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Laboratory Research

The Use of Composite Layering Technique to Mask a Discolored Background: Color Analysis of Masking Ability After Aging—Part II

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Clinical Relevance

The masking ability of resin composites can change over time and influence long-term performance of multilayered restorations.

SUMMARY

The aim of this study was to evaluate the effectiveness of the layering technique to mask a discolored background (C4) after one year of water aging. The technique was used with three resin composite restorative systems (IPS Empress Direct, Charisma Diamond, and Filtek Z350XT). Ninety 1.5-mm-thick specimens were divided into groups and subgroups according to the restorative system and resin composite shade combination used in the layering technique (enamel, body, and dentin). The color measurements were made by reflection spectrophotometer (SP60, EX-Rite) over the C4 substrate at two time points: after 24-hour water immersion (T_0) and after one-year water aging (T_1). The masking ability was evaluated by calculating the ΔE between an inherent color background and a C4 background at T_0 and T_1. CIELAB and CIEDE2000 formulas were used for comparative analysis between T_0 and T_1 color measurements. Analysis of variance and Turkey's *post hoc* test (a=0.05) were performed to analyze ΔE_{ab} and ΔE_{00} mean values. The Z350XT restorative system presented adequate masking ability in the combinations of 0.5 mm body + 1.0 mm dentin, 0.5 mm enamel + 1.0 mm dentin, and 1.5 mm dentin after 24-hour water immersion. The masking ability was affected negatively by water aging in most of the combinations. The IPS Empress Direct was the only system that remained stable after aging in the combinations of 0.5 mm enamel + 1.0 mm dentin and +

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1.5 mm dentin (p=0.05 and p=0.47 for CIELAB; p=0.15 and p=0.51 for CIEDE2000), although it did not present adequate masking ability in both time points. None of the combinations of any system presented adequate masking ability after prolonged water aging.

INTRODUCTION

Dental discoloration compromises an individual's esthetics and smile. Bleaching is the most conservative treatment for discolored teeth.[1] However, optimal results are not always achieved solely with this treatment. In these cases, resin composite restorations are indicated to achieve the expected results, because they are able to mask discolorations, require minimal or no substrate preparation, and are more affordable than indirect porcelain restorations.[2]

Masking discolored substrates with direct restorations is a complex procedure, because of the translucency of the resin composites, and requires correct diagnosis, treatment planning, and implementation of a restorative technique that promotes predictable and long-lasting results.[3] The multilayering technique using different resin composite translucencies is indicated in performing these procedures, depending on the characteristics of the tooth and the restorative system. When translucent materials are used, the shade of the underlying substrate may pass through the top layers, making the restoration grayish.[4] This undesirable effect can be minimized by applying an initial layer of an opaque dentin shade to create a masking effect. At the end of the treatment, the restorative procedure should mask the discolored background and make it clinically imperceptible.[2,5]

The color stability of resin composite restorations is an important parameter for successful clinical results.[6] Color changes in the resin composite are commonly associated with repairing and replacement of restorations.[3,7,8] Discoloration of the resin composite is linked to intrinsic and extrinsic factors. The extrinsic changes are related to food pigments and deficiencies in oral hygiene,[9] whereas the intrinsic factors are related to components and properties of the materials. Primers, inhibitory agents, monomers, water sorption, and degree of conversion of resin composites may influence degradation over time, affecting the clinical appearance of the restoration and decreasing the longevity.[10]

The presence of hydrophilic monomers may enhance water absorption and lead to greater discoloration. Conversely, hydrophobic monomers result in lower water sorption and greater color stability.[9,11-13] Hydrolytic degradation may also promote variation in opacity and change in the color stability of the resin composite.[10] Long-term studies using a relatively short storage period indicate that the major changes in color occur in the first days after polymerization.[11,14] The performance of color stability after prolonged aging could simulate the behavior of resin composite restorations closer to the clinical reality, considering that they are expected to remain functional and esthetic for many years.

A previous study found that some resin composite combinations applied by the multilayering technique are able to mask a discolored substrate (C4) immediately.[5] Long-term masking maintenance was not evaluated. The present study aims at complementing the previously reported initial data with an evaluation of masking ability effectiveness of the multilayering technique, using the same resin composite restorative combinations applied both immediately and 1 year after water aging. The null hypothesis was that aging does not affect the resin composite ability to mask a C4 background.

METHODS AND MATERIALS

This was the second study on masking ability using the same methodology as the first[5]; however, in this study the samples were analyzed after 24 hours of water immersion (T_0) and after 12 months of water aging (T_1). Three groups were formed with different restorative systems. These groups were divided into 18 subgroups (n=5), according to the layer-to-layer strategies of the different resin composite shades of each restorative system. The manufacturer, composition, color and translucency, and batch number of each system are presented in Table 1. The group distribution and multilayering technique are shown in Table 2.

Specimen Preparation

One trained and calibrated operator produced the specimens with three cylindrical metallic devices, measuring 11.0 mm in diameter by three different thicknesses: 0.5, 1.0, and 1.5 mm. The total built-up thickness of all the specimens was set at 1.5 mm. The single-layer specimens were prepared with a 1.5-mm-thick matrix, and the resin composite was inserted in a single increment. The two-layer specimens were prepared by first obtaining a 1.0-mm-thick layer from the 1.0-mm matrix. Then, the resin composite disc was placed inside the 1.5-mm-thick matrix, and the remaining 0.5 mm was filled with resin composite and light cured. The three-

Table 1: *Composition and Information Regarding the Restorative Systems*

Restorative System	Composition	Manufacturer	Shades	Batch Number
IPS Empress Direct	Dimethacrylate, Ba-Al-SiO_4 glass-oxide silicates, ytterbium fluoride nanoparticles (YbF_3)	Ivoclar Vivadent	A1 enamel	A1-010040
			A1 dentin	OL-010030
Z350 XT	Bis-GMA, urethane dimethacrylate (UDMA), Triethyleneglycol dimethacrylate (TEGDMA), bisphenol-A dimethacrylate (Bis-EMA), Polyethylene glycol dimethacrylate (PEGDMA), BHT, silcate, zirconia	3M-ESPE, St. Paul, MN, USA	A1E A1B A1D	1415300268
Charisma Diamond	UDMA, TCD-DI-HEA (TCD-urethane), Ba-Al-F glass silicate, YbF_3, SiO_2	Heraeus Kulzer GmbH, Hanau–Hessen, Germany	A1 Universal	A1-010040
			Opaque Light	OL-010030

layer specimens were prepared following the previously described procedures, using 0.5-, 1.0-, and 1.5-mm-thick matrices (Table 3). Each layer was light-cured for 40 seconds using a light-emitting diode (LED; Bluephase, Ivoclar Vivadent, Schaan, Liechtenstein) with 1000-mW/cm^2 irradiance. The upper and lower surfaces of the specimens were covered with polyester strips, and a glass plate with 1 Kgf of static load was applied before polymerization of both sides.[5]

Specimen Storage and Aging

The specimens were stored for one year in deionized water at 37°C, in a transparent plastic container with a hermetic lid. During this period, the water was changed weekly.[15]

Color Measurement

The color measurement of the specimens was performed according to the CIELAB shade scale for the D65 standard light source, on a white background, in a reflection spectrophotometer (SP60, EX Rite/Grand Rapid, MI, USA), at baseline and after aging. The CIELAB color system is a tridimensional color space, based on L*, a*, and b* coordinates.[16] L* refers to lightness, with values ranging from 0 (black) to 100 (white); a* and b* are considered chromatic coordinates: a* for red (+) and green (–), and b* for yellow (+) and blue (–). The mean value of

Table 2: *Division of Groups and Subgroups and Description of the Multilayering Technique*

Manufacturer	Shades	Layering Technique (n=5)	Layers
IPS Empress Direct (n=5)	A1E – A1 Enamel - E A1D – A1 Dentin - D	1.5 mm E	SL
		1.0 mm E + 0.5 mm D	DL
		0.5 mm E + 1.0 mm D	DL
		1.5 mm D	SL
Charisma Diamond (n=5)	A1U – A1 Universal - E OL – Opaque light - D	1.5 mm E	SL
		1.0 mm E + 0.5 mm D	DL
		0.5 mm E + 1.0 mm D	DL
		1.5 mm D	SL
Filtek Z350 XT (n=5)	A1E – A1 Enamel - E A1B – A1 Body - B A1D – A1 Dentin - D	1.5 mm E	SL
		1.0 mm E + 0.5 mm B	DL
		1.0 mm E + 0.5 mm D	DL
		1.5 mm B	SL
		0.5 mm E + 1.0 mm B	DL
		1.0 mm B + 0.5 mm D	DL
		1.5mm D	SL
		0.5mm E + 1.0mm D	DL
		0.5mm B + 1.0mm D	DL
		0.5mm D + 0.5mm B + 0.5mm E	TL

DL, two-layer specimens; SL, single-layer specimens; TL, three-layer specimens.

Table 3: *Mean Values of ΔE_{ab} (SD) Before and After Aging for Each Combination*[a]

Brand	Shade Combination	ΔE^*_{ab} T_0	ΔE^*_{ab} T_1
IPS Empress Direct	1.5 E	7.83 (0.14) [a]	10.79 (0.49) [a]
	1.0 E + 0.5 D	7.05 (0.31) [b]	10.32 (1.11) [ab]
	0.5 E + 1.0 D	6.65 (0.10) [bc]	7.54 (0.68) [cde]
	1.5 D	6.11 (0.20) [de]	6.50 (1.23) [def]
Charisma Diamond	1.5 E	5.77 (0.24) [ef]	9.23 (1.17) [abc]
	1.0 E + 0.5 D	5.71 (0.12) [ef]	9.29 (0.51) [abc]
	0.5 E + 1.0 D	6.08 (0.17) [de]	8.34 (0.86) [bcd]
	1.5 D	5.58 (0.09) [f]	8.69 (0.43) [bc]
Filtek Z350 XT	1.5 E	7.01 (0.25) [b]	10.00(1.25) [ab]
	1.0 E + 0.5 B	6.30 (0.14) [cd]	10.13 (0.69) [ab]
	1.0 E + 0.5 D	4.99 (0.27) [g]	11.01 (1.10) [a]
	1.5 B	5.73 (0.22) [ef]	9.44 (0.56) [abc]
	0.5 E + 1.0 B	5.87 (0.12) [def]	9.53 (0.46) [abc]
	1.0 B + 0.5 D	4.24 (0.12) [h]	8.41 (1.76) [bcd]
	1.5 D	**2.03 (0.15) [k]**	4.56 (0.84) [f]
	0.5 E + 1.0 D	**3.36 (0.21) [i]**	5.35 (0.43) [f]
	0.5 B + 1.0 D	**2.84 (0.26) [j]**	4.81 (0.55) [f]
	0.5 E + 0.5 B + 0.5 D	3.79 (0.06) [i]	6.04 (0.24) [ef]

[a] *Different lowercase letters in the same column indicate statistically significant differences. SDs are in parentheses. Bold values indicate adequate masking ability.*

L*, a*, and b* was calculated at baseline (T_0) and after one year of water aging (T_1).

Each specimen was analyzed three times, applied over two different backgrounds, with a coupling agent (glycerin) to simulate the oral environment.[17] The different backgrounds simulated two conditions: a severely discolored background and a tooth surface with no discoloration. The first was represented by a 2-mm-thick C4 opaque shade ceramic disc (C4; L*=69.18; a*=6.80; b*=23.61) and the latter by an inherent color background produced with an A1 dentin shade resin composite built up with a 4-mm thickness of each restorative system (Empress Direct: L*=82.99; a*=2.46; b*=17.88/Charisma: L*=81.87; a*=4.31; b*=18.55/Z350XT: L*=83.72; a*=1.52; b*=16.98).[5,18] It was reported in the literature that a 4-mm-thick resin-based composite disc was not affected by the underlying color background and could therefore be considered the inherent color of the resin composite.[17] All readings followed a chairside layering protocol of the resin composite restorative system, with the enamel layer facing upward. The groups that presented only body and dentin shades also followed the same protocol, with the body resin facing upward during color measurement.[5]

The total color difference of the same specimen placed over the discolored (C4) and the inherent backgrounds was calculated according to the CIELAB and CIEDE2000 equations at baseline and after aging (T_0 and T_1).

The CIELAB color difference (ΔE_{ab}) was calculated as follows[19]:

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

where ΔL*, Δa*, and Δb* corresponds to lightness, green-red, and blue-yellow differences of C4 and IC backgrounds, respectively.

The CIEDE2000 color difference (ΔE_{00}) calculation was as follows[19]:

$$\Delta E' = [(\Delta L'/K_L S_L)^2 + (\Delta C'/K_C S_C)^2 + (\Delta H'/K_H S_H)^2 + R_T(\Delta C'/K_C S_C)(\Delta H'/K_H S_H)]^{1/2}$$

where ΔL′, ΔC′, and $\Delta H'^0$ refer to lightness, chroma, and hue differences between color measurements, respectively. K_L, K_C, and K_H are the parametric factors for the conditions and illuminating influence, set at 1 in this study.[18] R_T (rotation function) accounts for the interaction of hue and chroma differences in the blue region. S_L, S_C, and S_H are the weighting functions for the color difference adjustment, considering the location variation of L*, a*, and b* coordinates.[16,19]

Adequate masking ability is achieved when the background color has no influence on the final color of the restoration, resulting in lower ΔE_{ab} and ΔE_{00}

Table 4: *Mean Values of ΔE00 (SD) Before and After Aging for Each Combination*[a]

Brand	Shade Combination	ΔE^*_{00} T_0	ΔE^*_{00} T_1
IPS Empress Direct	1.5 E	5.26 (0.13) [a]	7.14 (0.39) [a]
	1.0 E + 0.5 D	4.62 (0.24) [b]	6.62 (0.79) [abcd]
	0.5 E + 1.0 D	4.32 (0.04) [bc]	4.77 (0.54) [efg]
	1.5 D	3.81(0.16) [de]	4.06 (0.88) [gh]
Charisma Diamond	1.5 E	3.89 (0.18) [de]	5.78 (0.80) [bcde]
	1.0 E + 0.5 D	3.86 (0.09) [de]	5.84 (0.32) [abcde]
	0.5 E + 1.0 D	4.08 (0.12) [cd]	5.60 (0.54) [de]
	1.5 D	3.73 (0.07) [e]	5.43 (0.27) [de]
Filtek Z350 XT	1.5 E	5.07(0.20) [a]	7.09 (0.95) [ab]
	1.0 E + 0.5 B	4.50 (0.11) [b]	7.16 (0.50) [a]
	1.0 E + 0.5 D	3.31 (0.20) [f]	6.96 (0.51) [abc]
	1.5 B	3.85 (0.17) [de]	6.61 (0.40) [abcd]
	0.5 E + 1.0 B	4.05 (0.09) [cd]	6.68 (0.33) [abcd]
	1.0 B + 0.5 D	2.70 (0.08) [g]	5.70 (1.04) [cde]
	1.5 D	**1.27 (0.10) [j]**	3.04 (0.57) [h]
	0.5 E + 1.0 D	**2.12 (0.12) [h]**	3.67 (0.30) [gh]
	0.5 B + 1.0 D	**1.78 (0.16) [i]**	3.25 (0.41) [h]
	0.5 E + 0.5 B + 0.5 D	2.44 (0.04) [g]	4.22 (0.17) [fgh]

[a] *Different lowercase letters in the same column indicate statistically significant differences. SDs are in parentheses. Bold values indicate adequate masking ability.*

values. In this study, the clinical acceptance threshold of ΔE = 3.46 and ΔE = 2.25 for CIELAB and CIEDE2000, respectively, were considered. Color difference values above these thresholds can be visualized by a layman and cannot be considered acceptable.[16,20]

Statistical Analysis

The normal distribution was verified by the Kolmogorov-Smirnov test, and the mean values of ΔE_{ab} and ΔE_{00} were submitted to analysis of variance (ANOVA) and Tukey's *post hoc* test. Statistical analysis was performed at $\alpha = 0.05$ using Minitab software (Minitab, Inc, State College, PA, USA).

RESULTS

The mean values of ΔE for each combination taken from the CIELAB and CIEDE2000 color shade systems at T_0 and T_1 are shown in Tables 3 and 4. The lower ΔE value indicates better results. Although the combinations of 1.5 mm D, 1.0 mm D + 0.5 mm E, and 1.0 mm D + 0.5 mm B, all for the Z350XT restorative system, presented clinically acceptable values before aging (T_0), the results did not achieve the threshold parameters associated with clinical acceptability ($\Delta E_{ab} \geq 1.8 \leq 3.46$ and $\Delta E_{00} \geq 1.3 \leq 2.25$) after aging ($T_1$).[16] All the other combinations did not achieve clinically acceptable values in any of the periods evaluated (Figures 1 and 2).

Table 5 presents the comparison before and after aging. Most of the combinations presented statistical differences between the two periods (T_0 and T_1). Color analysis according to CIELAB showed that only the 0.5 mm E + 1.0 mm D and + 1.5 mm D combinations of the IPS Empress Direct system over a C4 background did not differ between the periods evaluated. All the other combinations differed statistically between the periods ($p<0.05$), resulting in an increase in all the values from T_0 to T_1. CIEDE2000 color analysis exhibited the same behavior.

The ΔE changes were predominantly influenced by b* coordinate that decreased for Empress Direct and Charisma Diamond and increased for Z350XT. The L* coordinate remained stable for IPS Empress Direct and Charisma Diamond and decreased for Z350XT. The a* coordinate had small variations in all the restorative systems.

DISCUSSION

Dark backgrounds are common in teeth that have suffered intrapulpal hemorrhage, trauma, endodontic treatment, discoloration,[21] and through-and-through class III and IV restorations.[4] These conditions can be masked with opaque shade resin composites.[2,22,23] The best results are achieved when

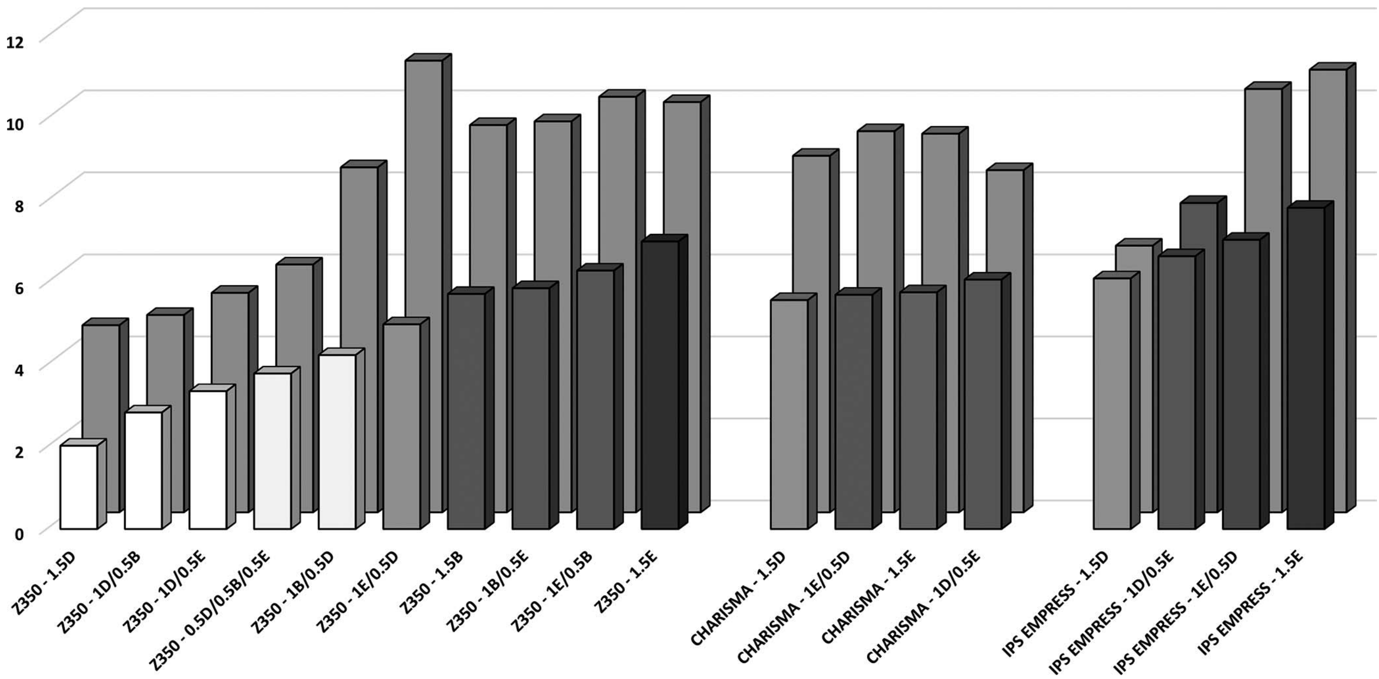

Figure 1. *Mean ΔE_{ab} values for different combinations of resin composites before (front) and after (back) aging.*

an increased thickness of opaque shade resin composite is used to cover up the discolored substrate.[2,4,18,23-25] Many studies have evaluated the optical properties of opaque shades alone.[2,4,18,24] However, the behavior and variations of the layering concept are not often studied.[5,23,26,27]

Masking ability can be evaluated by the ΔE of the resin composite over black and white backgrounds or by calculating the color difference between the inherent color (IC) of the resin composite and the resin composite placed over a discolored surface.[2,4] In the present study, a C4 background, representing

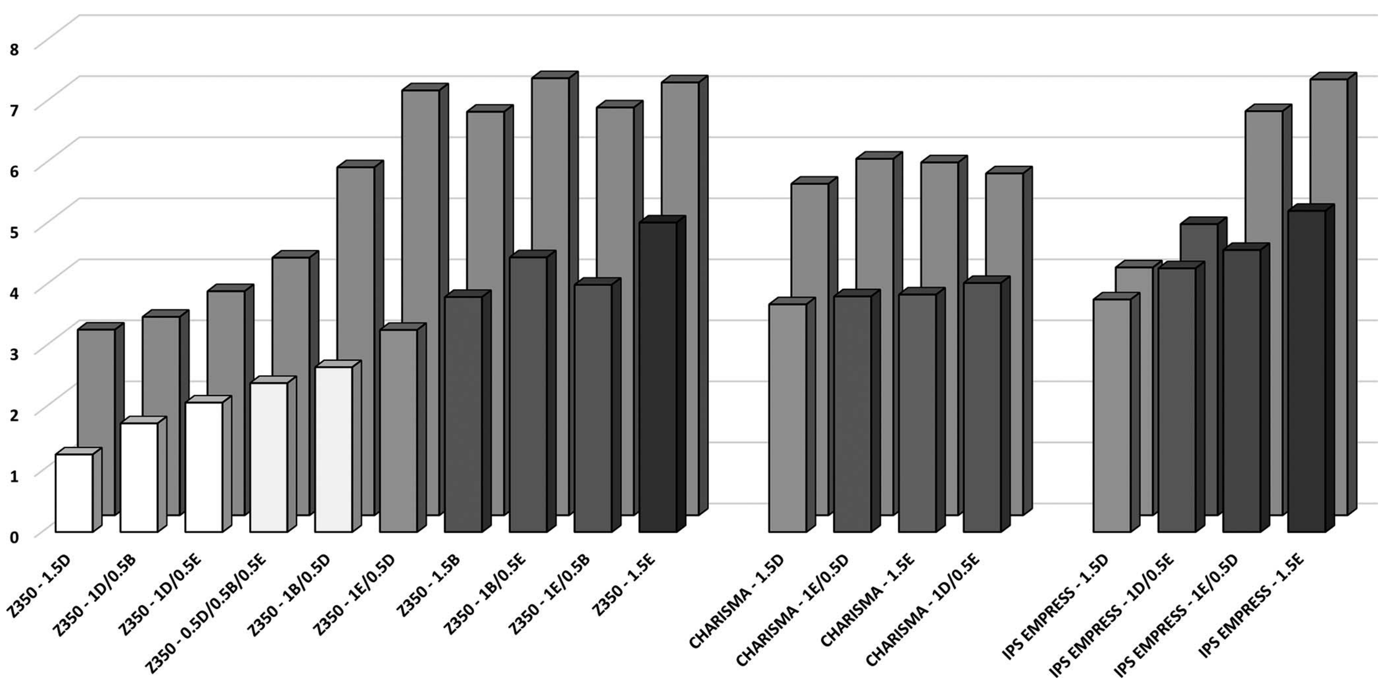

Figure 2. *Mean ΔE_{00} values for the different combinations of resin composites before (front) and after (back) aging.*

Table 5: *Differences in ΔE_{ab} and ΔE_{00} After One Year of Water Aging (Mean Values and SD)*

Brand	Shade Combination	ΔE_{ab}			ΔE_{00}		
		T_0	T_1	*p*-value	T_0	T_1	*p*-value
IPS Empress Direct	1.5 E	7.83 (0.14)	10.79 (0.49)	<0.001	5.26 (0.13)	7.14 (0.39)	<0.001
	1.0 E + 0.5 D	7.05 (0.31)	10.32 (1.11)	0.003	4.62 (0.24)	6.62 (0.79)	0.005
	0.5 E + 1.0 D	6.65 (0.10)	7.54 (0.68)	**0.053**	4.32 (0.04)	4.77 (0.54)	**0.150**
	1.5 D	6.11 (0.20)	6.50 (1.23)	**0.478**	3.81 (0.16)	4.06 (0.88)	**0.517**
Charisma Diamond	1.5 E	5.77 (0.24)	9.23 (1.17)	0.002	3.89 (0.18)	5.78 (0.80)	0.004
	1.0 E + 0.5 D	5.71 (0.12)	9.29 (0.51)	<0.001	3.86 (0.09)	5.84 (0.32)	<0.001
	0.5 E + 1.0 D	6.08 (0.17)	8.34 (0.86)	0.005	4.08 (0.12)	5.60 (0.54)	0.004
	1.5 D	5.58 (0.09)	8.69 (0.43)	<0.001	3.73 (0.07)	5.43 (0.27)	<0.001
Filtek Z350 XT	1.5 E	7.01 (0.25)	10.00 (1.25)	0.004	5.07 (0.20)	7.09 (0.95)	0.005
	1.0 E + 0.5 B	6.30 (0.14)	10.13 (0.69)	<0.001	4.50 (0.11)	7.16 (0.50)	<0.001
	1.0 E + 0.5 D	4.99 (0.27)	11.01 (1.10)	0.001	3.31 (0.20)	6.96 (0.51)	<0.001
	1.5 B	5.73 (0.22)	9.44 (0.56)	<0.001	3.85 (0.17)	6.61 (0.40)	<0.001
	0.5 E + 1.0 B	5.87 (0.12)	9.53 (0.46)	<0.001	4.05 (0.09)	6.68 (0.33)	<0.001
	1.0 B + 0.5 D	4.24 (0.12)	8.41 (1.76)	0.007	2.70 (0.08)	5.70 (1.04)	0.003
	1.5 D	2.03 (0.15)	4.56 (0.84)	0.002	1.27 (0.10)	3.04 (0.57)	0.002
	0.5 E + 1.0 D	3.36 (0.21)	5.35 (0.43)	0.001	2.12 (0.12)	3.67 (0.30)	<0.001
	0.5 B + 1.0 D	2.84 (0.26)	4.81 (0.55)	0.003	1.78 (0.16)	3.25 (0.41)	0.002
	0.5 E + 0.5 B + 0.5 D	3.79 (0.06)	6.04 (0.24)	<0.001	2.44 (0.04)	4.22 (0.17)	<0.001

Bold values indicate $p > 0.05$.

a substrate with severe discoloration, was used for the evaluation of the masking ability of different A1 shade combinations of three restorative systems. This condition was chosen not only because shade C4 has the darkest and lowest L* value in the Vitapan Classic Shade Guide,[2] but also because it simulates an extremely challenging situation.[4,21]

The multilayering technique is a conservative approach for masking discolored backgrounds, because it achieves natural-like results and meets the current esthetic demands.[22,23,25,27,28] When layering is used, the final color of the restoration is a result of the combined optical properties of all the layers.[27] In the present study, it was expected that the combination of A1 shades + C4 background would yield a restoration with the A1 shade or would be within the 50:50% acceptability threshold compared with the IC of the resin composite. When the L, a, and b values of the A1 + C4 combinations are similar to the IC of the restorative systems, the ΔE values are lower. This means that there is less influence of the background on the final color of the specimen + background, and, consequently, greater masking ability.

The CIELAB and CIEDE2000 formulas were used in this study to calculate the masking ability after a prolonged aging period. The CIELAB system calculates the total color difference, using the same weight for all the coordinates (L*, a*, and b*) in the formula. Conversely, CIEDE2000 uses important adjustments that approximate the analysis to how color change is perceived by the human eye. The formula weighting functions (SC, SH, and SL) adjust the color coordinates relative to chroma, hue, and luminosity, composing the total value for ΔE.[5,16] Although CIEDE2000 has a more recent formula, both are frequently used and compared.[5,6,23,29] After one year, the results recorded the same trend for both formulas, but with different absolute values.

The clinically acceptable parameters for CIELAB range between $\Delta E_{ab} \geq 1.8$ and ≤ 3.46, and those of CIEDE2000 between $\Delta E_{00} \geq 1.3$ and ≤ 2.25[15,16,]; that is, in clinical terms, the color variation is only perceived by the human eye when it presents values greater than these. Only a few combinations were able to mask the C4 background at T_0 within the acceptability thresholds, and all had the following common features: the Z350XT restorative system plus a 1.5-mm thickness of dentin shade alone or 1-mm thickness of dentin shade combined with enamel and/or body shades. When the dentin shade thickness decreased to 0.5 mm, the masking ability did not fit in the threshold parameters. This result corroborates study findings that consider thicknesses below 1 mm unable to mask dark substrates[2,23];

this is especially true for light shades,[23] such as that used in the current study.

In the anterior region, preparation thickness is limited. The creation of space for the layering of two or more shades may lead to additional dental tissue reduction. Therefore, to avoid excessive tooth preparation, resin composite should ideally present low translucency in very thin thicknesses. Conversely, when increments are very thin, resin composites have limited opacification ability.[21] The favorable results presented by Z350XT may be associated with the translucency pattern of the dentin shade. The Z350XT dentin shade appears to present less translucency than the other systems, whereas the Z350XT body shade seems to behave in the same way as the dentin shade of the other systems.[5,24] Therefore, the dentin shade acts more like an opaquer than a traditional dentin shade resin composite.

Dental restorative materials must resist wide-ranging adverse conditions, including temperature changes, continuous exposure to moisture, and mechanical stresses.[30] Water aging may affect optical properties related to maintaining the masking effect, such as translucency,[25] luminosity,[4,25] and color stability.[4,22,31,32] Alterations in the translucency parameter can be directly related to changes in masking ability over time. Greater translucency results in increased perception of the background color,[22] whereas less translucency may contribute to improving the masking ability.[4,23]

Considering that masking ability is influenced by the optical properties of the resin composites,[23] and that these features can change over time[25,32,33] and may influence the final color of the restoration,[22,23,32] all the restorative systems and combinations were exposed to prolonged water aging regardless of the initial results. Although a positive effect has been previously observed after water exposure,[6,25,29] this was not the case in the present study; thus, aging was not able to compensate the lack of masking ability.

The research hypothesis was partly rejected, because aging-dependent changes in masking ability depended on the brand of the restorative system and the shade combination. The combinations that were not able to mask the C4 background initially were still unable to mask it after aging, and the combinations that achieved adequate masking ability before aging were not able to mask the C4 background within the acceptability and perceptibility threshold after aging. Hence, it can be inferred that aging has a negative effect on masking ability. Therefore, when selecting shade combinations and applying the multilayering technique, the instability of the masking ability over time must be taken into consideration.

The IPS Empress Direct restorative system (0.5 mm enamel + 1.0 mm dentin and + 1.5 mm dentin) presented a ΔE value that did not differ between baseline and after aging, both based on CIELAB and CIEDE2000 analysis. Although the masking ability of this combination was clinically unacceptable at both measurements (T_0 and T_1), the resin composite remained stable. This color stability feature is desirable for maintaining both the masking ability over time and the restoration longevity of the esthetic parameters.

Regarding the other combinations, the relation between aging and masking ability may be linked to the composition of the restorative systems, because masking ability[5,32] and translucency,[33] before and after aging, depend on the shade and the brand of the resin composite system.[2,32] Water sorption by the triethylene glycol dimethacrylate (TEGDMA) monomer is greater than by the urethane dimethacrylate (UDMA) monomer, and could explain the change in color,[34] and, consequently, the loss of masking ability after aging. The presence of TEGDMA in the Z350XT resin composite may explain the change in masking ability presented by the combinations using this material, whereas the absence of TEGDMA would explain the same behavior of the IPS Empress Direct system before and after aging.

Photoinitiators, degree of conversion, and intensity of irradiance may also influence long-term masking ability.[31] Photoinitiators are formulated as coinitiators, basically by camphorquinone and amines. When the amines are submitted to light or heat, they form a byproduct leading to discoloration that ranges from yellow to brownish-red,[35] and that results in intrinsic stains that compromise the esthetic results.[36] The yellowish effect is directly proportional to photoinitiator concentration.[37] In restorative systems that use camphorquinone, aging is related to an increase in the b* coordinate of the CIELAB system. The yellowing effect presented by Z350XT after one year of aging, and confirmed by the highest value of b*, can be attributed to direct oxidation of amines and can negatively influence masking ability.[15]

The values of the L*, a*, and b* coordinates suggest that the restorative systems showed discoloration after aging. The L* coordinate remained stable in the IPS Empress Direct and Charisma Diamond restorative systems and did not impact the final ΔE. However, the L* value decreased for Z350XT, showing a tendency to turn gray, which corroborates the findings of previous studies.[25,30] In all the restorative systems, the ΔE changes were predominantly influenced by the b* coordinate. The b* coordinate decreased in IPS Empress Direct and Charisma Diamond but increased in Z350XT. The IPS Empress Direct system showed a tendency toward bluish-red (a* increased and b* decreased), corroborated by results found in other studies.[7,30,38-40] The Charisma Diamond resin showed a tendency toward bluish-green, with a decrease in a* and b* values, whereas the coordinate a* value decreased and b* value increased in the Z350XT system, tending toward yellowish-green. Although the results demonstrated perceptible color change, the aim of the study was to evaluate masking ability and not color stability after water aging. Nonetheless, these additional data provide relevant clinical information regarding color matching and color stability over time.

The methodology used in the preparation and storage of the specimens in our study followed the same protocol as that of Miotti and others.[5] A long-term aging protocol of one year was used to promote more predictable clinical conditions, given that aging is normally induced for a period of up to 90 days.[15,38,41,42] However, there are some limitations in the present study. The aging process was performed only by immersion in deionized water, whereas procedures such as immersion in pigments,[42] accelerated artificial aging,[13,15,41] or aging by exposure to ultraviolet light, were not performed.[41] Even so, the aging process used in our study did not compromise the findings and showed additional information concerning the hydrolytic degradation of resin composites.

Despite the constant evolution of resin composites, the masking of discolored substrates continues to pose a great challenge to clinicians, because the restorative systems that allow several layering possibilities do not guarantee clinically acceptable and long-lasting results. Further studies involving the masking of discolored backgrounds using different materials, shades, substrates, periods, and aging techniques are needed to validate this issue.

CONCLUSION

Based on ΔE CIELAB and ΔE CIEDE2000, none of the combinations of the multilayering technique presented adequate masking ability over a severely discolored background after prolonged water aging.

The multilayering technique combining the Z350XT resin composite system with the A1 shade was able to mask a severely darkened substrate at baseline. However, water aging produced a clinically perceptible change, ultimately influencing the masking ability obtained initially. The only system that remained stable after one year of water aging was the IPS Empress Direct in the combinations 0.5 mm enamel + 1.0 mm dentin and + 1.5 mm dentin (A1 shade), despite not presenting adequate masking ability.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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