formula: the 50:50% perceptibility threshold (PT: $\Delta E_{00} = 0.8$), below which a color difference is not detected by half of observers, and the 50:50% acceptability threshold (AT: $\Delta E_{00} = 1.8$), beyond which a color difference is judged clinically unacceptable by half of observers[12]. Because a statistically significant difference between materials does not in itself indicate whether a color difference would be perceived or accepted clinically, these thresholds provide the criteria against which the clinical relevance of the measured color differences can be judged, and they were therefore incorporated into the study hypotheses. The null hypotheses of the present study were: ($H_0 1$) there is no statistically significant difference in polymerization-induced color change among the three single-shade RBCs within each shade group; ($H_0 2$) there is no statistically significant difference in color matching ability (ΔE_{00} background mold vs. specimen) among the three single-shade RBCs within each shade group; and ($H_0 3$) for each material–background combination, neither the polymerization-induced color change nor the color difference relative to the background mold differs from the acceptability threshold ($\Delta E_{00} = 1.8$).

Materials and methods

Materials

Three commercially available single-shade resin-based composites were evaluated (Table 1): Omnichroma (OMN; Tokuyama Dental Corp., Tokyo, Japan), Vittra APS Unique (VTR; FGM Dental Group, Joinville, Brazil), and Charisma Diamond One (DIA; Kulzer GmbH, Hanau, Germany). A conventional multi-shade composite (G-aenial, GC Europe, Leuven, Belgium) served as the shade background material in four shades: A1, B1, JE (Junior Enamel), and BW (Bleach White).

These four backgrounds were selected to represent a range of colorimetric properties within the G-ænial Anterior shade system; their measured color coordinates are reported in Section "Color measurements".

Sample size determination

The required sample size was determined a priori using G*Power software (v3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Germany), specifying an F test for one-way analysis of variance (fixed effects, omnibus) entered with twelve groups, corresponding to the twelve material–shade subgroups. A large effect size was assumed (Cohen's $f = 0.40$, following Cohen's convention for a large effect), consistent with the low within-group variability in

Table 1 Materials used in the study.

Code	Material	Category	Resin matrix	Filler type and particle size	Filler content (wt%)	Manufacturer	Lot no
OMN	Omnichroma	Supra-nanofilled single-shade composite (structural color)	UDMA, TEGDMA	Spherical SiO_2–ZrO_2, 260 nm; composite filler	79	Tokuyama Dental Corp., Tokyo, Japan	188M3
VTR	Vittra APS Unique	Nanohybrid single-shade composite	UDMA, TEGDMA	Nanospheres of a zirconia complex, 200 nm; Advanced Polymerization System (APS) photoinitiator composition	82	FGM Dental Group, Joinville, Brazil	021,020
DIA	Charisma Diamond One	Nanohybrid single-shade composite	TCD-DI-HEA, UDMA, TEGDMA	B_2O_3–F–Al_2O_3–SiO_2 glass, silica, TiO_2, fluorescent, metallic oxide and organic pigments, 5–20 µm	81	Kulzer GmbH, Hanau, Germany	M010207
REF	G-ænial Anterior (A1, B1, JE, BW)	Microfilled hybrid conventional multi-shade composite (background molds)	UDMA and dimethacrylate co-monomers (Bis-GMA free)	Two pre-polymerised resin fillers (silica-containing; strontium- and lanthanoid-fluoride-containing), 16–17 µm; silica > 100 nm; fumed silica < 100 nm	76	GC Europe N.V., Leuven, Belgium	**A1-**2,406,131 **B1-**2,406,251 **JE-**2405081 **BW-**2306021

Composition data are as reported in the manufacturers' current instructions for use and technical documentation. Filler content is given by weight, as volumetric filler content is not reported by the manufacturer for all materials. All materials were used within their manufacturer-stated expiry dates. JE, Junior Enamel; BW, Bleach White.

ΔE_{00} previously reported for single-shade composites in cavity models[13]. With $\alpha = 0.05$ and statistical power $(1-\beta) = 0.95$, a total of 168 specimens was required, corresponding to 14 per subgroup. Fifteen specimens per subgroup were prepared (180 in total) to provide additional reliability and to account for potential specimen exclusions, consistent with comparable published studies[8,14].

Because the primary analyses compared the three composites within each shade background separately, a sensitivity analysis was additionally performed for a three-group design. With n = 15 per group, $\alpha = 0.05$, and 95% power, the smallest detectable effect size was $f = 0.61$. Observed effect sizes ranged from f = 0.40 to f = 2.91 and exceeded this value in six of the eight comparisons. Polymerization-induced color change within the A1 group (f = 0.55) and background matching within the B1 group (f = 0.40) were below the sensitivity threshold and should therefore be interpreted with corresponding caution.

Individual mold preparation

Shade-specific composite molds were individually fabricated from G-ænial Anterior resin composite (GC Europe, Leuven, Belgium) in each of the four designated shade backgrounds: A1, B1, JE (Junior Enamel), and BW (Bleach White). For each shade, rectangular blocks (8 mm × 4 mm × 4 mm) were prepared using a standardized stainless steel mold. The composite was packed in 2 mm increments and each increment was light-cured for 20 s through a polyethylene terephthalate (Mylar) strip using an LED curing unit (Valo, Ultradent Products, South Jordan, UT, USA) at a verified irradiance of 1000 mW/cm2 (confirmed by digital radiometer; Valo Calibrator, Ultradent). All molds were subsequently post-cured in a laboratory polymerization unit (Labolight Duo, GC Europe, Leuven, Belgium) at 1200 mW/cm2 for 3 min. This step was applied to the molds only, and not to the single-shade specimens, because the molds functioned as standardized optical substrates rather than as restorations: maximising monomer conversion minimises conversion-dependent drift in their color and ensures that each background remains chromatically stable throughout specimen preparation and measurement, so that any color difference recorded is attributable to the restorative material rather than to the reference against which it is measured.

Single-shade specimen preparation

Three cylindrical cavities (4 mm diameter × 2 mm depth) were created in each mold using a calibrated flat-end cylindrical carbide bur in a slow-speed handpiece, producing cavities with flat floors and parallel walls; one cavity in each mold was restored with each of the three single-shade composites, so that the three materials were evaluated against the same individual background within every mold. Cavity walls were isolated with a thin layer of petroleum jelly to prevent adhesion between the mold and the single-shade composite. After isolation, cavities were gently air-dried and filled with the respective single-shade RBC in a single increment. A Mylar strip was placed on the composite surface prior to polymerization to ensure a smooth, uniform surface finish. Because each cavity had fixed dimensions and was filled level with the mold surface in a single increment, the unpolymerized material presented a standardized thickness of 2 mm and a flat, reproducible surface at T0. The T0 color measurement was performed before light activation, with the Mylar strip remaining in place to contain and standardize the surface of the unpolymerized composite. Each specimen was then light-cured through the Mylar strip for 20 s using the same LED curing unit (Valo, Ultradent Products) at a verified irradiance of 1000 mW/cm2, with the light guide held in direct contact with the strip. Following polymerization, the Mylar strip was removed, and the T1 color measurement was performed directly on the polymerized composite surface within five minutes of light curing, so that the recorded difference reflects the immediate optical effect of the polymerization reaction. In contrast to the background molds, the single-shade specimens were not post-cured, so that their degree of conversion would correspond to that achievable under chairside conditions. Specimens were subsequently stored dry at room temperature (23 ± 1 °C) in light-protected containers. Fifteen specimens per subgroup per shade background were prepared, yielding a total of 180 single-shade specimens (3 materials × 4 shade backgrounds × 15 specimens).

Color measurements

Color measurements were performed using a calibrated clinical spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, Bad Säckingen, Germany), recalibrated against its built-in white reference tile at the start of each session. The Easyshade V is a contact-type clinical spectrophotometer developed primarily for intraoral measurement of natural teeth and ceramic restorations. It was selected because it has been widely used in in vitro studies of the color and color matching of resin composites, including two of the single-shade composites evaluated here[13,15], which allows the present results to be compared directly with the existing literature, and because its contact probe permitted repeated measurements at a reproducible position on the specimen surface without removing the specimen from its mold. The device was operated in Tooth Single mode, and all readings were performed under standardized D65 illuminant conditions with a 45°/0° geometry. The device recorded CIE L*, a*, and b* coordinates for each measurement point, and color differences were subsequently calculated from these coordinates using the CIEDE2000 (ΔE_{00}) formula with parametric factors $kL = kC = kH = 1$[11]. All calculations were performed in Python (version 3.12). At T0, the probe tip was positioned perpendicular to and in direct contact with the Mylar strip covering the unpolymerized composite. Following light curing and removal of the Mylar strip, the T1 measurement was performed with the probe tip positioned perpendicular to and in direct contact with the polymerized composite surface. For both measurements, the probe was centered over the restoration and held flush with the flat upper surface so that the measurement aperture was fully seated. Background mold color was recorded at a standardized location on the flat upper surface of each block, adjacent to the cavity margin. As each cavity occupied a fixed position within its mold and the probe was seated centrally over it, the same restoration site was measured at T0 and T1. Identical instrument settings were used for the specimen and background readings. All measurements were performed inside a measurement cabinet with a white interior. Throughout every measurement, the specimen remained within its mold, so that the restoration was backed by 2 mm of the shade-specific composite forming its optical background, and the mold rested on the white floor of the cabinet; no additional backing tile or contrasting substrate was introduced. All measurements were performed by a single trained operator. Every measurement — of both the background molds and the specimens, and at both

time points — was repeated three times and averaged. The reliability of the repeated readings was assessed by calculating the coefficient of variation of the L* coordinate across the three measurements taken at each point; L* was used for this purpose because a* and b* can approach zero, which renders the coefficient of variation unstable. Where the coefficient of variation exceeded 5%, all three readings for that point were discarded and the measurement was repeated.

The CIE L*, a*, b* coordinates of the four backgrounds, obtained from the background mold readings (mean ± SD, n = 15 molds per shade), were as follows: A1, L* = 78.37 ± 0.98, a* = 0.33 ± 0.35, b* = 16.65 ± 0.82; B1, L* = 83.35 ± 0.43, a* = −2.79 ± 0.08, b* = 12.03 ± 0.29; JE, L* = 79.69 ± 0.64, a* = −5.23 ± 0.10, b* = 5.03 ± 0.37; and BW, L* = 88.63 ± 0.83, a* = −0.25 ± 0.10, b* = 17.69 ± 0.29. The backgrounds therefore spanned a chroma range from C*ab = 7.3 (JE) to 17.7 (BW) and a lightness range from L* = 78.4 (A1) to 88.6 (BW). Because these values were obtained under the measurement conditions of the study, they describe the optical backgrounds as encountered by the specimens and may differ from the nominal characteristics of the corresponding shades.

Two ΔE_{00} outcomes were computed: (1) ΔE_{00} Before–After Polymerization: color difference between the unpolymerized composite (T0) and polymerized specimen (T1); and (2) ΔE_{00} background mold versus specimen: the color difference between the polymerized specimen (T1) and the surrounding surface of the shade-specific background mold in which it was placed. No separate reference disc was used; each specimen was compared with the mold that formed its own optical background. Color differences were interpreted against the CIEDE2000 perceptibility threshold (PT: $\Delta E_{00} = 0.8$) and acceptability threshold (AT: $\Delta E_{00} = 1.8$)[12].

A schematic overview of the specimen preparation and color measurement protocol is shown in Fig. 1.

Statistical analysis

Statistical analyses were performed in Python (version 3.12) using the SciPy library (version 1.17)[16]. Welch's analysis of variance, the Games–Howell procedure, and the Welch–James test, which are not available as built-in SciPy functions, were implemented according to their original descriptions. Normality was assessed within each of the twelve material–shade subgroups using the Shapiro–Wilk test, and homogeneity of variance using Levene's test. A two-way analysis of variance was performed for each outcome, with shade background and composite material as fixed factors, to test their main effects and interaction. Because Levene's test indicated heterogeneous variances for both outcomes, the two-way results were verified using the Welch–James approximate degrees-of-freedom test, which does not assume equal variances. To test the third hypothesis, one-sample t-tests compared the ΔE_{00} values of each material–shade combination against the acceptability threshold ($\Delta E_{00} = 1.8$), separately for polymerization-induced color change and for background matching; where a mean value fell below the acceptability threshold, it was additionally compared against the perceptibility threshold ($\Delta E_{00} = 0.8$). To control the familywise Type I error across the twelve tests within each outcome, a Bonferroni-adjusted significance level of $\alpha = 0.05/12 = 0.00417$ was applied to these tests. Because the interaction term was significant for both outcomes, simple main effects were examined within each shade background using Welch's analysis of variance, followed by Games–Howell post hoc comparisons; neither procedure assumes equal variances. These procedures were applied uniformly to all eight simple-effect analyses rather than selected on the basis of the preliminary assumption tests. To control the familywise Type I error arising from these eight analyses, a Bonferroni-adjusted significance level of $\alpha = 0.00625$ was applied; the nominal α for the two-way analyses and assumption tests was 0.05. Partial eta squared ($\eta 2_p$) is reported as a measure of effect size for the two-way analyses.

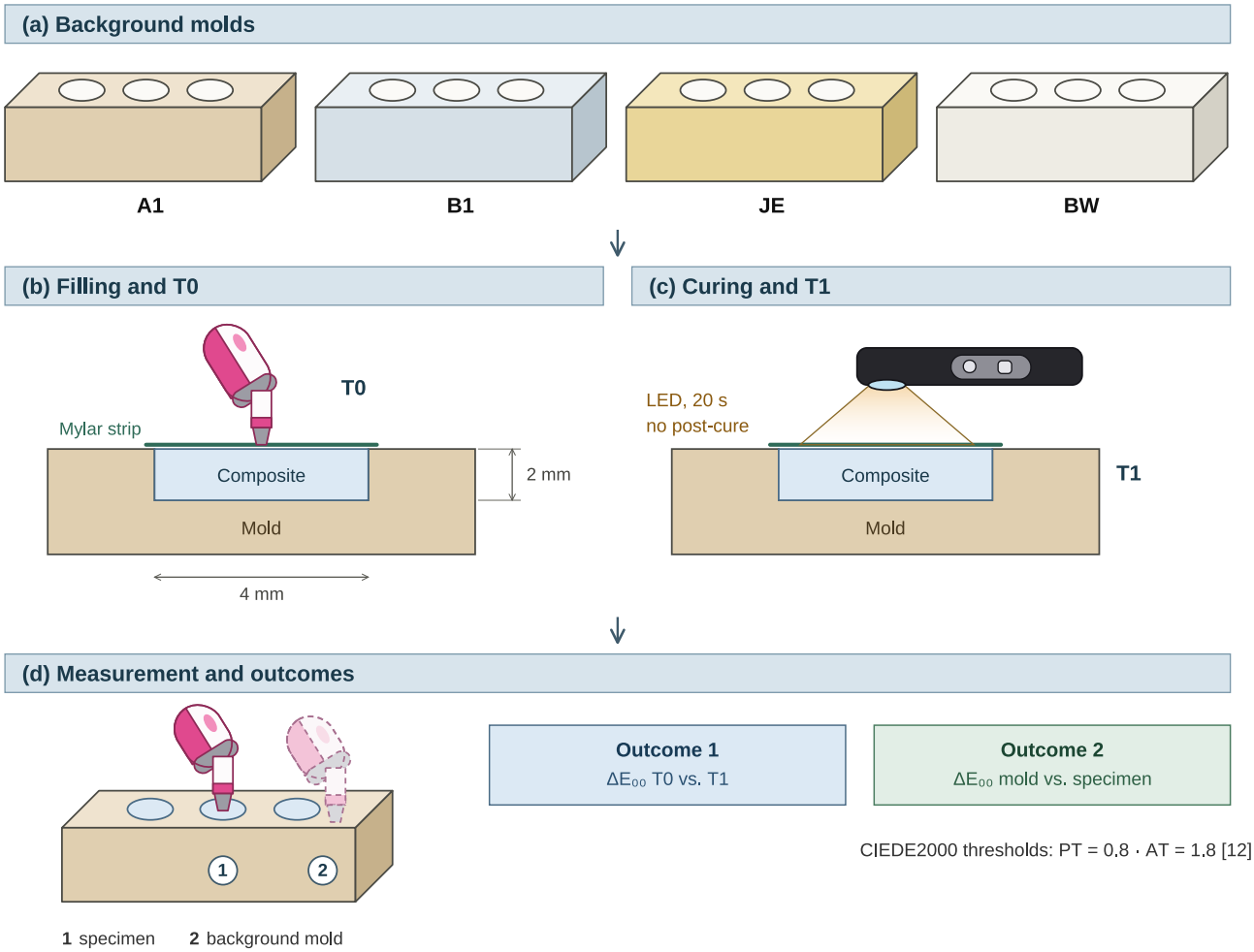


Fig. 1 Schematic overview of specimen preparation and color measurement. (**a**) Background molds fabricated from a conventional composite (G-ænial Anterior) in four shades—A1, B1, JE (Junior Enamel) and BW (Bleach White)—each containing cylindrical cavities of 4 mm diameter and 2 mm depth. Molds were built in 2 mm increments, each cured for 20 s, and were subsequently post-cured for 3 min to stabilize the optical reference; the tints shown are schematic and do not represent the actual shades. (**b**) Each cavity was isolated with petroleum jelly, filled with a single-shade composite in one increment level with the mold surface, and covered with a Mylar strip. The baseline reading (T0) was obtained through the strip, before light activation, from an unpolymerized layer of standardized 2 mm thickness (n = 15 per material and shade background; 180 specimens in total). (**c**) Specimens were light-cured through the Mylar strip for 20 s at 1000 mW/cm^2. The Mylar strip was then removed, and the T1 reading was obtained directly from the polymerized composite surface within five minutes of light curing. No post-curing was applied to the specimens, so that their degree of conversion corresponded to that achievable under chairside conditions. (**d**) Color was recorded with a contact spectrophotometer (VITA Easyshade V) operated in Tooth Single mode, with the probe held perpendicular and flush to the flat surface and the specimen remaining within its mold: (**1**) centrally over the restoration and (**2**) at a standardized location on the background mold adjacent to the cavity margin. Three readings were averaged per point, and CIE L*, a*, b* coordinates were used to calculate two CIEDE2000 outcomes—the polymerization-induced color change (T0 versus T1) and the color difference between the background mold and the restored specimen. PT, perceptibility threshold; AT, acceptability threshold.

Results

Two-way analysis of variance

Shapiro–Wilk tests did not indicate departures from normality in 23 of the 24 subgroups ($p \geq 0.051$); the single exception was background matching for DIA against the B1 background ($p = 0.046$). Levene's test

Table 2 Mean (± SD) ΔE_{00} values for polymerization-induced color change and color matching against the four shade backgrounds.

	ΔE_{00} (before–after polymerization)				ΔE_{00} (background mold vs. specimen)			
Shade	OMN	VTR	DIA	*p*	OMN	VTR	DIA	*p*
A1	7.41 ± 1.01	6.33 ± 0.77	6.76 ± 0.56	0.012 †	7.29 ± 0.71 [a]	8.69 ± 0.72 [b]	7.67 ± 0.66 [a]	< 0.001
B1	8.12 ± 0.51 [c]	6.72 ± 0.71 [b]	4.64 ± 2.67 [a]	< 0.001	4.87 ± 0.35	5.30 ± 0.41	4.59 ± 1.12	0.008 †
JE	10.18 ± 0.96 [c]	7.70 ± 1.11 [b]	6.67 ± 0.81 [a]	< 0.001	2.64 ± 0.64 [b]	1.29 ± 0.24 [a]*	3.26 ± 1.06 [b]	< 0.001
BW	7.02 ± 0.36 [c]	4.58 ± 0.54 [b]	3.31 ± 0.65 [a]	< 0.001	7.21 ± 0.65 [b]	7.61 ± 0.31 [b]	5.85 ± 0.44 [a]	< 0.001

Values are presented as mean ± standard deviation (n = 15 per subgroup). Omnibus comparisons were performed using Welch's ANOVA and evaluated against a Bonferroni-adjusted significance threshold of α = 0.00625. Games–Howell pairwise comparisons were interpreted only when the corresponding omnibus test met this adjusted threshold. Within each row and outcome, values sharing the same superscript letter did not differ significantly according to the Games–Howell test ($p > 0.05$). †The omnibus results for polymerization-induced color change within the A1 group ($p = 0.012$) and for background matching within the B1 group ($p = 0.008$) did not meet the Bonferroni-adjusted significance threshold; pairwise comparisons were therefore not interpreted and superscript letters are not presented. *Only value below the 50:50% acceptability threshold (AT, $\Delta E_{00} = 1.8$); the 50:50% perceptibility threshold (PT) is 0.8[12]. OMN, Omnichroma; VTR, Vittra APS Unique; DIA, Charisma Diamond One; JE, Junior Enamel; BW, Bleach White.

indicated heterogeneous variances across the twelve subgroups for both polymerization-induced color change ($F(11,168) = 17.99$, $p < 0.001$) and background matching ($F(11,168) = 9.22$, $p < 0.001$). Within individual shade backgrounds, variances were heterogeneous for polymerization-induced color change in the A1 ($p = 0.008$) and B1 ($p < 0.001$) groups, and for background matching in the B1 ($p < 0.001$), JE ($p < 0.001$), and BW ($p = 0.026$) groups.

For polymerization-induced color change, both main effects and their interaction were significant (shade background: $F(3,168) = 69.97$, $p < 0.001$, $\eta^2_p = 0.555$; material: $F(2,168) = 111.10$, $p < 0.001$, $\eta^2_p = 0.569$; interaction: $F(6,168) = 8.37$, $p < 0.001$, $\eta^2_p = 0.230$). For background matching, the shade background exerted a large main effect ($F(3,168) = 597.56$, $p < 0.001$, $\eta^2_p = 0.914$) and the material a small one ($F(2,168) = 4.95$, $p = 0.008$, $\eta^2_p = 0.056$), with a substantial interaction between the two factors ($F(6,168) = 26.83$, $p < 0.001$, $\eta^2_p = 0.489$). All effects remained significant when the assumption of equal variances was relaxed using the Welch–James test (polymerization-induced color change: shade background $F(3, 54.2) = 147.23$, material $F(2, 49.3) = 129.06$, interaction $F(6, 64.4) = 15.75$, all $p < 0.001$; background matching: shade background $F(3, 59.1) = 547.45$, $p < 0.001$; material $F(2, 78.4) = 5.57$, $p = 0.006$; interaction $F(6, 61.9) = 37.48$, $p < 0.001$). The significant interactions indicate that the relative performance of the three composites depended on the shade background, and simple main effects were therefore examined within each background separately, with a Bonferroni-adjusted significance level of $\alpha = 0.00625$.

Polymerization-induced color change (ΔE_{00} before–after)

Welch's ANOVA indicated significant differences in polymerization-induced color change among the three composites within the B1, JE, and BW groups ($p < 0.001$; Table 2). Within the A1 group, the nominal p value of 0.012 did not meet the Bonferroni-adjusted significance threshold, and this difference was therefore not considered statistically significant. Mean ΔE_{00} before–after values ranged from 3.31 to 10.18, substantially exceeding both the PT (0.8) and the AT (1.8). The largest change was observed for OMN in the JE group (10.18 ± 0.96), significantly greater than both VTR (7.70 ± 1.11) and DIA (6.67 ± 0.81; Games–Howell, $p < 0.001$). The smallest polymerization color change was recorded for DIA in the BW group (3.31 ± 0.65). One-sample t-tests confirmed that the polymerization-induced color change exceeded the acceptability threshold in every material–shade combination ($t = 4.13$–56.28, $p \leq 0.001$, below the Bonferroni-adjusted threshold of $\alpha = 0.00417$ in all cases), with effect sizes ranging from $d = 1.07$ for DIA against the B1 background to $d = 14.53$ for OMN against BW.

Color matching against shade background (ΔE_{00} background mold vs. specimen)

Welch's ANOVA indicated significant inter-material differences in shade-background matching for the A1, JE, and BW backgrounds ($p < 0.001$; Table 2). Although the nominal p value for the B1 background was 0.008, this result did not meet the Bonferroni-adjusted significance threshold of $\alpha = 0.00625$ and was therefore not considered statistically significant. No material–background combination produced a color difference below the perceptibility threshold (0.8). One combination fell between the two thresholds and was therefore perceptible but clinically acceptable: VTR against the JE shade background ($\Delta E_{00} = 1.29 \pm 0.24$), the sole clinically acceptable result across all tested conditions. All remaining combinations exceeded the acceptability threshold (1.8) and were therefore clinically unacceptable. One-sample t-tests confirmed this classification: the background-matching ΔE_{00} significantly exceeded the acceptability threshold in eleven of the twelve combinations ($t = 5.06–72.72$, $p < 0.001$), whereas VTR against the JE background was significantly below the acceptability threshold ($t = -8.28$, $p < 0.001$) and significantly above the perceptibility threshold ($t = 8.08$, $p < 0.001$). A1 and BW backgrounds consistently produced the highest ΔE_{00} Background Mold vs. Specimen values (range: 5.85–8.69).

Discussion

The present study evaluated polymerization-induced color change and background matching in three single-shade composites representing different optical adaptation strategies. The first null hypothesis was partially rejected: the three materials differed significantly in polymerization-induced color change within the B1, JE, and BW groups, whereas the difference observed for A1 did not meet the Bonferroni-adjusted significance threshold. The second null hypothesis was likewise partially rejected: significant inter-material differences in shade-background matching were detected for the A1, JE, and BW backgrounds, whereas the difference observed for B1 did not meet the Bonferroni-adjusted significance threshold. The third null hypothesis was rejected for every material–background combination. All polymerization-induced color changes, and the background-matching values of eleven of the twelve combinations, significantly exceeded the acceptability threshold ($AT = 1.8$); the single exception, VTR against the JE background, fell significantly below the AT while remaining above the perceptibility threshold ($PT = 0.8$). No combination therefore produced an imperceptible color difference, and the claim of universal color matching is not supported for any of the tested materials under the conditions of this study.

The large polymerization-induced color shifts observed (mean $\Delta E_{00} = 3.31–10.18$) consistently exceeded clinical thresholds. Such changes reflect the optical transition that occurs during photopolymerization, in which monomer-to-polymer conversion alters the refractive index of the resin matrix and thereby shifts the L*, a*, b* coordinates[10]. Changes of comparable magnitude have been reported for conventional composites: across 41 shades of eight conventional materials, polymerization-induced color change ranged from 1.1 to 7.9 ΔE^*ab units and was driven mainly by decreases in lightness and chroma[17]. In the present study, lightness and chroma likewise decreased after polymerization in all twelve groups, although the pattern differed between materials: the decrease in chroma predominated for OMN ($\Delta C^*ab = -7.9$ to -8.7), whereas the decrease in lightness predominated for VTR and DIA ($\Delta L^* = -4.9$ to -9.6). As ΔE^*ab values have been reported to be approximately 1.5 times the corresponding ΔE_{00} values[15], the changes recorded here correspond to roughly 5–15 ΔE^*ab units, overlapping with but extending beyond the range reported for conventional materials. This comparison is necessarily indirect, since specimen thickness, measurement timing, instrument, and color-difference formula differed, and no conventional composite was evaluated under the same protocol in the present study; the data therefore do not establish that single-shade composites undergo larger polymerization-induced color changes than conventional materials. They do show, however, that single-shade composites are not exempt from this general behavior of resin composites. This is of particular clinical relevance because these materials are intended to be placed without shade selection, so that the appearance of the unpolymerized material cannot serve as a guide to the final result[17]. The polymerization-induced color changes reported here reflect conversion levels attainable with

chairside light-curing alone, as the specimens were deliberately not post-cured; the magnitude of these changes is therefore clinically representative rather than an artefact of laboratory over-curing.

The most striking finding was OMN's exceptionally high polymerization color change in the JE group (10.18 ± 0.96). The reason for this cannot be determined from the present data. As the JE background had the lowest chroma of the four backgrounds (C*ab = 7.3), the effect cannot be attributed to a strongly chromatic substrate; it may instead relate to the change in translucency that OMN undergoes during polymerization, which would make the color of the unpolymerized material particularly dependent on the underlying substrate. It should be emphasised that this interpretation is speculative: neither filler geometry nor spectral reflectance was measured here, and the proposed mechanism cannot be inferred from ΔE_{00} values alone. Substrate-dependent variation in the color reproducibility of Omnichroma has likewise been reported previously[18], supporting the view that its structural color mechanism is not equally effective across all chromatic backgrounds. Spectrophotometric and microscopic analyses of the material before and after polymerization would be required to test this hypothesis.

VTR's perceptible but clinically acceptable matching against the JE background ($\Delta E_{00} = 1.29 \pm 0.24$) is the most clinically significant positive finding of this study. The coordinates recorded in this study indicate the basis of this result: against the JE background, polymerized VTR differed from the background by less than one unit in both lightness and chroma ($\Delta L^* = 0.0$; $\Delta C^*ab = +0.9$), whereas OMN and DIA were 3.3 and 4.5 units darker than the background, respectively. Why the intrinsic color of VTR after polymerization lay closer to this background than to the others cannot be determined from the present data and would require spectral reflectance measurements to establish. Importantly, VTR produced substantially higher ΔE_{00} values against the A1, B1, and BW backgrounds (5.30–8.69), confirming that this favorable result is shade-specific rather than evidence of universal color matching.

The consistent finding that A1 and BW backgrounds were the most challenging for all three materials warrants clinical consideration. These were the two backgrounds with the highest chroma (C*ab = 16.7 and 17.7, respectively), and the measured coordinates suggest that chroma was the principal source of mismatch. After polymerization, the chroma of all three composites remained within a narrow range (C*ab ≈ 7–11) regardless of the background, so that the restorations were 6.6–8.4 units less chromatic than the A1 and BW backgrounds, whereas against the low-chroma JE background the difference in chroma did not exceed one unit. Although these component differences were examined descriptively rather than tested statistically, they indicate that the capacity of the tested materials to adapt to highly chromatic substrates was limited under the conditions of this study. These findings are consistent with previous work reporting that single-shade composites, including VTR, showed increased ΔE_{00} values toward both extreme-value and high-chroma backgrounds[8], as well as with in vitro comparisons indicating that single-shade systems do not consistently outperform conventional multi-shade composites[19].

Three distinct concepts should be separated when interpreting these findings. Statistical significance indicates only that the composites differed from one another more than would be expected by chance; it does not indicate whether the observed color difference would be visible or clinically tolerated. Perceptibility refers to whether a color difference can be detected by an observer, whereas acceptability refers to whether a perceptible difference remains clinically tolerable. These concepts do not necessarily coincide: a difference may be statistically significant yet imperceptible, or perceptible yet clinically acceptable. Within the JE background, the differences among the three materials were statistically significant; however, VTR was perceptible but clinically acceptable ($\Delta E_{00} = 1.29$), whereas OMN and DIA exceeded the acceptability threshold ($\Delta E_{00} = 2.64$ and 3.26, respectively).

The background molds were post-cured in a laboratory unit, a procedure that does not correspond to routine clinical practice for direct restorations. This was a deliberate methodological choice rather than an attempt to simulate clinical conditions: because the molds served as the chromatic reference against which every specimen was assessed, their optical stability was a prerequisite for valid measurement, and additional polymerization minimises the residual conversion that would otherwise allow the reference color to shift between measurement sessions. The single-shade specimens, by contrast, were cured only with a chairside LED unit, so the restorative materials themselves were assessed under clinically representative conditions.

It should nevertheless be acknowledged that a fully converted conventional composite may not be optically identical to the same material cured at the chairside. Higher degrees of conversion have been associated with small changes in refractive index and translucency, and the background shades used here may therefore differ slightly from their clinical counterparts. Although this effect was applied consistently across all subgroups, it may have influenced the absolute background-matching values and potentially the relative performance of the materials. Therefore, the findings should be interpreted as applying to a standardized in vitro substrate rather than to a chairside-cured restoration.

A key methodological strength of this study is the use of individually fabricated shade-specific composite molds, which provided a standardized and reproducible optical background for each test condition—an approach that eliminates the variability inherent in natural tooth substrates and enables direct comparison of material performance across distinct chromatic backgrounds. Nevertheless, several limitations should be acknowledged. The in vitro design, by nature, does not capture the full complexity of the clinical environment, where surrounding enamel and dentin contribute dynamically to the optical behavior of restorations. An important limitation of the present design is the absence of a conventional multi-shade composite as a comparator group. G-ænial Anterior served solely as the substrate for the background molds and was not itself placed as a restoration; the study therefore does not allow the color-matching performance of the tested single-shade composites to be compared directly with that of a conventional, shade-matched restorative system. The ΔE_{00} values reported here describe the performance of the three single-shade materials against each background in absolute terms, but cannot indicate whether that performance is better or worse than would be achieved with a conventional composite selected to match the same shade. Additionally, the absence of artificial aging protocols means that long-term color stability under clinical service conditions was not assessed. Because the T0 measurement of the unpolymerized composite was necessarily performed through a Mylar strip, whereas the T1 measurement was obtained directly from the polymerized surface after removal of the strip, a minor influence of this difference in measurement interface on the recorded polymerization-induced color change cannot be excluded. In addition, because the molds rested on the white floor of the measurement cabinet, the white supporting surface may have contributed to the measured color of both the backgrounds and the specimens. A previous study using the same type of instrument reported a difference of only $\Delta E_{00} = 0.1$ between measurements of approximately 4 mm-thick composite specimens with and without a black backing[15], which suggests that this influence was small at the total composite thickness of 4 mm beneath the probe in the present study, although it may have been greater for the more translucent JE background. As the same configuration was used for every reading, it is unlikely to have affected the comparisons within the study.

The measuring instrument represents a further limitation. The VITA Easyshade V was developed primarily for measuring natural teeth and ceramic restorations and is not a reference-grade laboratory spectrophotometer. Like other contact-type devices with a small measuring aperture, it is susceptible to edge loss, whereby part of the light entering a translucent material is scattered laterally and exits outside the aperture, reducing the measured reflectance. Because resin composites are generally more translucent than ceramics, and because the translucency of the tested materials differed and changed during polymerization, this effect may have influenced not only the absolute L*, a*, b* values but also the magnitude of the recorded color differences, including the polymerization-induced changes and the differences between materials. Its influence was limited by using the same device, settings, operator, and probe position for every reading, so that each ΔE_{00} value reflects the difference between two measurements obtained under identical instrumental conditions. Nevertheless, the findings should be confirmed using a laboratory spectrophotometer with a larger measuring aperture or an integrating-sphere geometry. The study was powered to detect large between-material differences. The two comparisons whose observed effect sizes fell below the minimum detectable effect size—polymerization-induced color change within the A1 group and background matching within the B1 group—were also the only two that did not reach statistical significance after correction for multiple comparisons; the absence of a significant difference under these two conditions should therefore not be interpreted as evidence of equivalence among the materials. Future studies should include

a shade-matched conventional composite as a control group, incorporate thermocycling and intraoral simulation protocols, and extend the current model to include varying cavity geometries and restoration depths.

Conclusions

Within the limitations of this in vitro study, which evaluated three single-shade composites against four composite backgrounds using a clinical spectrophotometer, the following conclusions can be drawn. First, the color of all three materials changed markedly during polymerization, so the appearance of the unpolymerized material does not reliably indicate the final result, and color matching should therefore be judged only after light curing. Second, background matching depended on the specific combination of material and background, and none of the materials matched all four backgrounds acceptably; the claim of universal color matching was therefore not supported for any of the tested materials. Third, the poorest matching occurred against the most chromatic backgrounds, suggesting that the ability of these materials to adapt to strongly chromatic substrates is limited. As no conventional composite was included for comparison, these findings describe the absolute performance of the tested materials rather than their performance relative to shade-matched conventional composites, and clinical studies on natural teeth are needed before they can be applied to practice.

Acknowledgements None.

Author contributions Ç. B. contributed to the conceptualization, formal analysis, supervision, and validation of the study. M. A. was responsible for the investigation and methodology and drafted the original manuscript. M. A. also revised and edited the manuscript. All authors have read and approved the final version of the manuscript.

Funding No funding was obtained for this study.

Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Open Access This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

References

1. Paravina, R. D., Westland, S., Johnston, W. M., Powers, J. M. & Imai, F. H. Color adjustment potential of resin composites. *J. Dent. Res.* **85**, 854–858 (2006).

2. Fondriest, J. F. Shade matching in restorative dentistry: The science and strategies. *Int. J. Periodontics Restorative Dent.* **23**, 467–479 (2003).
3. Ismail, E. H. & Paravina, R. D. Color adjustment potential of resin composites: Optical illusion or physical reality, a comprehensive overview. *J. Esthet. Restor. Dent.* **34**, 42–54 (2022).
4. Sampaio, C. S., Atria, P. J., Rached, R. N., Mazur, R. F. & Giannini, M. Color adaptability of a single-shade composite resin in cavities of different backgrounds. *Am. J. Dent.* **32**, 263–268 (2019).
5. Pecho, O. E. et al. Color-matching ability of dental composites: CIEDE2000 and perceptibility and acceptability thresholds. *Dent. Mater.* **38**, 695–702 (2022).
6. Altınışık, H. & Özyürt, E. Instrumental and visual evaluation of the color adjustment potential of different single-shade resin composites to human teeth of various shades. *Clin. Oral Investig.* **27**, 889–896 (2023).
7. de Abreu, J. L. B., Sampaio, C. S., Benalcazar Jalkh, E. B. & Hirata, R. Analysis of the color matching of universal resin composites in anterior restorations. *J. Esthet. Restor. Dent.* **33**, 269–276 (2021).
8. Durand, L. B. et al. Color, lightness, chroma, hue, and translucency adjustment potential of resin composites using CIEDE2000 color difference formula. *J. Esthet. Restor. Dent.* **33**, 836–843 (2021).
9. Forabosco, E. et al. Color match of single-shade versus multi-shade resin composites: A systematic review with meta-analysis. *J. Esthet. Restor. Dent.* **37**, 1443–1451 (2025).
10. de Oliveira, D. C. et al. Effect of different photoinitiators and reducing agents on color stability and depth of cure of resin-based composites. *Dent. Mater.* **31**, 1202–1208 (2015).
11. Sharma, G., Wu, W. & Dalal, E. N. The CIEDE2000 color-difference formula: Implementation notes, supplementary test data, and mathematical observations. *Color Res. Appl.* **30**, 21–30 (2005).
12. Paravina, R. D. et al. Color difference thresholds in dentistry. *J. Esthet. Restor. Dent.* **27**, S1–S9 (2015).
13. Fernandes-e-Silva, P. et al. Influence of depth and translucency on the color matching of single-shade resin composites: An in vitro study. *Braz. Dent. J.* **36**, e24-6074 (2025).
14. de Castro, F. L. A. & Durand, L. B. Influence of cavity wall thickness on the color adjustment potential of single-shade resin composites. *J. Am. Dent. Assoc.* **155**, 605–613 (2024).
15. Browning, W. D., Contreras-Bulnes, R., Brackett, M. G. & Brackett, W. W. Color differences: Polymerized composite and corresponding Vitapan classical shade tab. *J. Dent.* **37**, e34–e39 (2009).
16. Virtanen, P. et al. SciPy 1.0: Fundamental algorithms for scientific computing in Python. *Nat. Methods* **17**, 261–272 (2020).
17. Kim, I.-J. & Lee, Y.-K. Changes in color and color parameters of dental resin composites after polymerization. *J. Biomed. Mater. Res. B Appl. Biomater.* **80**, 541–546 (2007).
18. Nakamura, N., Yamamoto, T., Fukuoka, H., Yoshida, Y. & Suzuki, M. Evaluation of color adjustment and color reproducibility of single shade composite resin (Omnichroma). *Dent. Mater. J.* **41**, 418–424 (2022).
19. Herout, P. et al. Color-matching performance of single-shade composites compared to multi-shade composites: an in vitro study. *Clin. Oral Investig.* **27**, 621–631 (2023).

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Authors and Affiliations

Meltem Akbaba[1] · Çağatay Barutçugil[1]

✉ Meltem Akbaba
meltemakbaba@akdeniz.edu.tr

[1] Department of Restorative Dentistry, Faculty of Dentistry, Akdeniz University, 07058 Antalya, Turkey