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Evaluation of Immediate Post-Polymerization Color Change in One-Shade and Multi-Shade Composite Resins Polymerized with Different Light-Curing Units

Farklı Işık Cihazları ile Polimerize Edilen Tek Renkli ve Çok Renkli Kompozit Rezinlerde Polimerizasyon Sonrası Anlık Renk Değişiminin Değerlendirilmesi

ABSTRACT

Objectives

This study aimed to evaluate the effect of different light-curing units on the immediate post-polymerization color change of one-shade and multi-shade composite resins.

Material and Methods

Eight composite resins, comprising 4 universal one-shade (Omnichroma, Charisma Diamond One, Essentia Universal, and Vittra APS Unique) and 4 multi-shade composite resins (Estelite Sigma Quick, Gænial Universal Injectable, Optishade Universal, and Filtek Ultimate) were evaluated. Standardized specimens were prepared using 8 mm-diameter, 2 mm-thickness Teflon molds (n = 10). Baseline color measurements were obtained with a contact-type spectrophotometer (Vita Easyshade Compact) before polymerization. Then the specimens were polymerized using 4 different light-curing units (Elipar S10, VALO Cordless, Woodpecker LED.E, and Woodpecker iLed), and second color measurements were performed. Color differences were calculated using the CIEDE2000 formula. Data were analyzed using a two-way ANOVA and post hoc Tukey tests, with $\alpha = 0.05$.

Results

Statistically significant differences in color change were observed among the tested composite resins and light-curing units ($P \leq 0.05$). The ΔE_{00} values ranged from 3.75 to 13.93. The most significant color change was detected in the Omnichroma group polymerized with the Woodpecker iLed unit (ΔE_{00} = 13.93). In contrast, Estelite Sigma Quick demonstrated the lowest color change when cured with the VALO Cordless (ΔE_{00} = 3.75).

Conclusion

Within the limitations of this study, both the type of composite resin and the light-curing units significantly influenced post-polymerization color change. Therefore, shade selection should be performed after polymerization, and the same light-curing unit should be used for polymerization to achieve optimal aesthetic outcomes in clinical practice.

Key Words

Color change, Composite resin, Light-curing unit, Polymerization

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ÖZ

Amaç

Bu çalışmanın amacı, farklı ışık cihazlarının tek renkli ve çok renkli kompozit rezinlerde polimerizasyon sonrası anlık renk değişimi üzerindeki etkisini değerlendirmektir.

Gereç ve Yöntemler

Çalışmada, dördü tek renkli universal kompozit (Omnichroma, Charisma Diamond One, Essentia Universal ve Vittra APS Unique) ve dördü çok renkli kompozit rezin (Estelite Sigma Quick, Gænial Universal Injectable, Optishade Universal, Filtek Ultimate) olmak üzere toplam 8 kompozit rezin değerlendirilmiştir. Standart örnekler, 8 mm çapında ve 2 mm derinliğinde silikon kalıplar kullanılarak hazırlanmıştır (n = 10). Polimerizasyon öncesinde, temas tipi bir spektrofotometre (Vita Easyshade Compact) ile başlangıç renk ölçümleri yapılmıştır. Daha sonra örnekler 4 farklı ışık cihazı (Elipar S10, VALO Cordless, Woodpecker LED.E ve Woodpecker iLed) kullanılarak polimerize edilmiş ve ikinci renk ölçümleri gerçekleştirilmiştir. Renk farkları CIEDE2000 formülü kullanılarak hesaplanmıştır. Veriler, iki yönlü ANOVA ve Tukey post-hoc testleri kullanılarak α = 0,05 anlamlılık düzeyinde analiz edilmiştir.

Bulgular

Test edilen kompozit rezinler ve ışık cihazları arasında renk değişimi açısından istatistiksel olarak anlamlı farklılıklar saptanmıştır ($P \leq 0.05$). ΔE_{00} değerleri 3.75 ile 13.93 arasında değişmiştir. En yüksek renk değişimi, Woodpecker iLed cihazı ile polimerize edilen Omnichroma grubunda (ΔE_{00} = 13.93) gözlenirken, en düşük renk değişimi VALO Cordless cihazı ile polimerize edilen Estelite Sigma Quick grubunda (ΔE_{00} = 3.75) görülmüştür.

Sonuç

Bu çalışmanın sınırlılıkları dahilinde, hem kompozit rezin tipi hem de kullanılan ışık cihazı polimerizasyon sonrası renk değişimini anlamlı derecede etkilemiştir. Bu nedenle, klinik uygulamada optimal estetik sonuçlar elde etmek amacıyla renk seçimi polimerizasyon sonrasında yapılmalı ve polimerizasyon için de aynı ışık cihazı kullanılmalıdır.

Anahtar Sözcükler

Renk değişimi, Kompozit rezin, Işık cihazı, Polimerizasyon

INTRODUCTION

The increasing demand for aesthetic treatments has led to the development of advanced restorative materials. Particularly in the anterior region, accurate color matching is essential to achieve satisfactory esthetic outcomes. Composite resin restorations are widely preferred in clinical practice because they can provide shade integration that is indistinguishable from natural teeth. Consequently, color stability and shade matching are critical factors influencing the long-term clinical success of these materials (1). Nevertheless, immediate color alterations following light curing have been reported in contemporary resin composites, suggesting that polymerization-related optical changes may affect the final clinical shade outcome (2).

Conventional shade reproduction in anterior composite restorations is commonly achieved through incremental layering of enamel and dentin shades to mimic natural optical depth and translucency (3). Although this technique allows precise esthetic characterization, it is technique-sensitive and may increase chair time. To simplify shade selection and reduce procedural complexity, single-shade or one-shade composite resins have been introduced (4). These materials aim to harmonize with surrounding tooth structure through controlled translucency and optimized light diffusion, and in some systems through structural color mechanisms rather than conventional pigment-based matching (5). Although manufacturers claim adaptation across the 16 VITA classic shades (VITA North America, Yorba Linda, CA, USA) (5), emerging evidence indicates that their color adjustment potential may be influenced by restoration thickness, background shade, and cavity configuration (6,7). Furthermore, their optical performance depends on filler morphology, refractive index matching, and photoinitiator systems, which may undergo alterations during polymerization (5).

Objective shade evaluation has therefore become increasingly important to minimize operator-dependent variability. Spectrophotometric measurements provide reliable and reproducible data within the CIE Lab* color space (8). While the conventional CIELAB (ΔE_{ab}) formula has been widely used, the CIEDE2000 (ΔE_{00}) formula offers improved correlation with human visual perception by incorporating corrections for lightness, chroma, and hue interactions (9). Previous studies (9,10) have shown that CIEDE2000 provides greater sensitivity in detecting clinically perceptible and acceptable color differences.

Light curing plays a fundamental role in determining the final optical properties of resin composites. During polymerization, changes in refractive index and the degree of conversion of photoinitiators such as camphorquinone or alternative initiator systems may result in measurable shifts in lightness and chromatic parameters (11,12). The spectral emission characteristics and irradiance output of light-curing units (LCUs) further influence polymerization kinetics and immediate color attributes (11,13). Mod-

ern LED LCUs are available as monowave or polywave systems, delivering different wavelength distributions that may interact variably with diverse photoinitiator compositions (14). Variations in light intensity and spectral distribution have been shown to affect not only the degree of conversion and mechanical properties but also the immediate optical behavior of resin composites (11,15). Therefore, the interaction between composite formulation and LCU characteristics represents a clinically relevant variable that may influence shade matching, particularly in simplified one-shade systems that rely heavily on optical blending mechanisms (16).

Despite the growing clinical adoption of universal one-shade composites, evidence remains limited regarding the immediate post-polymerization color behavior of both one-shade and multi-shade resin systems when cured with different LCUs. Given that polymerization-related optical alterations may compromise the initially selected shade, understanding these interactions is essential to refine clinical shade selection protocols and minimize the risk of perceptible color mismatch following light activation. Therefore, the aim of the present study was to evaluate the effect of different LCUs on the immediate post-polymerization color change of one-shade and multi-shade composite resins. The null hypothesis tested was that neither composite type nor light-curing unit type would significantly influence the immediate post-polymerization color change.

MATERIAL and METHODS

Study Design

This *in vitro* study was designed as a 2-factor experimental investigation evaluating the effects of composite type (one-shade vs multi-shade) and LCU on immediate post-polymerization color change. Eight contemporary resin-based composite materials were included, consisting of four one-shade systems (Omnichroma, Charisma Diamond One, Essentia Universal, and Vittra APS Unique) and four multi-shade systems (Estelite Sigma Quick, Gænial Universal Injectable, Optishade Universal, and Filtek Ultimate). Detailed information regarding their composition, filler characteristics, photoinitiator systems, and manufacturer specifications is presented in Table 1.

Table 1. The composite resins used in the study.

Composite Resins	Filler Type	Composition	Photoinitiator*	Manufacturer
Omnichroma (one-shade)	Spherical Nanofilled	UDMA, TEGDMA, supra-nano spherical filler, and composite fillers	Not disclosed	Tokuyama Dental, Tokyo, Japan
Charisma Diamond One (one-shade)	Nanohybrid	TCD-DI-HEA, Fluoro-alumino-borosilicate glass, silica, TiO_2, metallic oxide pigments, organic pigments	Not disclosed	Kulzer, Hanau, Germany
Essentia Universal (one-shade)	Microhybrid	UDMA, Bis-EMA, Bis-GMA, TEGDMA,Prepolymerized fillers, Barium glass, Silica	Not disclosed	GC Corp., Tokyo, Japan
Vittra APS UNIQUE (one-shade)	Nanohybrid	UDMA, TEGDMA, silane, boron aluminum silicate glass fillers	Advanced Polymerization System (APS); low-concentration CQ+ proprietary co-initiators	FGM Dental, Joinville, Brazil
Estelite Sigma Quick, A2 (multi-shade)	Nanofilled	Bis-GMA, TEGDMA, Composite filler, Silica-zirconia filler, prepolimerized fillers	Camphorquinone (CQ); Radical Amplified Photopolymerization (RAP) system	Tokuyama, Tokyo, Japan
Gænial Universal Injectable, A2 (multi-shade)	Nanohybrid	Bis EMA, UDMA, methacrylate monomers, barium glass, silica (SiO_2)	Diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide (TPO)	GC Corp., Tokyo, Japan
Optishade Universal, LT (multi-shade)	Nanohybrid	Bis-EMA, Bis-GMA, TEGDMA, PPF, BaO, Al_2O_3, SiO_2, silica and F_3Yb	Not disclosed	Kerr Dental, CA, USA
Filtek Ultimate, A2 Body (multi-shade)	Nanofilled	Bis-GMA, UDMA, Bis-EMA, PEGDMA, TEGDMA, Zirconia, Silica	Camphorquinone (CQ) + amine co-initiator	3M ESPE, St. Paul, MN, ABD

Abbreviations: Bis-EMA: ethoxylated bisphenol A glycol dimethacrylate; Bis-GMA: Bisphenol A-diglycidyl methacrylate; PEGDMA: polyethylene glycol dimethacrylate; PPF: pre-polymerized filler; TCD-DI-HEA: bis-(acryloyloxymethyl) tricycle-[5.2.1.02.6] decane; TEGDMA: triethylene glycol dimethacrylate; UDMA: urethane dimethacrylate. *Photoinitiator systems were recorded based on manufacturer safety data sheets (SDS) and technical documentation when explicitly disclosed.

An a priori power analysis was performed using G*Power software (Heinrich Heine University, Düsseldorf, Germany) (17) based on a two-way ANOVA design including 8 composite materials and 4 LCUs. An effect size of f = 0.40 was selected according to previous studies (11,15) reporting mode- rate-to-large color differences (ΔE) among resin composites under different polymerization conditions. The minimum statistical power was set at 80% with a significance level of $\alpha = 0.05$. The analysis indicated that at least 256 specimens were required to achieve the desired power. To ensure balanced subgroup allocation and increase statistical precision, a total of 320 specimens ($n = 10$ per subgroup) were included in the study.

Specimen Preparation

For each composite material, 40 disk-shaped specimens (8 mm in diameter and 2 mm in thickness) were fabricated using standardized Teflon molds, resulting in a total of 320 specimens across 8 materials. The composite resin was placed into the molds in a single increment to eliminate layering-related optical variability. The surface was covered with a polyester (Mylar) strip and gently pressed between 2 glass slides under constant manual pressure to obtain a smooth surface and standardized thickness while minimizing the oxygen-inhibited layer. Each composite group (n = 40) was randomly divided into 4 subgroups (n = 10) according to the LCU used, and the specimens were numbered for identification.

Color Measurement

Color measurements were performed using a contact-type spectrophotometer (Vita Easyshade Compact, Vita Zahnfabrik, Germany) directly from the Mylar strip-covered surface to standardize surface texture. The device was calib- rated before each measurement session according to the manufacturer's instructions. All measurements were obtained against a standardized white background (CIE L* = 93.2, a* = 0.3, b* = 1.2), which was consistently used for both baseline and post-polymerization recordings to eliminate background-related variability. Each measurement was performed 3 times per specimen, and the average baseline color values (L1*, a1*, b1*) were recorded before light curing.

Light-Curing Procedure

Following baseline measurements, the upper surface of the specimens was light-cured for 20 sec using 4 different LCUs (Elipar S10, VALO Cordless, Woodpecker LED.E, and Woodpecker iLed). The light-curing unit tip was positioned in direct contact with the Mylar strip-covered surface and maintained perpendicular to the specimen without applying additional pressure. The tip was centered over the specimen to ensure uniform light exposure. Irradiance values were verified using a radiometer (Bluephase Meter II, Ivoclar Vivadent, Schaan, Liechtenstein) before specimen preparation. The technical specifications and manufacturer information of the LCUs used in this study are presented in Table 2.

Table 2. The LCUs used in the study.

Light-Curing Units	Type	Wavelenghts	Light irradiance	Manufacturer
Elipar S10	2nd generation (monowave LED)	430-480 nm	1200 mW/cm²	3M ESPE, USA
VALO Cordless	3rd generation (polywave LED)	395-480 nm	1000 mW/cm² (Standard Mode)	Ultradent, USA
Woodpecker LED.E	2nd generation (monowave LED)	420-480 nm	1200 mW/cm²	Guilin Woodpecker Medical Instrument Co., Guilin, China
Woodpecker iLed	3rd generation (polywave LED)	385-515 nm	1200 mW/cm² (Normal Mode)	Guilin Woodpecker Medical Instrument Co., Guilin, China

Post-Polymerization Color Assessment

Immediately after light curing, second color measurements were obtained from the same Mylar strip-covered surface under identical conditions using the same white background. Each measurement was repeated 3 times per specimen, and the average post-polymerization color values (L2*, a2*, b2*) were recorded. Color differences between baseline and post-polymerization measurements were calculated using the CIEDE2000 (ΔE_{00}) formula. The CIEDE2000 color difference (ΔE_{00}) was calculated according to the following equation (9):

$$\Delta E_{00} = \sqrt{[(\Delta L' / K_L S_L)^2 + (\Delta C' / K_C S_C)^2 + (\Delta H' / K_H S_H)^2 + R_T (\Delta C' / K_C S_C)(\Delta H' / K_H S_H)]}.$$

The overall experimental stages are illustrated in Figure 1.

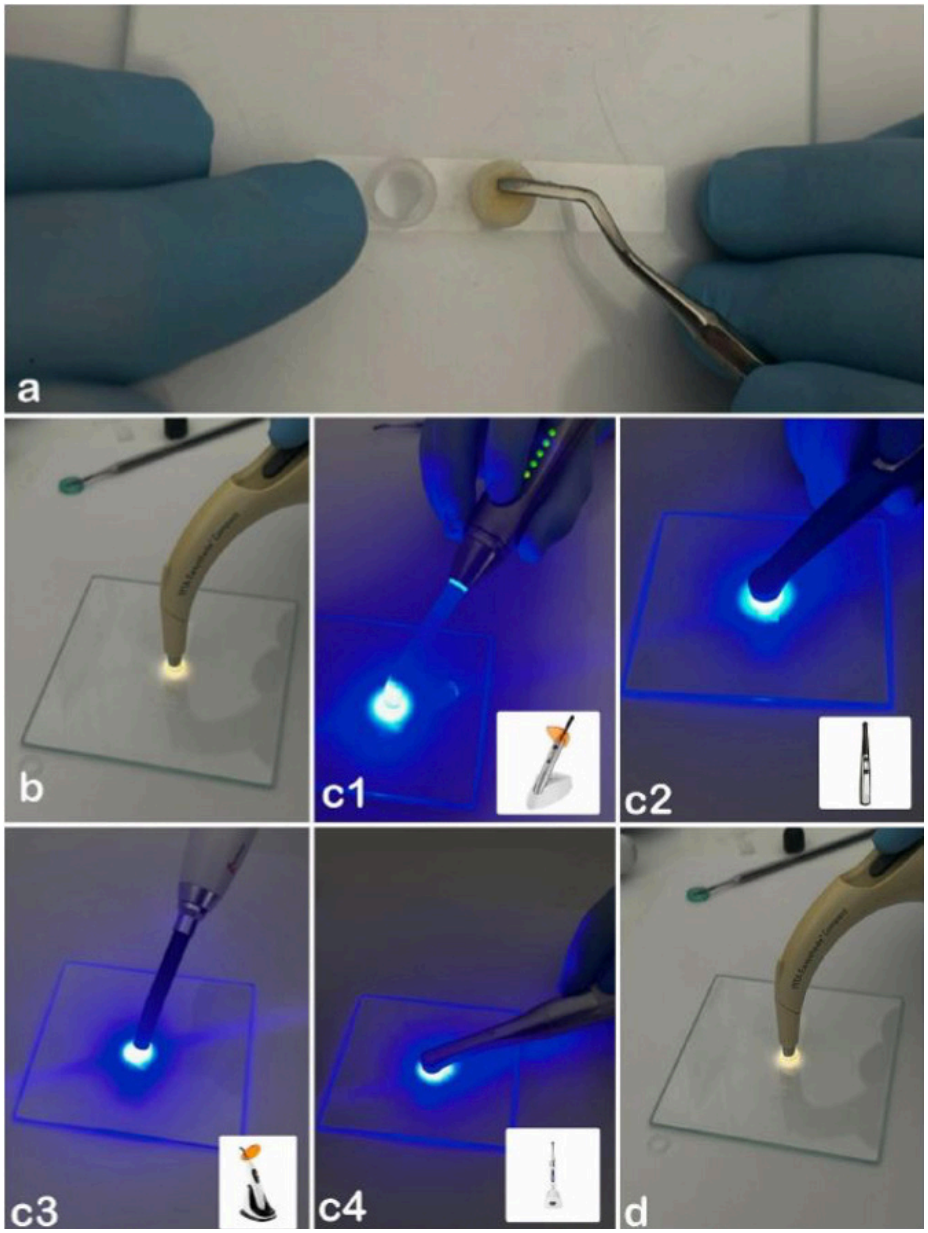

Figure 1. The stages of the study. *(a)* Samples preparation **b:** First color measurement (*c1)* Polymerization with VALO Cordless (*c2)* Polymerization with Woodpecker LED.E **c3:** Polymerization with Elipar S10 (*c4)* Polymerization with Woodpecker iLed (*d)* Second color mesurement

Statistical Analysis

All statistical analyses were performed using Jamovi software (Version 2.6; The Jamovi Project, Sydney, Australia) (18). Data distribution was assessed using the Shapiro-Wilk test, and homogeneity of variance was eva- luated with Levene's test. A two-way analysis of variance (ANOVA) was conducted to evaluate the main effects of composite type and LCU, as well as their interaction effect, on immediate post-polymerization color change (ΔE_{00}). When statistically significant differences were detected, pairwise comparisons were performed using Tukey's post hoc test. The level of statistical significance was set at $\alpha = 0.05$.

RESULTS

The mean and standard deviation (SD) values of immediate post-polymerization color change (ΔE_{00}) for all composite materials and LCUs are presented in Table 3. Statistical evaluation revealed that the color change (ΔE_{00}) values varied considerably among the tested materials and LCUs. The highest color change was observed in the Omnichroma specimens polymerized with the Woodpecker iLed unit. In contrast, the lowest ΔE_{00} values were recorded for Estelite Sigma Quick polymeri- zed with the VALO Cordless unit.

Two-way ANOVA demonstrated that both composite resin and LCU had statistically significant effects on immediate post-polymerization color change ($P < 0.001$). In addition, a significant interaction effect between composite type and LCU was detected ($P < 0.001$), indicating that the level of color change produced by each curing unit varied depending on the composite material (Tab. 4).

Table 3. The mean ± SD post-polymerization color change (ΔE_{00}) values of composite resins (CRs).

LCUs / CRs	Elipar S10	VALO Cordless	Woodpecker LED.E	Woodpecker iLed	p values
Omnichroma	$13.78 \pm 0.19^{A,a}$	$13.85 \pm 0.26^{AC,a}$	$12.91 \pm 0.18^{B,a}$	$13.93 \pm 0.23^{C,a}$	<0.001
Charisma Diamond One	$13.65 \pm 0.17^{A,a}$	$13.52 \pm 0.18^{A,b}$	$12.07 \pm 0.17^{B,b}$	$13.47 \pm 0.21^{A,a}$	<0.001
Essentia Universal	$9.11 \pm 0.20^{A,b}$	$8.91 \pm 0.26^{A,c}$	$8.59 \pm 0.20^{B,c}$	$9.03 \pm 0.29^{A,b}$	<0.001
Vittra APS UNIQUE	$8.32 \pm 0.17^{A,c}$	$10.75 \pm 0.25^{B,d}$	$7.07 \pm 0.32^{C,d}$	$7.94 \pm 0.20^{D,c}$	<0.001
Estelite Sigma Quick	$4.32 \pm 0.11^{A,d}$	$3.75 \pm 0.10^{B,e}$	$3.97 \pm 0.09^{B,e}$	$3.78 \pm 0.08^{B,d}$	<0.001
G-aenial Injectable	$8.77 \pm 0.18^{A,e}$	$7.88 \pm 0.19^{B,f}$	$7.28 \pm 0.20^{C,d}$	$6.27 \pm 0.17^{D,e}$	<0.001
OptiShade Universal	$6.62 \pm 0.20^{A,f}$	$5.72 \pm 0.18^{B,g}$	$6.01 \pm 0.16^{B,f}$	$5.98 \pm 0.15^{B,e}$	<0.001
Filtek Ultimate	$4.86 \pm 0.09^{A,g}$	$4.47 \pm 0.10^{B,h}$	$4.51 \pm 0.09^{B,g}$	$4.55 \pm 0.08^{AB,f}$	<0.001
p values	<0.001	<0.001	<0.001	<0.001	

*Different uppercase superscripts in rows and lowercase superscripts in columns indicate statistically significant differences.

Table 4. Two-Way ANOVA Results for Post-Polymerization Color Change (ΔE_{00}).

Source of Variation	Sum of Squares	df	Mean Square	F	p	Partial Eta Squared ($\eta^2 p$)
Composite resins (CRs)	3625.7	7	517.95	14661	<0.001	0.997
Light-Curing Units (LCUs)	42.2	3	14.07	398	<0.001	0.806
CRs * LCUs Interaction	97.4	21	4.64	131	<0.001	0.905

The graphical representation of the interaction effect (Fig. 2) revealed distinct separation patterns among the materials. One-shade composites, particularly Omnichroma and Charisma Diamond One, consistently exhibited higher ΔE_{00} values across most LCUs than multi-shade systems. In contrast, Estelite Sigma Quick and Filtek Ultimate demonstrated relatively stable color behavior, with smaller variations among different LCUs. The Woodpecker LED.E and Woodpecker iLed units generally produced greater color shifts than Elipar S10 and VALO Cordless, though this effect was material-dependent. Notably, Vittra Unique demonstrated marked variability, particularly under VALO curing. Overall, the extent of color change varied significantly across different composite–LCU combinations, confirming that both material formulation and curing protocol affect immediate post-polymerization optical properties.

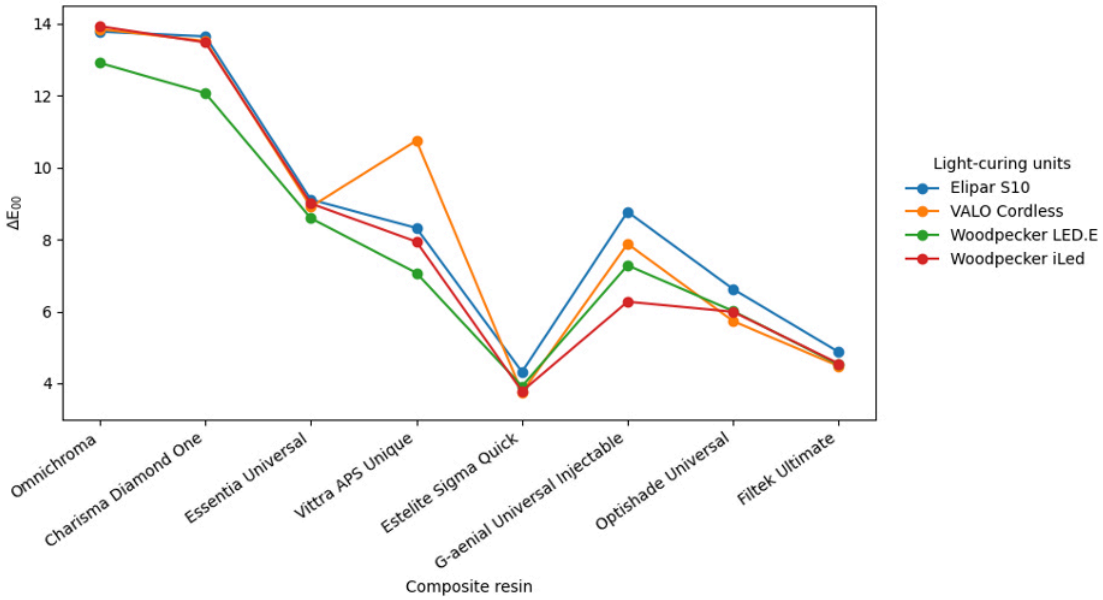

Figure 2. The graphical representation of the interaction effect.

DISCUSSION

The present study demonstrated that both composite resin type and formulation, and LCU characteristics significantly influenced immediate post-polymerization color change; therefore, the null hypothesis was rejected. In addition to the significant main effects, the strong interaction between composite type and LCU indicates that the level of color change cannot be attributed solely to energy delivery from LCUs but rather reflects a material-dependent photochemical response. These findings suggest that post-polymerization color behavior demonstrates the interplay between photochemistry, polymer network development, and composite-specific optical architecture.

Polymerization alters the optical structure of resin composites through multiple mechanisms. As monomers convert into a cross-linked polymer network, the refractive index of the organic matrix increases with the degree of conversion, affecting refractive index matching with filler particles. Even minor mismatches at the filler-matrix interface may modify light transmission and scattering behavior, leading to measurable changes in L*, a*, and b* coordinates (19,20). Korkut *et al*. (2) demonstrated that polymerization consistently induces perceptible chromatic alterations in contemporary composites, emphasizing that this phenomenon is intrinsic to the curing reaction itself. The ΔE_{00} values obtained in the present study (3.75-13.93) confirm that immediate post-curing color change is not negligible and may substantially affect clinical shade matching.

Clinical interpretation of these values must consider established perceptibility and acceptability thresholds. Paravina *et al*. (21) reported that the 50% perceptibility and acceptability limits for ΔE_{00} are approximately 0.8 and 1.8, respectively. When these thresholds are applied to the current findings, all composite-LCU combinations exceeded perceptibility limits and most exceeded acceptability thresholds. This indicates that color changes occurring immediately after curing are not merely instrumentally detectable but are highly likely to be visually apparent under clinical conditions. Therefore, shade selection based on uncured composite material may result in a visually detectable mismatch. This reinforces the necessity of evaluating shade after curing rather than relying on the uncured appearance.

The significant main effect of the LCU can be explained by differences in spectral emission profiles, irradiance distributions, and radiant exposures. Monowave devices primarily emit in the blue range suitable for camphorquinone (CQ) activation, whereas polywave systems additionally deliver shorter wavelengths capable of activating alternative photoinitiators. Previous studies (22-24) have demonstrated that emission spectrum and energy distribution influence the degree of conversion and post-cure properties of resin composites. Since the degree of conversion affects the refractive index of the polymerized matrix, differences in curing efficiency may translate into measurable optical changes (22-24). Consequently, the same composite material may exhibit different immediate optical behavior when polymerized with different LCUs.

The interaction effect observed in this study suggests that LCU-related differences are material-dependent. This finding is consistent with the concept that composite formulations vary in photoinitiator systems, filler morphology, pigment concentration, and resin composition (25). Materials containing alternative initiators or proprietary systems may respond differently to specific wavelength distributions, leading to variable polymer network formation and optical density (26). Thus, the curing device

cannot be considered independent of composite chemistry; instead, the polymerization outcome results from the combined effects of initiator absorption characteristics and light-spectrum compatibility (27).

This mechanistic framework is consistent with previously reported findings in the literature. Studies (28,29) evaluating polymerization-induced color shifts have shown that variations in curing protocols may result in measurable chromatic differences immediately after light activation. Pérez *et al*. (28) reported that different light-polymerization protocols significantly affected post-curing color and translucency parameters. Similarly, Mondelli *et al*. (29) demonstrated distinct color changes between pre- and post-curing states depending on the curing unit used. Collectively, these studies support the present results and confirm that immediate optical alterations are not solely material-dependent but are also strongly influenced by the spectral characteristics and energy delivery of the light-curing unit. However, it should be noted that contemporary literature specifically addressing uncured-to-immediate post-polymerization color differences across multiple LCU types remains limited. Most recent investigations have focused on post-curing aging or color stability rather than the direct optical transition occurring immediately after light activation. Therefore, the present study contributes to a relatively underexplored aspect of resin composite optics by directly examining the interaction between composite type and LCU characteristics during the immediate polymerization phase.

Material-specific patterns observed in this study further support this mechanism. The generally higher ΔE_{00} values observed for one-shade composites may be attributed to their structural color mechanism. Omnichroma consistently exhibited the highest ΔE_{00} values across all LCUs. As a structural color-based composite relying on controlled light diffusion through spherical fillers, its color expression is highly sensitive to changes in internal scattering conditions (28). Polymerization-induced refractive index shifts may therefore disproportionately affect its optical integration. In contrast, Estelite Sigma Quick and Filtek Ultimate demonstrated comparatively stable ΔE_{00} values across curing devices, suggesting more stable pigment-based shade formulation or optimized matrix-filler refractive index harmony. Vittra APS Unique exhibited a pronounced ΔE_{00} increase when polymerized with the VALO unit, suggesting wavelength-dependent interaction between its polymerization system and the spectral characteristics of that LCU. Because initiator activation efficiency varies according to emission spectrum (24,25), such material-dependent spectral compatibility may influence polymer network stabilization and immediate optical properties.

It should be noted that complete photoinitiator compositions were not fully disclosed by manufacturers for all tested materials. Although some products refer to proprietary or advanced polymerization systems, detailed information regarding initiator identity and concentration was not consistently available. Therefore, while initiator-LCU compatibility provides a plausible explanation for the observed interaction, definitive attribution to specific photoinitiator systems could not be established.

From a clinical perspective, these findings have direct implications for the button technique used during shade selection. Evaluating composite shade in the uncured state may lead to clinically unacceptable mismatch after polymerization, as ΔE_{00} values exceeded established acceptability thresholds (21). In agreement with Korkut *et al*. (2) composite increments used for shade selection should be polymerized before final evaluation. Furthermore, because immediate color change varied according to LCU type, the same curing unit employed during the button trial should be used during definitive restoration placement to minimize additional chromatic discrepancies.

This study has certain limitations that should be considered when interpreting the findings. One methodological consideration concerns the surface standardization protocol. In the present study, color measurements were obtained through Mylar strip-covered surfaces both before and immediately after polymerization to eliminate the potential influence of surface roughness on optical outcomes. Previous research (31) has shown that variations in composite surface roughness may result in measurable color differences even without exposure to staining agents. Therefore, the use of Mylar-covered surfaces enabled a controlled, reproducible assessment of polymerization-induced color change (28,32). However, it should be acknowledged that polished clinical surfaces may exhibit different optical behavior compared with Mylar-standardized laboratory specimens. Additionally, this study evaluated only the immediate post-polymerization color change; longer-term optical behavior, post-curing reactions, and aging-related effects were not assessed. In addition, incomplete disclosure of photoinitiator compositions limited mechanistic interpretation. Future studies incorporating aging protocols, spectroscopic analysis of initiator chemistry, and detailed spectral characterization of LCUs would provide deeper insight into curing-induced optical alterations.

CONCLUSION

Immediate post-polymerization color change was significantly affected by both composite type and LCU, with a material-dependent interaction pattern. The level of ΔE_{00} values indicates that curing-induced optical alterations are clinically relevant. Shade evaluation should therefore be performed under polymerized conditions, and consistency in the curing protocol is essential to enhance aesthetic predictability.

Abbreviations
LCU: Light-curing Units, SD: Standard Deviation, CQ: Camphorquinone

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Authors' Contributions
Concept: E.B.G., V.K.; Supervision: E.B.G., V.K.; Resources: N.Ş.; Materials: E.B.G., V.K., N.Ş.; Data Collection and/or Processing: E.B.G., V.K., N.Ş.; Analysis and/ or Interpretation: E.B.G., V.K., N.Ş.; Literature Search: E.B.G., V.K., N.Ş.; Writing Manuscript: E.B.G., V.K., N.Ş.; Critical Review: E.B.G., V.K., N.Ş.

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Data Availability
Data is available from the corresponding author upon request.

Ethics Approval
This study was conducted as an in vitro experimental investigation. As no human participants or animal subjects were involved, ethical approval and informed consent were not required.

Conflicts of Interest
The authors declare no conflicts of interest.

AI Declaration
No AI tools were used.

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REFERENCES

1. Leal CFC, Miranda SB, Alves Neto EL, *et al.* Color stability of single-shade resin composites in direct restorations: a systematic review and meta-analysis of randomized controlled trials. Polymers (Basel). 2024; 16: 2172. doi: 10.3390/polym16152172

2. Korkut B, Dokumacigil G, Murat N, *et al.* Effect of Polymerization on the color of resin composites. Oper Dent. 2022; 47: 514-26. doi: 10.2341/20-155-L

3. Dietschi D, Fahl N. Shading concepts and layering techniques to master direct anterior composite restorations: an update. Br Dent J. 2016; 221: 765-71. doi: 10.1038/sj.bdj.2016.944

4. Pereira Sanchez N, Powers JM, Paravina RD. Instrumental and visual evaluation of the color adjustment potential of resin composites. J Esthet Restor Dent. 2019; 31: 465-70. doi: 10.1111/jerd.12488

5. Ahmed MA, Jouhar R, Khurshid Z. Smart monochromatic composite: a literature review. Int J Dent. 2022; 2022: 2445394. doi: 10.1155/2022/2445394

6. Castro FLA, Durand LB. Influence of cavity wall thickness on the color adjustment potential of single-shade resin composites. J Am Dent Assoc. 2024; 155: 605-13. doi: 10.1016/j.adaj.2024.03.006

7. Iyer RS, Babani VR, Yaman P, *et al.* Color match using instrumental and visual methods for single-, group-, and multi-shade composite resins. J Esthet Restor Dent. 2021; 33: 394-400. doi: 10.1111/jerd.12621

8. Joiner A. Tooth colour: a review of the literature. J Dent. 2004; 32: 3-12. doi: 10.1016/j.jdent.2003.10.013

9. Sharma G, Wu W, Dalal EN. The CIEDE2000 color-difference formula: implementation notes, supplementary test data, and mathematical observations. Color Res Appl. 2005; 30: 21-30. doi: 10.1002/col.20070

10. Paravina RD, Ghinea R, Herrera LJ, *et al.* Color difference thresholds in dentistry. J Esthet Restor Dent. 2015; 27: S1-9. doi: 10.1111/jerd.12149

11. Kim IJ, Lee YK. Changes in color and color parameters of dental resin composites after polymerization. J Biomed Mater Res B Appl Biomater. 2007; 80: 541-6. doi: 10.1002/jbm.b.30628

12. Gao F, Berzins DW. Color change in commercial resin composites with different photoinitiators. Bioengineering (Basel). 2025; 12: 1047. doi: 10.3390/bioengineering12101047

13. Rueggeberg FA, Giannini M, Arrais CAG, *et al.* Light curing in dentistry and clinical implications: a literature review. Braz Oral Res. 2017; 31: E61. doi: 10.1590/1807-3107BOR-2017.vol31.0061

14. Rencz A, Hickel R, Ilie N. Curing efficiency of modern LED units. Clin Oral Investig. 2012; 16: 173-9. doi: 10.1007/s00784-010-0498-3

15. Çelik EU, Aladağ A, Türkün LŞ, *et al.* Color changes of dental resin composites before and after polymerization and storage in water. J Esthet Restor Dent. 2011; 23: 179-88. doi: 10.1111/j.1708-8240.2011.00421.x

16. Prodan CM, Gasparik C, Ruiz-López J, *et al.* Color and translucency variation of a one-shaded resin-based composite after repeated heating cycles and staining. Materials (Basel). 2023; 16: 3793. doi: 10.3390/ma16103793

17. Faul F, Erdfelder E, Lang AG, *et al.* G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods. 2007; 39: 175-91. doi: 10.3758/bf03193146

18. The Jamovi Project. Jamovi (Version 2.6) [Computer software]. Sydney, Australia, 2025. Available from: https://www.jamovi.org

19. Howard B, Wilson ND, Newman SM, *et al.* Relationships between conversion, temperature and optical properties during composite photopolymerization. Acta Biomater. 2010; 6: 2053-9. doi: 10.1016/j.actbio.2009.11.006

20. Shim JE, Kim HJ, Oh S, *et al.* Optical and mechanical characteristics of one-shade composite resins. J Funct Biomater. 2025; 16: 419. doi: 10.3390/jfb16110419

21. Paravina RD, Pérez MM, Ghinea R. Acceptability and perceptibility thresholds in dentistry: A comprehensive review of clinical and research applications. J Esthet Restor Dent. 2019; 31: 103-12. doi: 10.1111/jerd.12465

22. Rocha MG, Maucoski C, Roulet JF, *et al.* Depth of cure of 10 resin-based composites light-activated using a laser diode, multi-peak, and single-peak light-emitting diode curing lights. J Dent. 2022; 122: 104141.doi: 10.1016/j.jdent.2022.104141

23. Hasanain FA, Nassar HM. Utilizing light cure units: a concise narrative review. Polymers (Basel). 2021; 13: 1596. doi: 10.3390/polym13101596

24. Marović D, Daničić P, Bojo G, *et al.* Polywave light-curing units: effect on light transmission of composite without alternative photoinitiators. Acta Stomatol Croat. 2024; 58: 30-8. doi: 10.15644/asc58/1/3

25. AlShaafi MM. Factors affecting polymerization of resin-based composites: a literature review. Saudi Dent J. 2017; 29: 48-58. doi: 10.1016/j.sdentj.2017.01.002

26. Santini A, Miletic V, Swift MD,*et al.* Degree of conversion and microhardness of TPO-containing resin-based composites cured by polywave and monowave LED units. J Dent. 2012; 40: 577-84. doi: 10.1016/j.jdent.2012.03.007

27. Shimokawa C, Sullivan B, Turbino ML, *et al.* Influence of emission spectrum and irradiance on light curing of resin-based composites. Oper Dent. 2017; 42: 537-47. doi: 10.2341/16-349-L

28. del Mar Pérez M, Saleh A, Pulgar R, *et al.* Light polymerization-dependent changes in color and translucency of resin composites. Am J Dent. 2009; 22: 97-101.

29. Mondelli RFL, Tavares FC, Medina-Valdivia JR, *et al.* Color changes induced by light curing of resin composites. Rev Sul-Brasileira Odontol. 2016; 13: 241-7. doi:10.21726/rsbo.v13i4.345

30. Kobayashi S, Nakajima M, Furusawa K, *et al.* Color adjustment potential of single-shade resin composite to various-shade human teeth: effect of structural color phenomenon. Dent Mater J. 2021; 40: 1033-40. doi: 10.4012/dmj.2020-364

31. Ghinea R, Ugarte-Alvan L, Yebra A, *et al.* Influence of surface roughness on the color of dental-resin composites. J Zhejiang Univ Sci B 2011; 12: 552-62. doi: 10.1631/jzus.B1000374

32. Hatırlı H, Yaşa B, Gök A, *et al.* Evaluation of color change after polymerisation of esthetic restoratives with different composition. Int Arch Dent Sci. 2015; 36: 79-85. doi: 10.5505/eudfd.2015.50023