BMC Oral Health

RESEARCH Open Access

Effect of modeling liquid application on color stability and surface roughness of single-shade composites

Melek Güven Bekdaş[1*] and Ihsan Hubbezoglu[2]

Abstract

Objectives The objective of this study was to examine the effects of modeling liquid application on the color stability and surface roughness of single-shade composites.

Materials and methods Single-shade composites were divided into 4 main groups according to their contents. A total of 64 disc-shaped samples (8 × 2 mm) were prepared, 16 in each group, by using Teflon molds. The samples were divided into two subgroups on the basis of the application of a modeling liquid. After the initial color and roughness measurements, the samples were immersed in coffee for 12 days. Color changes were assessed via a spectrophotometer and ΔE values were calculated via the CIELAB formula. The surface roughness (Ra) was measured via a profilometer. The data were subjected to statistical analysis via two-way analysis of variance and Tukey's test to examine pairwise differences at a significance level of 0.05.

Results The application of modeling liquid reduced discoloration in Charisma Diamond One (CDO) and Vittra APS Unique (VUA), whereas it slightly increased discoloration in Omnichroma (OMN) and Zenchroma (ZNC). However, only the changes in CDO were statistically significant ($p < 0.05$). Among the composite control groups baseline and after the coloring procedures, the highest surface roughness degree was observed in the CDO group, while the lowest surface roughness degree was observed in the OMN and ZNC groups ($p < 0.05$), and the differences between them were found to be significant ($p > 0.05$). The surface roughness and color changes approached the mean values in the subgroups where the modeling liquid was applied, and there was no significant difference between them ($p > 0.05$). The application of modeling liquid was observed to reduce the variation in initial roughness among the composites, bringing their roughness values closer to an average range (0.26–0.34).

Conclusion Modeling liquid application increased roughness and discoloration in composites with initially low surface roughness (OMN and ZNC) while reducing roughness and discoloration in composites with initially high surface roughness (VUA and CDO).

Clinical relevance Modeling liquid application should be approached more cautiously in composites with high polishability, despite contributing to clinical use in composites with high roughness values.

Keywords Modeling liquid, Single-shade composite, Color stability, Surface roughness

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Introduction

Composite resins are the most preferred restorative materials due to their aesthetic properties, mechanical strength, and relatively low cost [1]. In line with the demands of clinicians for shorter application times and a reduction in clinical procedures, there have been numerous advancements in composite resins [2]. Single-shade resin composites, which are designed to match the color of surrounding teeth without the need for complex shade selection, have been developed specifically to reduce the time spent at the patient's chairside and to facilitate a color selection protocol, which is a complex process [3]. The color adjustment in dental materials involves two fundamental factors: the blending effect, which is predominantly derived from perceptual aspects, and the physical component, which is related to translucency [3]. De Abreu et al. [4] investigated restorations performed on teeth with different color characteristics and reported that there was no significant difference in color matching between single-shade composites and composite systems containing multiple colors.

Although advancements in composite resins have significantly facilitated the mimicking of natural anatomical structures, the presence of viscous organic monomers within the composite structure poses challenges in terms of handling and sculpting during the restoration process [5]. Manufacturers have developed various products, such as titanium/aluminum-coated hand tools and composite brushes, to facilitate the manipulation of composites and prevent the resin from sticking to hand tools [6]. On the other hand, clinicians widely prefer low-viscosity materials such as dental adhesives and modeling liquids to facilitate manipulation of the composite. The use of these low-viscosity materials offers ease of application and prevents pore formation by reducing air trapping on the restoration surface [7, 8]. Adhesive materials and low viscosity materials (such as acetone and isopropyl alcohol) are not specifically designed to facilitate the manipulation of composite resins. While there have been no reported negative outcomes concerning the application of these materials on interface layers [9], the surface characteristics of the restoration might undergo alterations upon exposure to the oral environment if they are utilized in the final phase [10].

The surface characteristics of restorative materials play crucial roles in both the longevity of the material and in meeting patients' aesthetic expectations. Deterioration of surface properties, such as color stability and surface roughness, over time can lead to increased plaque accumulation and color mismatches between natural teeth and restorative materials. This necessitates the renewal of restorations resulting in both time loss and increased financial costs [11].

The discoloration of composite restorations can be attributed to various internal and external factors [12, 13]. The intrinsic discoloration of composites is a consequence of their chemical properties, specifically the structure of the resin matrix, the matrix–particle interface, and the size and volume of filler particles [13, 14]. The external discoloration of dental composites is the consequence of several factors, including oral hygiene, occupational factors, smoking habits, and contact with food and beverages [13, 15]. The color changes that occur in composite resins can be quantified via a variety of instruments, including spectrophotometers, colorimeters, spectroradiometers, and digital cameras. Spectrophotometers are primarily used in more professional fields, such as scientific research, color identification, and quality control [16]. The two systems most commonly used for color calculation are CIE Lab* and CIEDE 2000. An examination of studies related to dentistry revealed that the CIEDE 2000 formulation provides data that are closer to the perception values of the eye in color measurements of materials [17]. However, there is no significant difference between this system and the CIE Lab* system [18].

Although modeling liquids are frequently preferred in clinical applications, there are insufficient studies examining their use with single-shade composites. The objective of this study was to investigate the effects of modeling liquids, which are frequently used in routine dental procedures and for which there is a paucity of studies on their impact on the surface properties of restorative materials, on the color stability and surface roughness of single-shade composites. The null hypotheses tested in this study were that (a) the application of modeling liquid has no significant effect on the color stability of single-shade composites, and (b) the application of modeling liquid has no significant effect on the surface roughness of single-shade composites.

Materials and methods

Sample size calculation

The sample size was determined in consultation with the Department of Biostatistics at Sivas Cumhuriyet University Faculty of Medicine. In this study, with $\alpha = 0.05$, $\beta = 0.10$, and a power of $1\text{-}\beta = 0.90$, it was decided to include $N = 16$ samples per group, for a total of 64 composite samples. The power of the test was calculated as $p = 0.90698$ [10].

Preparation of samples

Ethics Committee approval dated 21.11.2023 and numbered 2023-12/08 was obtained from Sivas Cumhuriyet University Non-Interventional Clinical Research Ethics Committee to begin the study. The composition, type, and manufacturers of the tested resin-based materials are

Table 1 The tested materials and their compositions

Groups	Filler Type	Main Compenents	Manufacturer
Omnichroma	Supra- nano sferical	79% by weight (68% by volume) spherical silica-zirconia fillers (average particle size: 0.3 µm, particle size range: 0.2 to 0.4 µm) and composite fillers, 1.6-bis (methacryl-ethyloxy) carbonyl amine), trimethyl hexane (UDMA), (TEGDMA), Contains Mequinol, Dibutyl hydroxyl toluene and UV absorber.	Tokuyama Dental, Tokyo, Japan
Vittra APS Unique	Zirconium oxide glass particle	Methacrylate monomer mixture UDMA, TEGDMA, photoinitiator composition (APS), initiators, stabilizers, silane, boron-aluminum silicate glasses. (72–80% by weight, 52–60% by volume)	FGM Dental, Joinville, SC Brazil
Charisma Diamond One	TCD matrix	(UDMA), TCD- DI-HEA, (TEGDMA), barium, Aluminum, boron, fluorine, silicon glass, PPF, silicon oxide 75% by weight (59% by volume) inorganic filler	Kulzer, Hanau, Germany
Zenchroma	Radio-opaque glass with filler microhybrid	Glass powder, diurethane dimethacrylate, silicon dioxide, (Bis-GMA), tetramethylene dimethacrylate. 75% by weight (by volume 53% inorganic filler (0.005-3.0μm)	President Dental Germany
GC Modeling Liquid		UDMA, 2-hydroxyethyl methacrylate,3 dimethacryloxy propane, 2-hydroxy-1	GC Corporation, Tokyo, Japan

Bis-GMA: bisphenol A dimethacrylate, UDMA: urethane dimethacrylate, TEGDMA: triethyleneglycol dimethacrylate,

UV: Ultraviolet, TCD-DI-HEA tricyclodecane-urethaneacrylate, TCD: Tricyclodecane

listed in Table 1. A total of 64 disc-shaped samples each with dimensions of 8 mm × 2 mm were prepared by using standard Teflon molds.

Experimental groups

Group 1 Omnichroma (OMN): Nanohybrid single-shade composite with spherical fillers sized at 260 nm, without the inclusion of color pigments.

Group 2 Vittra APS Unique (VUA): BPA-free single-shade composite synthesized via an advanced polymerization system.

Group 3 Charisma Diamond One (CDO): Single-shade nanohybrid composite featuring a TCD matrix structure.

Group 4 Zenchroma (ZNC): Single-shade microhybrid composite containing glass particles.

The samples were divided into two subgroups according to the application of the modeling liquid: the control group and the modeling liquid group.

Subgroup 1 (control)

Composite resins were incrementally compressed between glass slides and Mylar strips without surface treatment. Samples were polymerized using a Valo Cordless light-curing unit (Ultradent, USA) with a wavelength of 395–480 nm and a power output of 1000 mW/cm², for 20 s on both the upper and lower surfaces.

Subgroup 2 (modeling liquid)

Composite resins were similarly compressed between glass slides and Mylar strips following the application of a modeling liquid (GC Modeling Liquid, GC Corporation, Tokyo, Japan) with a clean applicator that was renewed for each sample. Polymerization was performed under identical conditions as the control group. The prepared samples were subsequently stored in distilled water at 37 °C for 24 h prior to further analysis.

All samples underwent a two-stage polishing process using the Sof-lex Spiral Diamond Polishing System (3 M ESPE, St. Paul, MN, USA). The polishing and numbering processes of the specimens in each composite group were performed by the same investigator in accordance with the manufacturers' instructions.

Pre-polishing

Beige spiral rubber at 15,000–20,000 rpm under wet conditions for 15–20 s.

High-gloss polishing

Pink spiral rubber at 15,000–20,000 rpm under wet conditions for 15–20 s.

Coloring procedure

Following the initial color and roughness measurements, the samples were immersed in a coffee solution (Tchibo

Gold Selection Rich & Intense, Tchibo, Germany) for 12 days to simulate a one-year coloring process [19]. The coffee solution was prepared using 6 g of filter coffee per 100 ml of water. For 300 ml, 18 g of filter coffee was placed in a V60 dripper, and boiling water was poured over it [20]. The resulting solution was allowed to stand for 10 min before use.

The coffee solution was refreshed daily, and the samples were maintained at room temperature throughout the coloring period. At the end of the 12-day immersion, the samples were rinsed under running tap water for 10 s and subsequently stored in opaque containers.

Measuring color change values (ΔE)

Color measurements were made with a Vita Easyshade Advanced 4 (Vita Zahnfabrik, Bad Sackingen, Germany) spectrophotometer against a white background. Measurements were performed under D65 standard lighting conditions, and the spectrophotometer was calibrated according to the manufacturer's recommendations before each measurement. The measurements were repeated three times for each sample, their averages were recorded as L*, a* and b* values, and the device was calibrated after all three measurements. Color measurements were made in 2 stages: baseline and end of the coloring procedure. The following formula was used to calculate the ΔE values according to the CIELAB color system:

$\Delta E^{*} = [(L1^{*}-L0^{*})^2+(a0^{*}-a1^{*})^2+(b0^{*}-b1^{*})^2]^{½}$ [18].

Measuring surface roughness values

To measure the surface roughness values of the samples, a profilometer device (Mitutoyo, Surftest SJ-301, JAPAN) with a scanning length of 4 mm and a surface cutting length of 0.25 mm was used. The surface roughness of each sample was measured at three different regions, and the average of these values was calculated to determine the Ra value. These measurements were taken at two stages: initially and after the coloring procedure.

Statistical analysis

The variation data were analyzed via the SPSS statistical software program (Version 22.0. Armonk, NY: IBM Corp.) The data were subjected to statistical analysis via two-way analysis of variance and Tukey's test to examine pairwise differences at a significance level of 0.05.

Results

The color changes in the composite samples after the coloring procedures are given in Table 2. When comparing color changes after the coloring procedure of the composite groups, the most significant color change was observed in the CDO within the control groups, with significant differences between this group and all other groups ($p < 0.05$). Compared with the control groups of the composites, ZNC resulted in the least color change (Fig. 1). Moreover, the differences between the ZNC and VUA groups were statistically significant ($p < 0.05$). There was no significant difference in color change values among the composite subgroups where modeling liquid was applied ($p > 0.05$). When compared to the control groups, the application of modeling liquid to the composite samples resulted in a decrease in discoloration in the CDO and VUA groups, whereas an increase was observed in the OMN and ZNC groups. Among all these changes, only the alteration in CDO was found to be significant ($p < 0.05$).

The surface roughness changes in the composite at baseline and after the coloring procedures are given in Table 3. Among the composite control groups, both at baseline and after the coloring procedures, the highest surface roughness degree was observed in the CDO group, while the lowest surface roughness degrees were observed in the OMN and ZNC groups (Fig. 2). The differences in surface roughness between CDO and the OMN and ZNC groups were statistically significant ($p < 0.05$), while there was no significant difference between OMN and ZNC ($p > 0.05$). When comparing the composite samples subjected to the modeling liquid with the control groups, it was observed that roughness values decreased for the CDO and VUA groups, while roughness values increased for the OMN and ZNC groups. However, these differences were not statistically significant ($p > 0.05$). The application of modeling liquid was observed to reduce the variation in initial roughness

Table 2 Mean and standard deviation (SD) (min/max) of ΔE values according to application

	Control Group Mean (SD)	Modeling Resin Mean (SD)	Control Group		Modeling Resin	
			Min	Max	Min	Max
Omnichroma	6.46 (1.03)$^{A, ac}$	6.80 (1.25)$^{A, a}$	5.21	8.02	4.61	8.12
Vittra APS Unique	7.46 (0.59)$^{A, a}$	5.77 (1.27)$^{A, a}$	6.85	8.48	4.00	7.63
Charisma Diamond One	10.29 (2.31)$^{B, b}$	6.59 (1.10)$^{A, a}$	6.78	12.54	5.08	8.41
Zenchroma	4.45 (1.16)$^{A, c}$	5.74 (1.31)$^{A, a}$	3.37	6.42	3.99	7.29

By two-way analysis of variance: F = 13.178, $P = 0.000$, $p < 0.05$, a significant main effect of composite type on color stability (ΔE) was identified. However, the main effect of modeling liquid application and its interaction with composite type were not statistically significant

$^{A, B}$ The different uppercase letter in the horizontal rows indicates a difference at the 5% significance level

$^{a, b, c}$ The different lower case letter in vertical columns indicates difference at 5% significance level

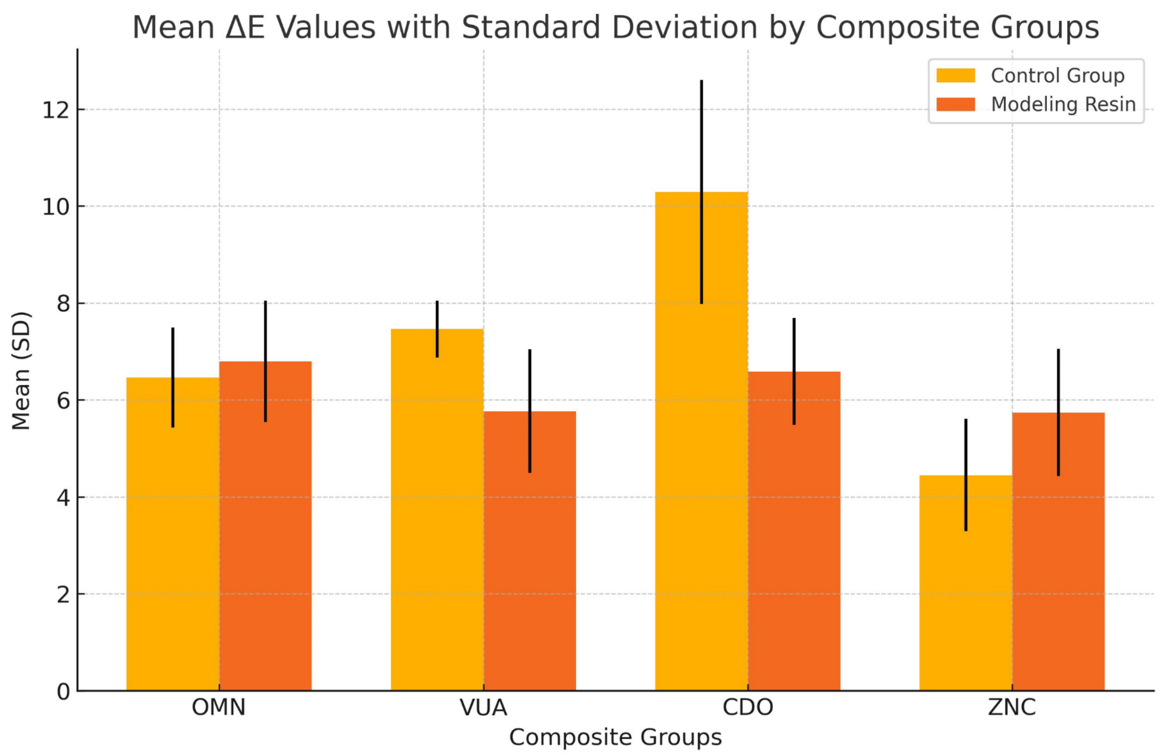

Fig. 1 Comparison of color stability values (ΔE) among the study groups (Group 1 Omnichroma (OMN); Group 2:Vittra APS Unique (VUA); Group 3:Charisma Diamond One (CDO); Group 4: Zenchroma (ZNC) (-)

Table 3 Mean and Standard Deviation (SD) of Ra values according to treatment

Composite Groups	Baseline		After Coloring Procedure	
	Control Group Mean (SD)	Modeling Liquid Mean (SD)	Control Group Mean (SD)	Modeling Liquid Mean (SD)
Omnichroma	0.15 (0.07)$^{A, a}$	0.26 (0.11)$^{A, a}$	0.21 (0.09)$^{A, a}$	0.32 (0.12)$^{A, a}$
Vittra APS Unique	0.36 (0.14)$^{A, ab}$	0.27 (0.17)$^{A, a}$	0.49 (0.19)$^{A, ab}$	0.40 (0.17)$^{A, a}$
Charisma Diamond One	0.47 (0.20)$^{A, b}$	0.33 (0.16)$^{A, a}$	0.63 (0.33)$^{A, b}$	0.44 (0.11)$^{A, a}$
Zenchroma	0.20 (0.11)$^{A, a}$	0.34 (0.12)$^{A, a}$	0.20 (0.11)$^{A, a}$	0.38 (0.11)$^{A, a}$

By two-way analysis of variance: $F = 5.294$, $P = 0.000$, $p < 0.05$, a significant main effect of composite type on surface roughness was identified, indicating differences among composite groups. However, the effects of modeling liquid application and its interaction with composite type were not statistically significant

[A, B] The different uppercase letters in the horizontal columns indicates a difference at the 5% significance level

[a, b] The different lowercase letters in vertical columns indicates difference at 5% significance level

among the composites, bringing their roughness values closer to an average range (0.26–0.34).

Discussion

Recently, in restorative dentistry, modeling liquids have been frequently used to facilitate manipulation and better adapt the resin to the cavity. However, the impact of modeling liquid application on the properties of the composite material, such as color stability and surface roughness, is not precisely known [21, 22]. The present study compared the surface roughness and color stability of different single-shade composites after applying the modeling liquid [23]. In this study, first null hypothesis (a) was partially rejected but second null hypothesis (b) was accepted. The results indicate varying degrees of color change and surface roughness after immersion in filter coffee, depending on the material.

In contemporary evaluations of the success of dental composites, a variety of mechanical and aesthetic properties, including color stability, surface roughness, and microhardness, are critically considered. Patients' daily consumption habits are a major factor in external discoloration, and the diversity of these habits is reflected in the variability of discoloration problems. This color change occurs when external colorants interact with the

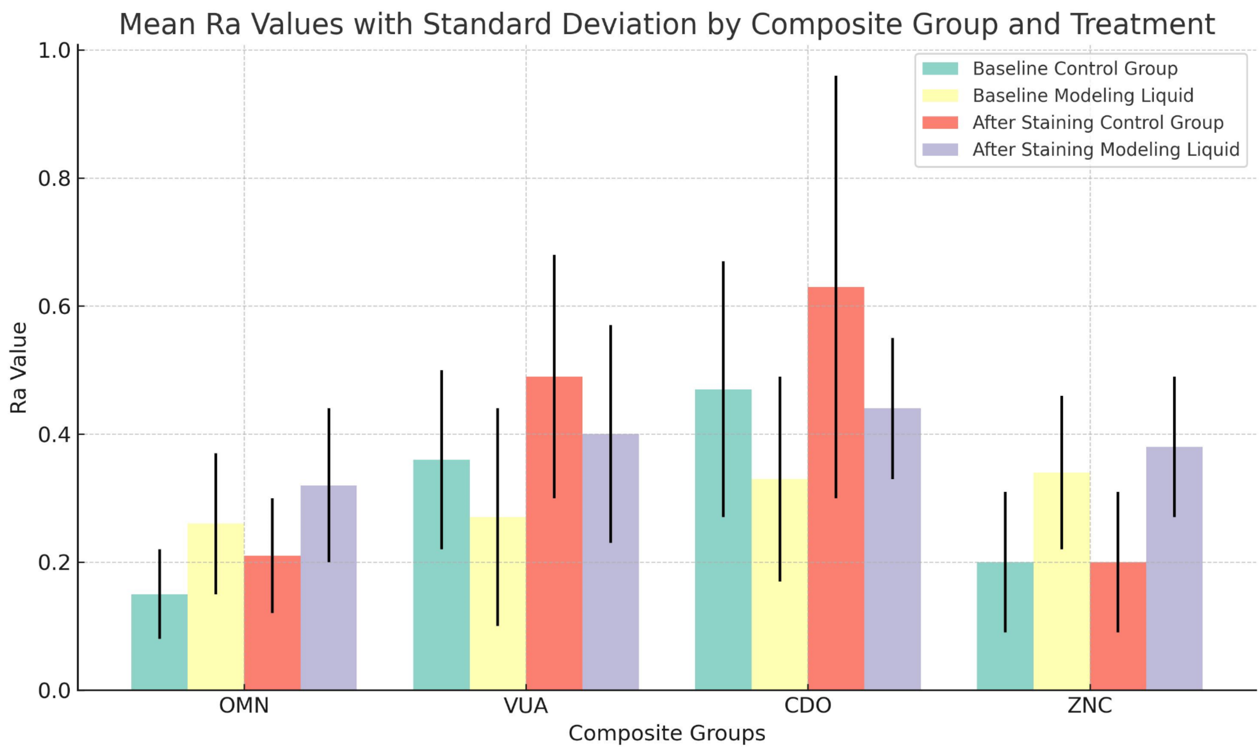

Fig. 2 Comparison of surface roughness (Ra) among the study groups (Group 1: Omnichroma (OMN); Group 2:Vittra APS Unique (VUA); Group 3:Charisma Diamond One (CDO) ; Group 4: Zenchroma (ZNC))

composite resin materials. Beverages such as coffee, tea, cola, fruit juices, mouthwashes, and various foods can significantly impact the color stability of resin-based composites (RBCs) [14]. In this study, we used filter coffee as it is a universal beverage with a wide consumer base and is consumed frequently.

Finishing and polishing are critical steps in composite resin restorations, and leaving rough areas on the surface of composite restorations can lead to aesthetic degradation, plaque retention, surface coloring, and secondary caries formation [24]. Many researchers have reported that the utilization of transparent strips during composite resin restorations results in a reduction in surface roughness. Compared with various polishing systems, the smoothest surface is achieved with the use of transparent strips. Additionally, it has been reported that the oxygen inhibition layer on unpolished composite surfaces containing unpolymerized monomers should be removed through polishing, as it is prone to coloration and cytotoxicity [24, 25]. In accordance with the above-mentioned data, the samples in this study were prepared by first using transparent strips for finishing, followed by polishing with aluminum oxide and diamond particles containing polishing discs.

In our study, among the composite control groups, the highest surface roughness values were observed in the CDO group at both baseline and after the coloring procedures, while the lowest values were recorded in the OMN and ZNC groups, a statistically significant difference. In contrast, in samples where modeling liquid was applied, roughness values converged towards an average range at both baseline (0,26 – 0,34) and after coloring (0,32 – 0,44).

Alp et al. [26] investigated and compared the surface properties of single-shade and universal-shade composites. The study reported that CDO exhibited the highest roughness values among the single-shade composites (OMN, VUA, and CDO). These findings align with our observed roughness values in the control groups after coloring. The researchers attributed this result to the fact that composite materials have different filler particle sizes and amounts, as well as the distinctive monomer structures inherent to composite materials. The structural properties of the fillers in composite resins influence the restored surface area. As the filler size increases, surface roughness can be observed due to the ruptures that occur in the fillers following surface treatments like polishing [26, 27]. Consistent with this information, in the SEM images of our previous study [28], in which we examined the effect of whitening paste on single-shade composites, the roughness values were found to be greater because larger particles separated from the surface of the CDO created larger voids.

Hafez et al. [29] reported that immersing samples in solution for 24 h corresponds to approximately one month of clinical aging. Various immersion time protocols are used in studies examining the composite discoloration. However, most studies consider the 7th day as the threshold for assessing whether coloration is acceptable during this period [14]. In our research, we immersed the samples in freshly brewed filter coffee for 12 days to simulate one year of clinical coloration in vitro.

Previous studies have reported that the threshold for the eye to perceive color differences is ΔE = 3.3 with color changes above this value are clinically unacceptable [21, 28]. Consistent with these findings, all the composites in the present study exhibited coloration above the clinically acceptable threshold. As a result, the greatest color change among the control groups was observed for CDO (ΔE = 10.29), followed by VUA (ΔE = 7.46), OMN (ΔE = 6.46), and ZNC (ΔE = 4.45).

Özara et al. [30] studied the color stability of different resin materials (Filtek Z350XT, IPS Empress Direct, CDO) when exposed to various acidic beverages (coffee, tea, and cola) and saliva for 14 days. Their results indicated that, CDO exhibited in the lowest color change among the resin composites. On the other hand, it is noteworthy that the color change was significantly greater in the CDO subgroups kept in coffee.

In another study, Chen et al. [31] The color change of samples prepared with CDO and three multishade composites when exposed to distilled water (12 days at 37 °C), coffee (12 days at 37 °C), and thermal cycles (10,000 cycles between 5 °C and 55 °C) was examined. The most notable change was observed in CDO. The researchers attributed the higher coloration of CDO to the relatively higher TEGDMA monomer content and larger filler sizes. They reported that with increasing TEGDMA monomer ratio in the matrix structure, the material exhibited more hydrophilic properties, and the color stability decreased, although a low-shrinkage monomer, TCD-urethane acrylate, was present in CDO's composition. Our study results are consistent with the findings of Chen et al. However, considering that TEGDMA is present in the other composite (except ZNC) structures utilized in our study and given the lack of precise proportions provided by manufacturers, it is not feasible to directly attribute the low color stability solely to TEGDMA. On the other hand, we believe that the larger filler size in the CDO structure and therefore the high surface roughness adversely affect color stability, as reported by Chen et al.

Fidan et al. [32] investigated the effects of universal adhesives on the color coordinates and color stability of different single-shade composites by comparing them with a multi-shade composite. As a result, they observed the greatest color change in the CDO. Although there were differences depending on the adhesive system used among the other composites subjected to thermal cycling (10,000 cycles of thermocycling between 5 °C and 55 °C with a dwell time of 30 s) in their study, the color change in the control groups and overall values showed a pattern similar to that in our study. Researchers have reported that the high surface roughness of CDO may negatively affect color stability. They also reported that the presence of pigments in the CDO structure may negatively affect color stability. Additionally, the low color stability of CDO may be due to weak cross-link bonds between the polymer matrix and the filler.

According to previous research findings, CDO decreases color stability, especially in acidic solutions [26, 28, 30]. A previous study [26] reported that Ba, an electropositive element in the structure of CDO, can undergo hydrolytic degradation by interacting with water in acidic environments. Additionally, the interaction of prepolymerized monomers with acidic solutions may lead to the deterioration of weak cross-links within the polymer structure.

As a result of a study investigating the color stability of single shade and multishade composites under different conditions, the greatest color change was observed in VUA, followed by OMN, in the samples stored in coffee. Given that, there was no significant difference between these composites, the authors attributed the results to the presence of TEGDMA in their structures [33]. In addition, a previous study [34] reported that the presence of water in the APS photoinitiator system's solvent in the VUA structure may cause more water leakage into the hybrid layer than camphorquinone does. In a related investigation [35], researchers posited that the failure of OMNs may be attributed to intrinsic subsurface defects associated with their nano structural characteristics rather than surface-related factors.

The findings of our study indicate that modeling liquid application resulted in enhanced coloration in the ZNC and OMN, whereas it reduced coloration in CDO and VUA. Modeling liquid applications resulted in a statistically significant change only in the CDO.

Tuncer et al. [36] investigated the surface hardness, surface roughness and color changes of different composites following liquid application and thermal cycling. Consequently, they reported that the color change was more pronounced in the non-polished group where modeling liquid was applied. This finding was attributed to the formation of an oxygen inhibition layer on the surface because the samples were not polished after finishing with transparent tape. In the present study, a statistically insignificant increase was observed in OMN and ZNC due to the application of the modeling liquid. However, as all the samples were polished before analysis, it may be concluded that this increase is not attributable to the oxygen inhibition layer. The increase in roughness may be attributed to the resin-containing structure of the modeling liquid and the relatively lower UDMA ratio in its composition compared with the composite to which it is applied. The use of UDMA-containing resins has been associated with increased polymerization rates and a high degree of conversion [36]. It has been reported that urethane causes an increase in the number of cross-links in the composite structure, which increases the mechanical properties of the material [37]. The presence of diurethane in the UDMA structure of ZNC may contribute to the color stability of the material.

Studies [10, 38] have suggested that modeling liquid application contributes to the color stability and surface properties of composite resins. Our data from the CDO group was consistent with these findings. Researchers have posited that this positive effect may be due to the nonfiller structure and hydrophobic character of the modeling liquid [10].

When all these results were combined, the first null hypothesis (a) was partially rejected, while the second null hypothesis (b) was accepted, reflecting the varying effects of modeling liquid application on different composite resins. Although some properties of resin materials can be enhanced through subsequent applications, the main components, such as organic matrix structures, filler types and proportions, and photoinitiators, play a more decisive role in determining the mechanical and aesthetic characteristics of the material. For instance, in this study, the larger filler size and the presence of Ba ions in CDO, along with their interaction with pre-polymerized monomers and acidic solutions, were associated with reduced color stability. We propose that the application of modeling liquid enhances CDO's color stability by compensating for its large filler structure and minimizing interactions with acidic solutions due to its hydrophobic properties. Similarly, the presence of APS in the VUA structure negatively affects water absorption and discoloration resistance compared to camphorquinone, while the application of modeling liquid positively impacts discoloration resistance due to its hydrophobic properties and its ability to reduce surface roughness. However, in OMN and ZNC, which initially exhibited relatively lower surface roughness values, the modeling liquid may have increased surface roughness, potentially leading to a negative impact on discoloration. These findings highlight the complexity of the multi-component structure of composite resins, which can lead to varying outcomes under different application conditions. Therefore, instead of relying on generalized expressions about materials, in vitro and clinical studies should focus on identifying the specific conditions under which these materials can provide optimal results.

This study is subject to several limitations. Firstly, as it was conducted in vitro, it may not fully capture the complexities of the oral environment, underscoring the need for complementary clinical studies. Secondly, only one coloring agent was used (filter coffee), selected for its common use in aging procedures, but additional beverages could provide a broader understanding of discoloration effects. Thirdly, this study did not include a multi-shade composite as a control, which could provide a comparative basis for evaluating the performance of single-shade composites. Finally, incorporating additional measurement and imaging methods could enhance the assessment of color stability and surface roughness. In examining the effect of modeling liquid on surface properties, it would also be beneficial to investigate its effect on microhardness.

Conclusion

The results obtained within the limits of this in vitro study are as follows.

1) The application of modeling liquid increased the roughness and discoloration of composites with initially low surface roughness (OMN and ZNC) and decreased the roughness and discoloration of composites with initially high surface roughness (VUA and CDO).
2) The application of modeling liquid appeared to standardize the surface roughness across composites with varying initial roughness values, bringing them closer to a more consistent average roughness range. This effect suggests that modeling liquid may help reduce disparities in surface texture, potentially enhancing uniformity across different composite materials.
3) The use of modeling liquid should be supported by additional in-vitro and clinical studies before application, particularly in composites with initially low surface roughness.

Abbreviations

CDO	Charisma Diamond One
VUA	Vittra APS Unique
OMN	Omnichroma
ZNC	Zenchroma
Bis-GMA	Bisphenol A dimethacrylate
UDM	Urethane dimethacrylate
TEGDMA	Triethyleneglycol dimethacrylate
UV	Ultraviolet
TCD-DI-HEA	Tricyclodecane-urethaneacrylate

Acknowledgements

Not applicable.

Author contributions

Author contributions Conceptualization: M.G.B and İ.H. Methodology: M.G.B and İ.H Investigation: M.G.B Resources: M.G.B Formal analysis: İ.H and M.G.BWriting-original draft: M.G.B Writing-review and editing: İ.HVisualization: M.G.B and İ.H Project administration: M.G.B and İ.H.

Funding
The authors declare that no funds, grants, or other support was received during the preparation of this manuscript.

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

Declarations

Ethics approval and consent to participate
Ethics Committee approval dated 21.11.2023 and numbered 2023–12/08 was obtained from Sivas Cumhuriyet University Non-Interventional Clinical Research Ethics Committee to start the study. This study does not contain any studies with human participants and subjects or animals performed by any of the authors.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Competing interests
The authors declare that they have no competing interests.

Informed consent
For this type of study, formal consent is not applicable.

Clinical trial number
Not applicable.

Received: 19 August 2024 / Accepted: 17 January 2025
Published online: 23 January 2025

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