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RESEARCH AND EDUCATION

Effect of layering strategy and prolonged water aging on masking ability of composite resins

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ABSTRACT

Statement of problem. Layered composite resins may adequately mask discolored substrates. However, whether color changes that occur over time affect masking ability is unclear.

Purpose. The purpose of this in vitro study was to investigate the effect of layering and water aging on the masking ability of 2 composite resins.

Material and methods. Disk specimens (1.5 mm-thick and shade A1) from Charisma Diamond (CD) and Filtek Z350XT (Z350) were made according to the composite resin shade combination used in the layering strategies: bilayer for CD (enamel/dentin) and for Z350 (enamel/body and enamel/dentin) and trilayer for Z350 (enamel/body/dentin) (n=5). Color measurements were obtained with a spectrophotometer over an A3.5 ceramic substrate, and the whiteness index for dentistry (WI_D) was calculated. The specimens were aged in water at 37 °C and evaluated at different times: 24 hours, 1 week, 1 month, 2 months, 6 months, 12 months, 18 months, and 24 months. CIEDE2000 color differences (ΔE_{00}) and WI_D differences (ΔWI_D) were calculated and interpreted by 50:50% color and whiteness perceptibility and acceptability thresholds. Changes among strategies and aging times were analyzed using the Kruskal-Wallis test (α=.05). Contrasts were made using the Mann-Whitney U test with Bonferroni correction (α=.001).

Results. ΔE_{00} decreased from 24 hours to 2 months of aging. From 2 months onwards, ΔE_{00} increased for all layering strategies and times, without significant changes in lightness for CD (*P*>.004). Overall, for the CD restorative system, an increase in ΔWI_D was observed after 1 month of aging (*P*<.001), while for the Z350 restorative system, ΔWI_D decreased after aging (*P*<.001), except for the Z350 bilayer strategy (enamel + dentin) at 1 week and 2 months (*P*>.004). For all layering strategies and aging times, color differences were higher than the 50:50% perceptibility threshold for ΔE_{00} and, after 6 months, higher than the 50:50% acceptability threshold for ΔE_{00} and the 50:50% whiteness acceptability threshold.

Conclusions. The ability of the tested composite resins to mask a discolored substrate was affected by the layering approach applied and by prolonged water aging. (J Prosthet Dent 2023;130:745.e1-e8)

The increasing demand for improved esthetics has necessitated natural-looking, imperceptible restorations that harmonize with the surrounding tooth structure.[1–3] Adequate shade matching and excellent masking of the underlying structures have been major challenges, especially when restoring a single discolored tooth.[4–7] Direct restorations with composite resin have the potential to obtain the expected outcomes under these circumstances, as they offer esthetic, conservative, and durable results.[8,9]

The layering strategy is an effective and conservative approach to masking discolored substrates.[4,5,7] Layering may combine various shades, translucencies, and different thicknesses of the composite resin.[10–12] The correct application of the layering strategy, thickness and the different combinations of the composite resin layers (dentin/body/enamel), are essential for adequate masking.[4,5,7,13,14] Unfortunately, even though excellent masking may be attained immediately after the placement of the restoration, color alterations of the composite resin may subsequently affect its masking ability.[5,15–24] The lack of

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Clinical Implications

Composite resin restorative systems applied either by bilayer or trilayer strategies provided acceptable masking of an A3.5 substrate after 2 months of water aging. It was observed that the masking ability improved from baseline until 2 months of water aging. Acceptable masking tended to decrease progressively after this time, up to 24 months, indicating that water aging has a negative effect on the ability of layered composite resins to mask discolored substrates.

color stability and the discoloration of the composite resins have been linked with the need to repair or replace these restorations.[2,22,23,25–27] Major reasons for color-related failure include composite resin discoloration, surface staining, and marginal mismatch.[28]

Composite resins have improved in the past decades, but color stability still remains a clinical concern.[15–18,21–23,29–33] Although studies have evaluated the effects of aging on the color stability and optical properties of composite resins,[15–17,23,27,31,34–36] the authors are aware of only 1 study that measured the effect of prolonged water aging on the masking ability of layered composite resins[5]; however, the critical moment when masking becomes compromised by aging has not yet been established. The investigation of the factors associated with the application method, masking difficulty, and long-term water exposure may help clinicians better understand aspects related to the long-term maintenance of the masking ability of composite resins.

Therefore, the aim of this in vitro study was to evaluate the effect of layering and water aging on the masking ability of 2 composite resins. The research hypotheses were that the masking ability of the tested composite resins would be affected by the layering strategy and water aging time.

MATERIAL AND METHODS

Two composite resin restorative systems applying bilayer and trilayer strategies were tested: Charisma Diamond; Kulzer GmbH (CD) and Filtek Z350XT; 3M (Z350). CD has 2 opacity options (enamel and dentin) and Z350 has 3 opacity options (enamel - E, body - B, and dentin - D) for each shade; thus, for CD, only a bilayer strategy (E + D) was tested, and, for Z350, bilayer (E + D and E + B) and trilayer (E + B + D) strategies were tested. The study design, composite resins, layering strategies, and water-aging times are shown in Figure 1. The specifications of the composite resins are presented in Table 1.

A trained operator (B.G.P.) produced 1.5-mm-thick specimens (n=5) using three Ø11.0 cylindrical metal molds with a thickness of 0.5 mm, 1.0 mm, and 1.5 mm. Bilayer specimens were prepared by first obtaining a 1.0-mm-thick disk from the 1.0-mm mold, placing it inside the 1.5-mm-thick mold, filling the remaining 0.5 mm with composite resin, and then light polymerizing. Trilayer specimens were prepared following similar procedures using 0.5-, 1.0-, and 1.5-mm-thick molds. The layers were polymerized for 40 seconds on both sides after the application of a 9.8-N load with a light-emitting diode (LED) device with 1000 mW/cm^2 irradiance.[4,5,37]

The specimens were stored in deionized water at 37°C and evaluated after different times: 24 hours (T0), 1 week (T1), 1 month (T2), 2 months (T3), 6 months (T4), 12 months (T5), 18 months (T6), and 24 months (T7). During the aging process, the water was replaced weekly, and the specimens were always immersed in water.[31]

A 2-mm-thick ceramic disk (shade A3.5) was produced from feldspathic porcelain, dentin opacity, and VM13 (Vita VM13; Vita Zahnfabrik)[4,5,38] to simulate a discolored substrate. Additionally, dentin shade A1 was used as the substrate control for the tested composite resins; therefore, 4-mm-thick disks were produced for each composite resin.

A previously calibrated reflectance spectrophotometer with an 8-mm aperture size (SP60; X-Rite, Inc) was used to measure the color of each layered specimen over the simulated discolored substrate and each control group over a white background (L^*=91.9, a^*=−1.0, and b^*=6.7). According to the manufacturer of the spectrophotometer, the average white repeatability was 0.1 ΔE^*_{ab} units, and the inter-instrument agreement was 0.4 ΔE^*_{ab} units. The experimental design corresponded to the International Commission on Illumination (CIE) diffuse/8-degree illuminating/measuring geometry. The CIE 2-degree standard observer and CIE D65 standard illuminant were used. A drop of glycerin was placed between the specimens and the substrates to achieve optical contact[29] and to simulate the oral environment.[8,39] Color readings were performed at T0 (24 hours of water aging), and the consecutive water-aging time points and chroma (C^*) and hue angle ($h°$) coordinates were implemented. Three consecutive measurements of the specimens were performed under controlled temperature and lighting conditions. All readings were made according to the layering concept by placing the enamel shade upward.[4,5]

The total color difference of each specimen placed over the discolored substrate (A3.5) and of each of them placed over the respective composite resin substrate control at different water-aging time points was calculated using the CIEDE2000 color difference metric

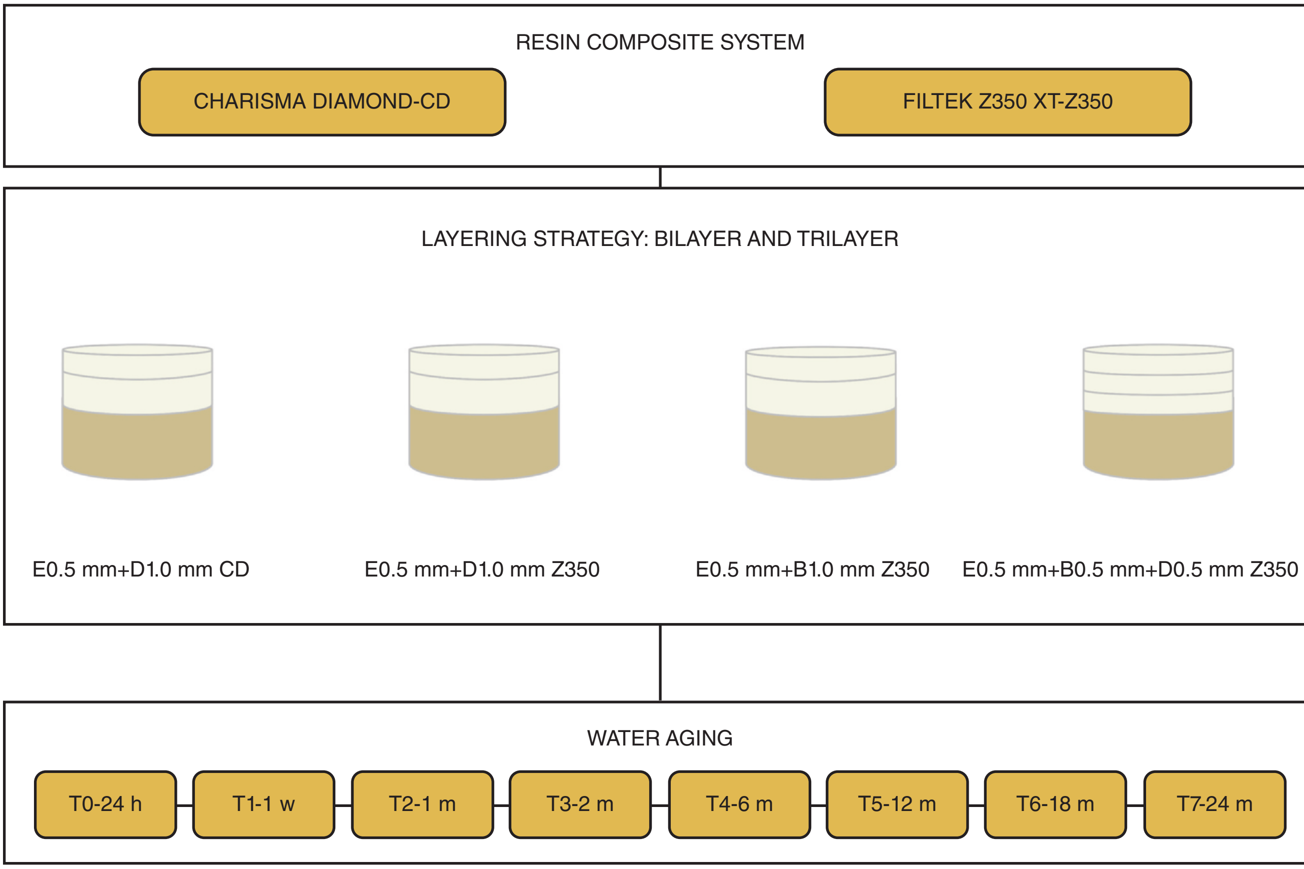

Figure 1. Schematic representation of experimental design and group division according to composite resin restorative system, layering strategy, and water aging time points. B, body; CD, Charisma Diamond; D, dentin; E, enamel; Z350, Filtek Z350XT.

(ΔE_{00})[40,41] with the same parameter values used in previous studies[42–44]:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)\right]^{\frac{1}{2}}$$

ΔE_{00} was evaluated by comparison with respective perceptibility (PT_{00}=0.8 ΔE_{00} units) and acceptability (AT_{00}=1.8 ΔE_{00} units) 50:50% thresholds[45] according to the International Organization for Standardization technical report (ISO/TR) 28642:2016.[46] Furthermore, in conjunction with PT_{00} and AT_{00}, the color threshold ratings have also been strongly recommended to interpret color differences[47]: excellent match (EM) ($\Delta E_{00} \leq 0.8$), acceptable match (AM) ($0.8<\Delta E_{00} \leq 1.8$), moderately unacceptable mismatch (MU) ($1.8<\Delta E_{00} \leq 3.6$), clearly unacceptable mismatch (CU) ($3.6<\Delta E_{00} \leq 5.4$), and extremely unacceptable mismatch (EU) ($\Delta E_{00}>5.4$).

Total color differences in CIEDE2000 (ΔE_{00}) were evaluated in terms of the differences of color perceptual attributes: lightness, chroma, and hue (ΔL_{00}, ΔC_{00}, and ΔH_{00}, respectively)[48]:

$$\Delta L_{00} = \frac{\Delta L'}{k_L S_L}; \Delta C_{00} = \frac{\Delta C'}{k_C S_C}; \Delta H_{00} = \frac{\Delta H'}{k_H S_H}$$

These 3 attributes can be presented in percentages calculated as: $\%\Delta attribute = 100(\Delta attribute/\Delta E_{00})^2$ and, therefore, from this definition, it follows that:

Table 1. Composition and information regarding composite resin

Restorative System	Manufacturer	Composition	Shade/Opacity	Batch Number
Charisma Diamond (CD)	Kulzer GmbH	UDMA, TCD-DI-HEA, Ba-Al-F glass silicate, YbF3, SiO2, Bis-GMA, and TEGDMA	A1 Universal Opaque Light	A1–010040 OL- 010030
Filtek Z350XT (Z350)	3M ESPE	Bis-GMA, UDMA, TEGDMA, Bis-EMA, PEGDMA, BHT, silicate, and zirconia	A1E A1B A1D	1415300268

B, body; CD, Charisma Diamond; D, dentin; E, enamel; Z350, Filtek Z350XT.

Table 2. Reference values ±standard deviations for color difference calculation for each combination tested

	Layering Strategy	L*	a*	b*	C*	h°	WI_D
Reference value (A1)	0.5E ±1.0D CD	79.9 ±0.3	3.5 ±0.1	15.3 ±0.8	15.7 ±0.7	77.1 ±0.5	15.9 ±1.0
	0.5E ±1.0D Z350	80.3 ±0.6	1.8 ±0.1	16.4 ±0.4	16.5 ±0.4	83.8 ±0.2	18.8 ±0.7
	0.5E ±1.0B Z350	80.1 ±1.1	2.3 ±0.1	16.3 ±0.4	16.5 ±0.4	81.9 ±0.2	17.6 ±1.2
	0.5E ±0.5B ±0.5D Z350	78.6 ±0.7	1.6 ±0.1	15.2 ±0.3	15.3 ±0.3	83.9 ±0.5	19.8 ±0.7

B, body; CD, Charisma Diamond; D, dentin; E, enamel; SD, standard deviation; WI_D, whiteness index for dentistry; Z350, Filtek Z350XT.

$$\%\Delta L_{00} + \%\Delta C_{00} + \%\Delta H_{00} = 100\%$$

Whiteness was evaluated using the whiteness index for dentistry (WI_D) values for layering strategies at different water-aging times. This index has been defined as follows[49]:

$$WI_D = 0.511L^* - 2.234a^* - 1.1b^*$$

Whiteness differences (ΔWI_D) were interpreted using the 50:50% whiteness perceptibility threshold (WPT=0.7 WI_D units) and 50:50% whiteness acceptability threshold (WAT=2.6 WI_D units).[50] CIELab-based whiteness index WI_D differences between layering strategies and between water-aging times were also interpreted using the categorization proposed by Paravina et al[47]: excellent match ($\Delta WI_D \leq 0.72$), acceptable match ($0.72 < \Delta WI_D \leq 2.62$), moderately unacceptable mismatch ($2.62 < \Delta WI_D \leq 5.2$), clearly unacceptable mismatch ($5.2 < \Delta WI_D \leq 7.8$), and extremely unacceptable mismatch ($\Delta WI_D > 7.8$).

For the statistical analysis, a 1-way analysis of variance by ranks, the Kruskal-Wallis test, was applied to evaluate changes between strategies and during aging times since equal variances could not be assumed for all color coordinates and WI_D groups after performing the Levene test of homogeneity of variance (α=.05). Contrasts were made between each stratification strategy and its reference values at each aging time and between the different layering strategies at each aging time using the Mann-Whitney U test with Bonferroni correction (α=.001). All statistical analyses were executed using a statistical software program (IBM SPSS Statistics, v20.0; IBM Corp).

RESULTS

CIELab color coordinates and whiteness index (WI_D) for the reference values and all layering strategies at all aging times are shown in Tables 2 and 3, respectively. In general, for the same aging times, strategies 0.5E ±1.0B Z350 and 0.5E ±0.5B ±0.5D Z350 did not show significant differences for lightness (*P*>.009). In general, significant differences were also not found for layering strategies 0.5E ±1.0D Z350 and 0.5E ±0.5B ±0.5D Z350 for a* (*P*>.004).

CIELab color polar coordinate chroma (C*) and hue angle (h°) mean values of the 4 strategies at each time are presented in Figure 2. For all strategies, the hue angle decreased from T0 to T7. However, no clear trend was found for chroma over time.

Figure 3 shows the magnitude of the 3 components (ΔL_{00}, ΔC_{00}, and ΔH_{00}) in total CIEDE2000 metric for each aging time and each layering strategy with respect to the A1 reference and comparison with the 50:50% AT_{00} and PT_{00}. ΔE_{00} decreased from 24 hours to 2 months of aging. However, from 2 months onward, ΔE_{00} increased for all layering strategies and times. For all layering strategies and aging times, color differences were higher than 50:50% PT_{00}, and, after 6 months, higher than 50:50% AT_{00}, except for the 0.5E + 1.0D Z350 strategy that presented values above 50:50% AT_{00} from 12 months of aging onward.

After 24 hours, the lightness component was higher than hue and chroma for all strategies. Also, the 0.5E +1.0 CD strategy showed a chromatic change from 2 months to 24 months of aging, mainly due to chroma, while the other strategies were influenced by lightness and hue. For all strategies, as aging progressed over time, the contribution of the hue component to the color difference increased. In addition, in general, the 0.5E +1.0D Z350 layering strategy showed the lowest color differences for all aging times.

Figure 4 shows the magnitude and guidance of whiteness differences (ΔWI_D) for each aging time and each layering strategy. For all strategies and aging times, whiteness differences were higher than 50:50% WPT_{00}, except for the 0.5E+1.0D Z350 strategy at 24 hours and 1 month and the 0.5E+0.5B+0.5D Z350 strategy at 24 hours and 2 months. In general, the 0.5E+1.0B Z350 strategy showed the greatest reduction in whiteness for all aging times (*P*<.001), while the 0.5E+1.0 CD strategy showed an overall nonsignificant increase in whiteness from 2 months of aging onward (*P*>.005).

DISCUSSION

The research hypotheses that the masking ability of the tested composite resins would be affected by the

Table 3. Mean values ±standard deviations of L*, a*, and b* coordinates for all layering strategies and all aging times studied

Water Aging	Layering Strategy	L*	a*	b*	WI_D
24 h	0.5E ±1.0D CD	76.1 ±0.6^{a}	3.6 ±0.1*	15.5 ±0.3^{*,a,b}	13.4 ±0.6
	0.5E ±1.0D Z350	78.3 ±0.8	2.0 ±0.1^{a}	15.2 ±0.3^{a}	18.8 ±0.8^{a}
	0.5E ±1.0B Z350	76.6 ±0.5^{a,b}	3.3 ±0.1	15.6 ±0.3^{b}	14.3 ±0.7
	0.5E ±0.5B ±0.5D Z350	76.5 ±0.8^{b}	2.0 ±0.2^{a}	13.7 ±0.3	19.4 ±0.8^{a}
1 WEEK	0.5E ±1.0D CD	78.1 ±1.1^{a,b}	3.5 ±0.2^{*,a}	13.4 ±1.8^{*,a,b}	17.2 ±2.9^{*,a,b}
	0.5E ±1.0D Z350	79.1 ±1.2^{*,a}	2.0 ±0.1^{b}	14.5 ±0.3^{a,c}	19.8 ±0.9^{*,c}
	0.5E ±1.0B Z350	77.0 ±0.6^{b,c}	3.5 ±0.1^{a}	15.4 ±0.2	14.2 ±0.7^{a}
	0.5E ±0.5B ±0.5D Z350	77.2 ±1.2^{*,c}	2.2 ±0.2^{b}	14.1 ±0.4^{b,c}	18.9 ±1.2^{*,b,c}
1 MONTH	0.5E ±1.0D CD	77.7 ±1.1^{a,b,c}	3.9 ±0.2	15.2 ±1.3^{*,a,b,c}	14.0 ±2.1^{*,a}
	0.5E ±1.0D Z350	79.1 ±1.1^{*,a}	2.2 ±0.1^{a}	15.2 ±0.3^{a,d}	18.6 ±1.0^{*,b}
	0.5E ±1.0B Z350	78.1 ±0.3^{b,d}	3.4 ±0.1	15.6 ±0.2^{b,d}	14.8 ±0.6^{a}
	0.5E ±0.5B ±0.5D Z350	77.5 ±1.0^{*,c,d}	2.4 ±0.3^{a}	14.6 ±0.2^{c}	18.0 ±1.0^{b}
2 MONTHS	0.5E ±1.0D CD	80.1 ±1.3^{*,a,b,c}	3.5 ±0.2^{*,a}	13.1 ±1.4^{a}	18.5 ±2.4^{a,b}
	0.5E ±1.0D Z350	80.8 ±0.5^{*,a}	2.1 ±0.1^{b}	15.3 ±0.2^{b}	19.6 ±0.5^{*,a,c}
	0.5E ±1.0B Z350	79.8 ±0.4^{*,b,d}	3.3 ±0.1^{a}	15.3 ±0.2^{b}	16.2 ±0.6*
	0.5E ±0.5B ±0.5D Z350	79.2 ±0.8^{*,c,d}	2.3 ±0.2^{b}	14.2 ±0.4^{a}	19.4 ±1.1^{*,b,c}
6 MONTHS	0.5E ±1.0D CD	80.9 ±1.1*	3.4 ±0.3*	12.1 ±1.8^{a}	20.1 ±3.1^{a}
	0.5E ±1.0D Z350	79.0 ±0.9	2.5 ±0.1	16.2 ±0.3*	16.7 ±0.8^{a,b}
	0.5E ±1.0B Z350	76.8 ±0.6^{a}	4.2 ±0.2	15.2 ±0.1	12.8 ±0.8
	0.5E ±0.5B ±0.5D Z350	76.6 ±1.2^{a}	2.9 ±0.3	14.2 ±0.1^{a}	16.7 ±1.3^{b}
12 MONTHS	0.5E ±1.0D CD	79.2 ±1.1^{*,a}	3.7 ±0.3*	12.4 ±1.2	18.2 ±2.3^{*,a}
	0.5E +1.0D Z350	78.5 ±0.9^{a}	2.9 ±0.1^{a}	15.9 ±0.3^{*,a}	16.0 ±0.8^{a,b}
	0.5E +1.0B Z350	77.2 ±0.2^{b}	4.1 ±0.1	16.1 ±0.1^{*,a}	12.7 ±0.3^{b}
	0.5E +0.5B ±0.5D Z350	76.9 ±0.7^{b}	3.0 ±0.3^{a}	15.5 ±0.2	15.2 ±1.0
18 MONTHS	0.5E +1.0D CD	80.0 ±0.9*	3.8 ±0.3*	12.8 ±1.3	18.0 ±2.4*
	0.5E +1.0D Z350	78.2 ±0.8	3.0 ±0.1^{a}	16.7 ±0.2*	14.6 ±0.8^{a}
	0.5E +1.0B Z350	77.0 ±0.4^{a}	4.3 ±0.1	16.3 ±0.3*	11.4 ±0.6
	0.5E ±0.5B ±0.5D Z350	76.6 ±1.3^{a}	3.2 ±0.3^{a}	15.5 ±0.4*	14.6 ±1.7^{a}
24 MONTHS	0.5E +1.0D CD	79.9 ±1.1*	3.6 ±0.3^{*,a}	11.4 ±1.4	20.0 ±2.4
	0.5E +1.0D Z350	78.5 ±0.7	3.0 ±0.1^{b}	15.2 ±0.9^{a}	16.6 ±1.2^{a}
	0.5E +1.0B Z350	76.8 ±0.4^{a}	4.2 ±0.1	16.1 ±0.2*	11.8 ±0.4
	0.5E +0.5B +0.5D Z350	76.9 ±1.0^{a}	3.2 ±0.3^{a,b}	14.9 ±0.2^{*,a}	15.5 ±1.3^{a}

B, body; CD, Charisma Diamond; D, dentin; E, enamel; SD, standard deviation; WI_D, whiteness index for dentistry; Z350, Filtek Z350XT.
* indicates no statistical significance ($P \geq .001$) with corresponding reference value (A1). Same lowercase letter in same time interval and column indicates no statistical significance ($P \geq .001$) – comparison between strategies for same time interval.

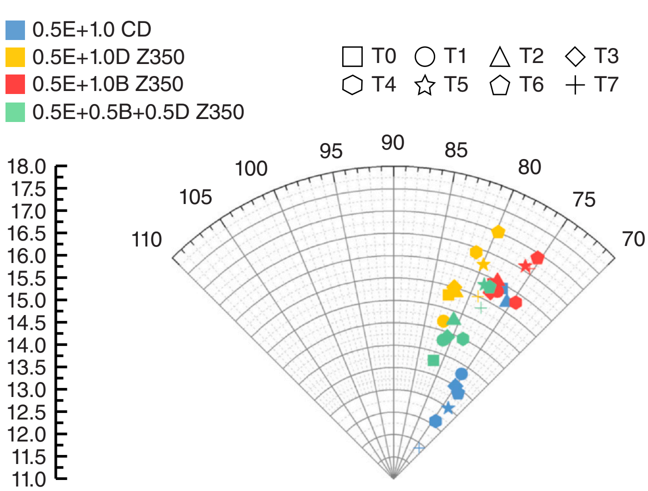

Figure 2. Color coordinates C* and h° mean values of 4 strategies at each timepoint. 24 h (T0), 1 week (T1), 1 month (T2), 2 months (T3), 6 months (T4), 12 months (T5), 18 months (T6), and 24 months (T7). B, body; CD, Charisma Diamond; D, dentin; E, enamel; T0, 24 h; T1, 1 week; T2, 1 month; T3, 2 months; T4, 6 months; T5, 12 months; T6, 18 months; T7, 24 months; Z350, Filtek Z350XT.

layering strategy and water aging time were accepted based on the results. The masking ability of composite resins can be evaluated by calculating the ΔE between the composite resin specimen placed over a discolored substrate[12,13] and a reference background (Fig. 3). An A3.5 substrate was used for the evaluation of the masking abilities of the different layering strategies. The A3.5 shade was chosen because it simulates a common situation in clinical practice and also represents moderate masking difficulty.[14]

Comparisons with 50:50% perceptibility (PT_{00}=0.8) and 50:50% acceptability (AT_{00}=1.8) thresholds[47] were used to analyze the effect of the layering strategy and water aging on masking ability. All strategies tested and evaluation times for both restorative systems presented ΔE_{00} values above the PT_{00} limit. However, considering the AT_{00} limit, the restorative systems and times presented different results. Also, recommended categorization was used to interpret and classify the color differences values.[47] Acceptable matches ($\Delta E_{00} \leq 1.8$) were observed for all strategies after 2 months of water aging. Moderately unacceptable ($1.8 < \Delta E_{00} \leq 3.6$) mismatches were observed in most of the layering strategies from 6 months to 24 months of water aging. Thus, it can be assumed that aging has a detrimental effect on the masking effectiveness of layered composite resins, consistent with a previous study that reported the loss of masking ability after long-term water aging.[14]

Color stability is an important issue related to the longevity of composite resin restorations.[2] Once acceptable masking ability has been achieved, it should be

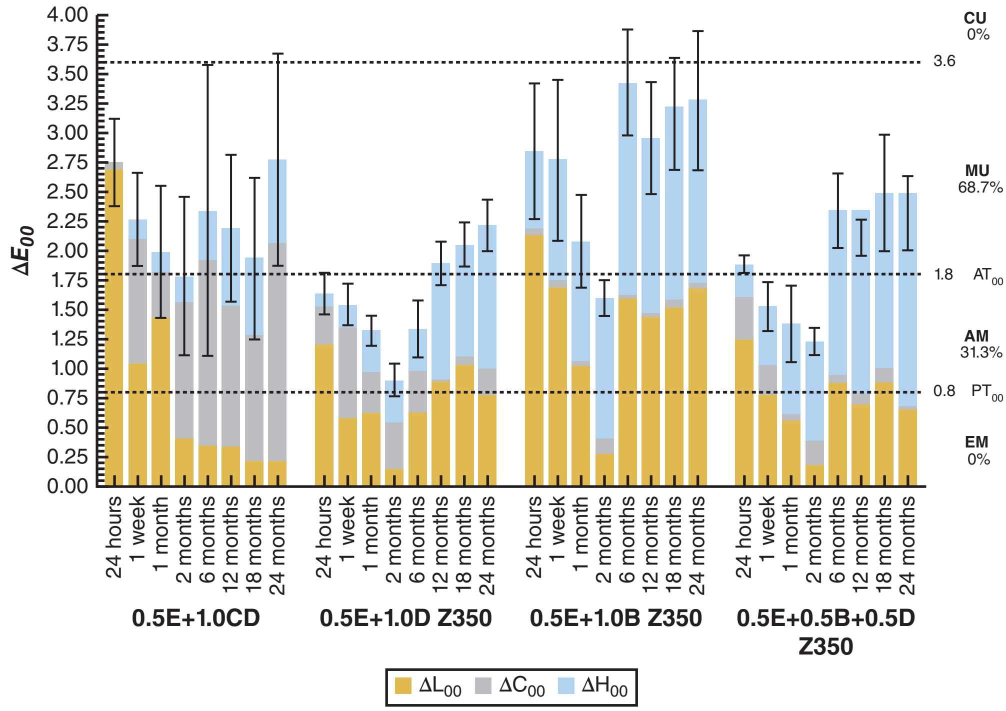

Figure 3. CIEDE2000 total color differences (ΔE_{00}), divided into 3 components (lightness, chroma and hue), for each layering strategy and aging time with color threshold interpretation. AM, acceptable match; B, body; CD, Charisma Diamond; CU, clearly unacceptable mismatch; D, dentin; E, enamel; EM, excellent match; MU, moderately unacceptable mismatch; ΔE00, CIEDE2000 total color difference; Z350, Filtek Z350XT.

maintained over time. Staining, water degradation, and artificially accelerated aging may cause color changes in composite resins,[5,24,25,34] and thus affect their masking ability. Furthermore, changes in the translucency parameter of composite resins after aging may also compromise the stability of their masking ability.[14]

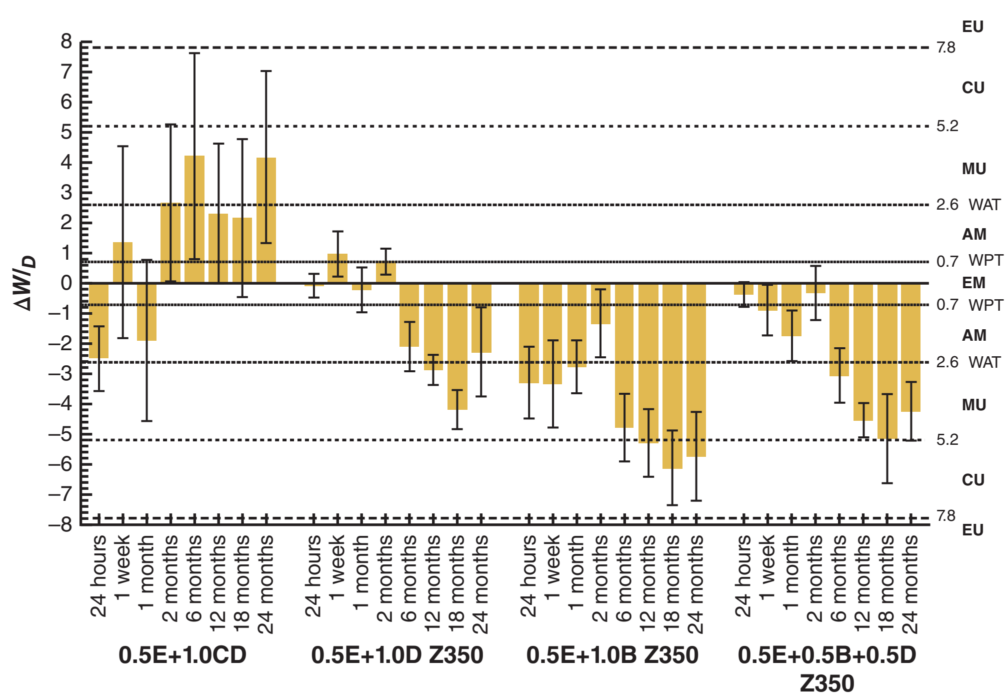

Figure 4. Whiteness differences (ΔWI_D) for each layering strategy and aging time with whiteness threshold interpretation. AM, acceptable match; B, body; CD, Charisma Diamond; CU, clearly unacceptable mismatch; D, dentin; E, enamel; EM, excellent match; MU, moderately unacceptable mismatch; ΔWI_D, whiteness index for dentistry difference; Z350, Filtek Z350XT.

The specimens were submitted to a 24-month water-aging protocol simulating the conditions of temperature and humidity in the oral environment for a prolonged time.[5,25] Overall, the masking ability was affected by aging; the results showed that the layering strategies with unacceptable masking increased after 2 months of water aging. The inorganic particles and monomers of the composite resin undergo water degradation, which may explain the color changes after aging. Additionally, color stability is material- and shade-dependent. The present in vitro study applied the layering strategy using an A1 shade. Previous studies[5,10,15,21,22] have reported that lighter shades of composite resin tend to present color changes after water aging, which is consistent with the findings of the present study.

The combined effect of different layering strategies and prolonged water aging on masking ability has not been thoroughly studied. The current study assessed the effect of water aging on masking ability at different time intervals between 24 hours and 24 months to identify the critical moment for the loss or improvement of the results. It was observed that the masking ability improved after 2 months of aging, but that acceptable masking ability tended to progressively decrease after this time up to 24 months of aging. These results suggest that water aging causes composite resin degradation after 2 months and produces color changes that directly impact masking effectiveness.

Whiteness is an important color attribute. Similar to measuring the color of composite resins, measuring the whiteness is also important for research, manufacturing, and clinical practice. Considering the CIELab color space, a white material is represented by a very high lightness and very low (preferably zero) saturation.[49] A whiteness index based in CIELab color space (WI_D) has been proposed to assess this attribute in dentistry.[49] This index was used to analyze the effect of the aging and layering strategies on the masking ability. Regardless of the strategies applied, after 2 months of water aging, the whiteness showed differences above the whiteness threshold of perceptibility. Overall, for the CD system, an increase in ΔWI_D was observed over time, while for the Z350 system, ΔWI_D decreased after of aging. Both situations, either the increase or decrease in whiteness, may affect the masking ability because the definitive restoration will likely present color incompatibility with the neighboring structures affecting the esthetics of the smile.

As color and whiteness are psychophysical properties, a color or whiteness difference, although statistically significant, may not be clinically relevant if it is small enough to be imperceptible to the human eye. In this context, as recommended in the ISO/TR 28642:2016 standard,[46] the optimal tool for analyzing color differences in dentistry and for dental materials is the comparative analysis with the previously established perceptible and acceptable color discrimination thresholds for dentistry. Ideally, both ΔE_{00} and ΔWI_D should present mean values within the limits of perceptibility and acceptability over time to provide adequate color matching with the neighboring structures as well as maintenance of the masking achieved by the layering strategy.

Limitations of this in vitro study included that the aging simulation was done only by immersion in water, other aging protocols such as artificially accelerated aging,[27,31,32] or ultraviolet light aging[32] were not executed. Additionally, only 1 discolored substrate was evaluated. Moreover, the findings should not be extrapolated to other restorative systems. Studies involving dental substrates, other restorative systems, and artificially accelerated aging[16–18,23,32] are recommended to understand the impact of aging on the maintenance of the masking ability of composite resins applied by the layering technique for a prolonged time. Nevertheless, the present study was able to clarify some important issues concerning the use of layered composite resins to mask a discolored substrate and also contribute to the understanding of the critical moment at which water aging affected the masking ability of the tested composite resins.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn

1. The layering strategy and the prolonged water aging affected the masking abilities of the 2 composite resins.
2. All tested layering strategies presented visually acceptable masking of a moderately discolored background after 2 months of water aging.
3. However, from 6 months to 24 months of water aging, acceptable masking was not achieved for all tested strategies and restorative systems.

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