Color stability of a bulk-fill composite resin light-cured at different distances

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Abstract: The aim of this in vitro study was to evaluate the color stability of a bulk-fill (Filtek One Bulk Fill, 3M ESPE) and a conventional (Filtek Z350 XT, 3M ESPE) composite resin light-cured at different distances, before and after being submitted to staining with a coffee solution. Sixty specimens of each composite resin were prepared and light-cured at distances of 0, 2 and 4 mm, using a LED light-curing unit (Valo, Ultradent). The specimens were separated (n = 10) for immersion in either distilled water or coffee solution (10 minutes a day for 8 days) to stimulate staining. Color evaluations were performed before and after immersion in the solutions, according to CIELab ($\triangle$Eab), CIEDE2000 ($\triangle$E00) and the Whiteness Index for Dentistry ($\triangle$WID). Kruskal Wallis and Dunn tests, Mann-Whitney tests and Wilcoxon test were applied (α = 5 %). The a* value for conventional composite resin showed a significant increase after immersion in coffee and distilled water ($p < 0.05$). Both composite resins showed greater b* values when immersed in coffee than in distilled water, with no significant difference among the light-activation distances ($p > 0.05$). There was no significant difference for L* among the light-activation distances; both resins showed significant decrease in L* after immersion in coffee ($p < 0.05$). Color change ($\triangle$Eab, $\triangle$E00) and difference in whiteness ($\triangle$WID) were higher for conventional resin when immersed in the coffee solution at all the light-activation distances. Conventional composite resin presented a higher staining value than bulk-fill composite resin, regardless of the light-activation distance.

Keywords: Coffee; Color; Composite Resins.

Introduction

Composite resins have become the material of choice for aesthetic restorations, because they have the physical properties that reproduce the natural-looking beauty of teeth.[1] In this respect, color stability is of utmost importance, since the staining of restorations by dyes of food and beverage consumption can impair their quality and aesthetic longevity.[2,3,4,5,6,7,8]

Composite resin staining may occur due to extrinsic and intrinsic factors. Among the intrinsic factors, the color change of the restoration from the oxidation of tertiary amines, the polymeric matrix, or the oxidation of residual methacrylate groups can be pointed out. These factors are dependent on the formulation and the quality of the light-activation of

the resin-based material.[5,6] Organic matrix content is also related to potential staining, and Bis-EMA (bisphenol A polyethylene glycol dimethacrylate) tends to react less favorably to pigment incorporation than UDMA (urethane dimethacrylate) and Bis-GMA (bisphenol-A glycidyl methacrylate), which have higher water sorption capacity because they are hydrophilic. The inorganic filler content may be influential, since possible spaces between the filler particles favor pigment deposition.[7] The causes related to the extrinsic factors include color change by adsorption or dye absorption, as a result of contact with exogenous sources, such as an individual's diet.[8]

Some drinks in the diet of the population have greater potential to change the color of composite resins, such as coffee, tea, juices and wine.[9,10] Coffee is a commonly consumed beverage and has strong potential to stain both dental structure and resin materials, because it has water-soluble dyes and polyphenols, such as tannin, caffeine and caffeic acid. Lower polarity causes the coffee pigments to have higher adsorption and dye penetration in the composite resin.[1,3,5]

Although bulk-fill resins have a monomeric chemical composition similar to that of conventional composite resins,[11] it has been found that the degree of staining may increase as the thickness of the increment increases, since light-activation may not be effective at greater thicknesses.[12] Bulk-fill composite resins are known to exhibit greater translucency than conventional resins, and facilitate light transmission. This allows better polymerization of the material when it is inserted in thicker increments, and the built-in monomers that trigger and control polymerization kinetics enable better polymerization thickness.[11,13] However, the polymerization effectiveness related to greater insertion thicknesses of bulk-fill composite resins is inconsistent, and data are contradictory.[14] This is especially true in situations where the resin may be exposed to the cavity, as in proximal surfaces of Class II cavities, in which the light needed to cure the layers in the cervical region can be minimized by the distance of light-activation. Although bulk-fill resin composites are mostly used for posterior restorations, problems related to color stability may make it difficult to decide whether to replace a restoration because of a color difference from the dental structure, especially in cervical regions.[15] The more cervical the resin increment, the more intense the staining, owing to the greater distance of light-activation, and to the lower polymeric conversion.[16,17,18,19]

Therefore, the aim of this study was to evaluate the influence of the staining solution on the color stability of conventional composite and photo-cured bulk-fill resins at different distances. The null hypotheses to be evaluated were: a) the staining solution would not influence the color stability of conventional and bulk-fill resins; b) different light-activation distances would not influence the color stability of conventional and bulk-fill resins.

Methodology

Specimens preparation

The composite resins used in the study are specified in Table 1. A total of 60 specimens of each resin composite were randomly selected. They were divided into three groups of 20 specimens each according to light-activation distances (0, 2 or 4 mm). Afterwards, they were divided into two groups (n = 10), according to the immersion media: staining with distilled water (control) or with a coffee solution.

The specimens were prepared using rubber matrices 2 mm high and 10 mm internal diameter. The matrix was positioned on a glass plate, and the composite resin was inserted in a single increment into the matrix using spatulas (LM-Arte Modella, LM-Arte Condensa - LM-Dental, Parainen, Finland). Two strips of polyester were positioned at the ends (bottom and top) to eliminate bubbles and obtain a smooth surface. A glass coverslip was positioned on top of this, applying a weight of 500 grams for 30 seconds. Next, the coverslip was removed for light-activation of the composite resin.

The tip of the curing device was positioned according to the light-activation distances (0, 2 or 4 mm). These distances were chosen based on what seemed most commonly used in clinical procedures. Although a 0-mm curing distance is ideal to use in light-curing resin composites, clinical procedures do not always allow this approach.[20] A 2-mm curing distance seems to be the best clinical case scenario.[20]

Table 1. Specification of materials under study.

Trademark / Manufacturer (City, State, Country) / Lot	Resin type (Shade)	Composition (% by weight) *	Maximum increment thickness/ light-activation time of each increment indicated by manufacturer
Filtek One Bulk Fill - 3M ESPE / (St. Paul, MN - USA)/ N691406 N690323 N891340	Single increment bulk-fill (A1)	Treated Silanized Ceramics (60-70), Aromatic Urethane Dimethacrylate (10-20), Ytterbium Fluoride (YbF3) (1-10), Diurethane Dimethacrylate (UDMA) (1-10), Treated Silica (1-10)), 1,12-Dodecane dimethacrylate (DDDMA) (<5), Treated silanized zirconia (<5), Water (<5), Modified methacrylate monomer (<1), Ethyl 4-dimethyl aminobenzoate (EDMAB) (<0.5), Benzotriazole (<0.5)	4 to 5 mm / 10 s each face.
Filtek Z350 XT -3M ESPE/ (St. Paul, MN - USA)/ 591639 688002 856543 734193	Conventional (A1 Enamel)	Treated Silanized Ceramics (60-80), Treated Silane Silica (1-10), Diurethane Dimethacrylate (UDMA)(1-10), Bisphenol A Polyethylene Glycol Diether Methacrylate (Bis-EMA) (1-10), Bisphenol Diglycidyl Ether Di-Methacrylate (BisGMA) (1-10), Treated Silanized Zirconia (1-10), Polyethylene Glycol Dimethacrylate (<5), Triethylene Glycol Dimethacrylate (TEGDMA) (<5), 2,6-Di-tert butyl p-cresol (<1)	2 mm / 20 s

*According to Manufacturer's Materials Safety Data Sheet (MSDS).

The irradiation ratio seems to be device-dependent at distances of 4 to 6 mm,[21] but may compromise resin composite properties when these or farther distances are used.[20]

The device tip was positioned over the polyester strip to obtain the distance of 0 mm. The distances of 2 and 4 mm required that one or two other rubber matrices of 10 mm internal diameter and 2 mm high, respectively, be superimposed over the specimen in which the composite resin was inserted. This enabled obtaining the distance required for light-activation, performed by positioning the tip (9.75 mm diameter) of the LED light-curing device on the composite resin (Valo, Ultradent, South Jordan, USA / 395–400nm / 1000 mW/cm²) for 20 seconds.

The specimens were fabricated and then removed from the rubber matrices, identified according to the surface that was cured and immersed in 3 mL of distilled water for 24 hours to be submitted to the initial color evaluation test. The resin surfaces were not finished or polished.

Baseline color evaluation

The specimens were fabricated and submerged in distilled water for 24 hours, and then removed from the storage medium and dried with sterile gauze. The baseline color analysis was performed by a single operator using a calibrated digital spectrophotometer (VITA Easyshade® Advance, Vita Zahnfabrik, Bad Säckingen, Germany), in which the tip of the apparatus was placed perpendicular to the surface of the composite resin. The evaluations were performed using a 40-cm wide, 60-cm long and 29-cm deep black box with a white inner background to prevent against the influence of external light. Color stability was measured by spectrophotometer, using the CIELab (Commission Internationale de L'Eclairage) color space coordinates. The measurements were performed by placing the specimens over a white background to observe the indication by the Vita Classical scale, and were obtained in duplicate. When the two readings of the Vita Classical scale coincided, the value obtained in the second reading of the L*, a* and b* data was used. If the two readings did not match the same result for Vita Classical, a third measurement was performed to enable agreement between the two previous readings.

Immersion media

The specimens were immersed in different immersion media, namely distilled water or coffee solution. The coffee solution was prepared with 25 grams of coffee powder (Nescafé, Nestlé SA, Vevey, Switzerland) and 250 mL of distilled water. The coffee solution was prepared with boiling distilled water, and only when it reached room temperature (24°C ± 1°C) did the staining process begin.

Half of the specimens made with each composite resin and light-activation distance were immersed in the coffee solution (pH = 4.88). The other half represented the control group, which remained immersed in individual vials containing 3 mL of the distilled water (pH = 5.65), at 37°C for 7 days. The specimens submitted to the coffee solution remained immersed in 3 mL of the dye solution for 10 minutes a day at 37°C, under constant agitation on a shaker table (SK 0330-Pro, Dragonlab Laboratory Instruments Limited, Beijing, China). They were then washed with distilled water for 5 seconds, and remained immersed in distilled water. This cycle was repeated for 8 days, according to Borges et al.[3]

Final color evaluation

The specimens remained for another 24 hours in relative humidity following the staining process, and were subsequently re-evaluated for color stability, using the same protocols described previously.

The ΔE_{ab} values were calculated by comparing the baseline and final values (48 hours after the end of treatment), considering the values of ΔL^*, Δa^* and Δb^* between the start and end times of the evaluation for each treatment. Next, the ΔE_{ab} (color change) was calculated using the following mathematical formula:[21] $\Delta E_{ab} = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$; $\Delta L^* = L^*final - L^*initial$; $\Delta a^* = a^*final - a^*initial$; $\Delta b^* = b^*\backslash final - b^*initial$. The perceptibility and acceptability thresholds considered for ΔE_{ab} were 1.2 and 2.7, respectively.[22,23] Color change was also evaluated by CIEDE2000 (ΔE_{00}), which uses h (hue) and C (chroma) values.[24] ΔE_{00} values of 0.8 and 1.8 were adopted as the perceptibility and acceptability thresholds.[22]

Difference in whiteness was also calculated using the whiteness index for dentistry (WI_D), in which the L^*, a^* and b^* parameters are used in the following equation:[25] $WI_D = 0.511L^* - 2.324a^* - 1.100b^*$. Differences in WI_D between initial and final evaluations were also evaluated to obtain (ΔWI_D), whereas the thresholds for ΔWI_D were 0.72 for perceptibility and 2.60 for acceptability.[26]

Statistical analysis

After exploratory analysis, the data were analyzed by the nonparametric Kruskal Wallis and Dunn tests for comparison of the three distances, Mann Whitney for comparison of the resins and of the immersion solutions, and Wilcoxon test (paired) for comparison of the time periods. Analyses were performed using a software program,[27] considering a significance level of 5%.

Results

L* baseline values revealed that the conventional resin presented higher luminosity than the bulk-fill resin. After immersion in coffee and distilled water, the resins showed no difference, considering that they had lower L* values after coffee immersion and higher values after immersion in distilled water (Table 2). There was also an increase in the a* values for conventional composite resin, regardless of the distance (Table 3). An increase in the a* value occurred in the bulk-fill resin only when it was immersed in coffee (p<0.05), differing significantly from when it was immersed in water (p < 0.05). Conventional composite resin presented less negative or more positive (reddish) values after immersion in water or coffee, respectively, than bulk-fill resin, except at a distance of 4 mm when immersed in coffee.

At baseline, the b* value was significantly higher in the bulk-fill composite resin. Despite an increase in the b* value after coffee immersion, and a decrease after distilled water immersion, there was no statistical difference between the resins after the respective immersions (Table 4).

The conventional resin showed a higher color change (ΔE_{ab}, ΔE_{00}) and higher difference in WI_D (ΔWI_D) than the bulk-fill resin when immersed in coffee at all light-activation distances (Table 5). Although the conventional resin presented a higher color change (ΔE_{ab}) when immersed in coffee than in distilled water, both resins showed higher color change for ΔE_{00} and higher difference in whiteness (ΔWI_D) in coffee than in distilled water at all light-activation distances (p<0.05). ΔWI_D was also higher for the conventional resin than the bulk-fill resin when immersed in distilled water, and showed a whiter effect when immersed in this solution (Table 5). Figure shows the specimens before and after coffee staining at all curing distances.

Table 2. Median (minimum value; maximum value) of L* value as a function of composite resin, immersion medium, light-activation distance and evaluation time periods.

Time	Immersion	Resin	Light-activation distance		
			0 mm	2 mm	4 mm
Baseline	Coffee	Conventional	86.20 (84.40; 88.10) Aa	85.30 (84.10; 87.80) Aa	86.50 (83.60; 87.30) Aa
		Bulk-fill	84.05 (81.90; 85.30) Ab	83.10 (81.30; 85.50) Ab	83.50 (82.00; 84.60) Ab
	Distilled water	Conventional	84.60 (83.30; 86.60) Aa	84.45 (82.40; 86.60) Aa	85.60 (82.70; 87.10) Aa
		Bulk-fill	83.40 (81.70; 85.00) Ab	83.15 (82.10; 86.40) Ab	83.00 (81.90; 85.10) Ab
After immersion	Coffee	Conventional	$^{\$}$82.80 (81.40; 84.70) Aa	$^{\$}$82.35 (81.30; 84.40) Aa	$^{\$}$82.15 (79.90; 83.40) Aa
		Bulk-fill	$^{\$}$82.20 (79.90; 83.90) Aa	$^{\$}$81.95 (80.50; 84.40) Aa	$^{\$}$82.00 (79.40; 84.00) Aa
	Distilled water	Conventional	*$^{\$}$85.60 (83.10; 88.40) Aa	*$^{\$}$86.30 (84.10; 88.00) Aa	*$^{\$}$86.30 (84.30; 88.90) Aa
		Bulk-fill	*$^{\$}$84.95 (82.70; 85.70) Aa	*$^{\$}$84.85 (84.10; 86.90) Ab	*$^{\$}$84.85 (84.00; 86.40) Ab

*Differs from the group immersed in coffee under the same resin conditions, distance and time (p ≤ 0.05). $^{\$}$Differs from baseline under the same resin, distance and immersion conditions (p ≤ 0.05). Medians followed by distinct letters (uppercase horizontally, comparing distances for each resin; lowercase vertically, comparing resin for each distance) at each time period (baseline or after immersion) differ from one another (p ≤ 0.05).

Table 3. Median (minimum value; maximum value) of a* value as a function of composite resin, immersion medium, light-activation distance and evaluation time periods.

Time	Immersion	Resin	Light-activation distance		
			0 mm	2 mm	4 mm
Baseline	Coffee	Conventional	-1.40 (-1.50; -0.80) Aa	-1.40 (-1.50; -0.90) Aa	-1.40 (-1.50; -1.00) Aa
		Bulk-fill	-1.95 (-2.20; -1.10) Ab	-1.20 (-2.20; -1.10) Aa	-1.20 (-2.20; -1.00) Aa
	Distilled water	Conventional	-1.50 (-1.60; -1.40) Ab	-1.40 (-1.60; -1.10) Aa	-1.40 (-1.50; -1.30) Ab
		Bulk-fill	-1.25 (-2.00; -1.10) Aa	-1.25 (-1.80; -1.00) Aa	-1.25 (-1.50; -1.00) Aa
After immersion	Coffee	Conventional	$^{\$}$0.80 (0.20; 1.50) Aa	$^{\$}$0.75 (0.50; 1.70) Aa	$^{\$}$0.40 (0.10; 1.00) Aa
		Bulk-fill	$^{\$}$-0.25 (-0.70; 0.70) Ab	$^{\$}$0.10 (-0.70; 1.20) Ab	$^{\$}$0.20 (-0.80; 1.20) Aa
	Distilled water	Conventional	*$^{\$}$-0.85 (-1.00; -0.60) Aa	*$^{\$}$-0.70 (-0.90; -0.50) Aa	*$^{\$}$-0.75 (-0.90; -0.50) Aa
		Bulk-fill	*-1.25 (-2.00; -0.90) Ab	*-1.15 (-1.50; -1.00) Ab	*-1.15 (-1.50; -0.90) Ab

*Differs from the group immersed in coffee under the same resin conditions, distance and time (p ≤ 0.05). $^{\$}$Differs from baseline under the same resin, distance and immersion conditions (p ≤ 0.05). Medians followed by distinct letters (uppercase horizontally, comparing distances for each resin; lowercase vertically, comparing resin for each distance) at each time period (baseline or after immersion) differ from one another (p ≤ 0.05).

Table 4. Median (minimum value; maximum value) of b* value as a function of composite resin, immersion medium, light-activation distance and moment of evaluation.

Time	Immersion	Resin	Light-activation distance		
			0 mm	2 mm	4 mm
Baseline	Coffee	Conventional	15.10 (14.50; 15.80) Ab	15.10 (14.60; 15.80) Ab	15.30 (14.60; 16.60) Ab
		Bulk-fill	16.80 (15.20; 17.70) Aa	16.55 (15.40; 18.00) Aa	16.35 (15.60; 18.30) Aa
	Distilled water	Conventional	15.45 (15.00; 16.40) Ab	15.65 (15.00; 16.30) Ab	15.80 (15.10; 16.50) Ab
		Bulk-fill	16.45 (14.60; 18.00) Aa	16.50 (16.10; 17.20) Aa	16.65 (15.60; 17.20) Aa
After immersion	Coffee	Conventional	$^{\$}$18.15 (16.30; 19.50) Aa	$^{\$}$17.15 (16.60; 22.20) Aa	$^{\$}$17.25 (15.40; 19.70) Aa
		Bulk-fill	$^{\$}$18.05 (16.10; 18.70) Aa	$^{\$}$17.70 (15.70; 18.40) Aa	$^{\$}$17.30 (15.70; 18.30) Aa
	Distilled water	Conventional	*$^{\$}$14.40 (12.20; 15.70) Ab	*$^{\$}$14.30 (12.10; 16.40) Ab	*$^{\$}$14.40 (12.10; 16.00) Ab
		Bulk-fill	*$^{\$}$15.65 (12.80; 16.30) Aa	*$^{\$}$15.45 (14.40; 16.70) Aa	*$^{\$}$15.40 (14.70; 17.10) Aa

*Differs from the group immersed in coffee under the same resin conditions, distance and time (p ≤ 0.05). $^{\$}$Differs from baseline under the same resin, distance and immersion conditions (p ≤ 0.05). Medians followed by distinct letters (uppercase horizontally, comparing distances with each resin; lowercase vertically, comparing resins with each distance) at each time period (baseline or after immersion) differ from one another (p ≤ 0.05).

Table 5. Median (minimum value; maximum value) color change (ΔE_{ab} and ΔE_{00}) and difference in whiteness (ΔWI_D), according to composite resin, immersion medium, and light-activation distance.

Color change	Immersion	Resin	Light-activation distance		
			0 mm	2 mm	4 mm
ΔE_{ab}	Coffee	Conventional	4.64 (2.20; 7.20) Aa	4.46 (3.54; 8.68) Aa	4.93 (2.36; 6.20) Aa
		Bulk-fill	2.45 (1.93; 4.72) Ab	1.90 (1.19; 4.93) Ab	2.56 (1.45; 4.25) Ab
	Distilled water	Conventional	*2.00 (0.64; 3.49) Aa	*2.19 (0.70; 3.54) Aa	*2.64 (0.87; 3.54) Aa
		Bulk-fill	*2.00 (0.62; 2.90) Aa	1.99 (1.05; 2.63) Aa	2.10 (0.51; 3.74) Aa
ΔE_{00}	Coffee	Conventional	3.47 (1.88; 4.91) Aa	3.52 (3.06; 5.64) Aa	3.76 (2.21; 4.42) Aa
		Bulk-fill	2.24 (1.86; 3.41) Ab	1.92 (1.35; 3.99) Ab	2.34 (1.46; 3.62) Ab
	Distilled water	Conventional	*1.41 (0.73; 2.34) Aa	*1.47 (0.76; 2.40) Aa	*1.74 (0.72; 2.35) Aa
		Bulk-fill	*1.25 (0.36; 1.87) Aa	*1.23 (0.7; 1.65) Aa	*1.37 (0.32; 2.45) Aa
ΔWI_D	Coffee	Conventional	-9.53 (-12.33; -4.82) Ab	-8.49 (-15.86; -7.66) Ab	-8.00 (-10.54; -4.74) Ab
		Bulk-fill	-5.38 (-9.36; -4.77) Aa	-4.33 (-9.10; -2.22) Aa	-5.06 (-8.25; -2.69) Aa
	Distilled water	Conventional	*0.27 (-1.39; 1.94) Ab	*0.51 (-1.83; 2.27) Ab	*0.84 (-0.87; 2.51) Ab
		Bulk-fill	*2.25 (0.38; 2.68) Aa	*1.98 (-0.05; 2.84) Aa	*1.96 (0.67; 2.98) Aa

*Differs from the group immersed in coffee under the same resin conditions, distance and time (p ≤ 0.05). Medians followed by distinct letters (uppercase horizontally, comparing distances with each resin; lowercase vertically, comparing resins with each distance) at each time period (baseline or after immersion) differ from one another (p ≤ 0.05).
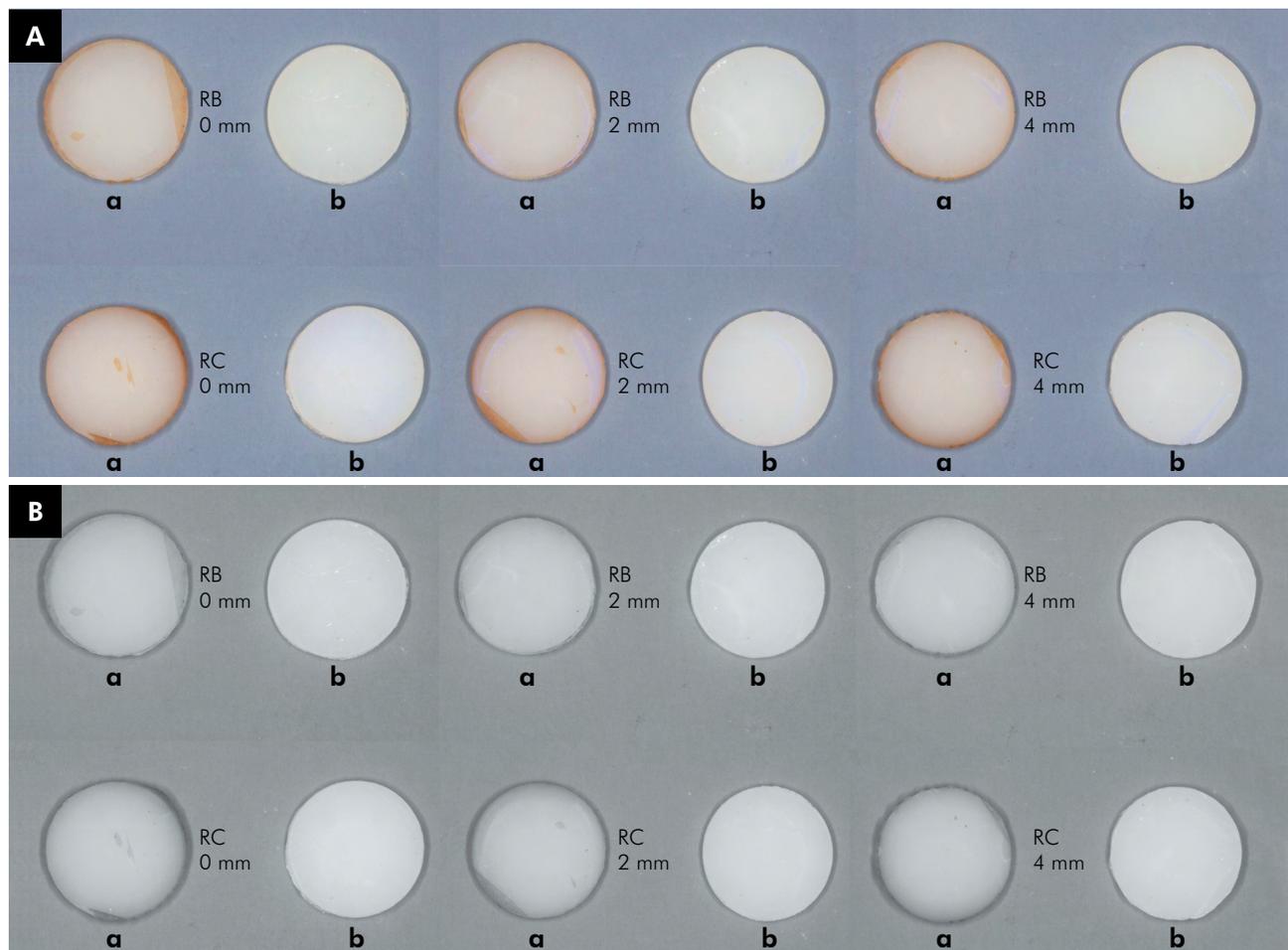

Figure. Specimens before and after coffee staining at all curing distances (A - color; B - black and white; RB = resin composite bulk-fill; RC = resin composite conventional; b = before coffee staining; a = after coffee staining).

Discussion

Although conventional and bulk-fill resins have different recommended maximum increment thickness to provide better polymerization at greater distances from the activating light source,[11,13,28,29] both have similar percentages of inorganic component weight, namely 78.5% filler for conventional composite resin and 76.5% filler for bulk-fill composite resins.[7] Despite modifications in the physical properties of bulk-fill resins—such as greater translucency—and the addition of polymerization modulators, the composition of both resins studied does not differ considerably.[11,13,30]

Although the same color (A1) of conventional and bulk-fill composite resins was used in the present study, differences were observed in the baseline for L* values, that is, the conventional resin was brighter compared to the bulk-fill resin, regardless of light-activation distance. Bulk-fill resins have a relatively lower filler amount and a larger particle size than conventional resins. This is related to the direct influence on the translucency of the material, which allows a greater amount of light to penetrate the thickness of the material, thus making the values for the bulk-fill composite resins lower.[14]

Increased luminosity was observed for both resins after immersion in water. Some factors determine the extent to which the material will be affected by the aqueous medium, including sorption and solubility, crosslinking density, hydrophilicity, and the network porosity of polymeric materials,[30] thus confirming that water immersion at different time periods may interfere with the color stability of composites. Water molecule affinity to the hydrophilic groups of the polymeric chain causes them to bind together, thus causing polymer swelling and plasticization. The solvent diffuses within the polymeric chain, causing separation of these chains and expansion of the network.[30] Thus, alterations in water sorption may explain the change in the luminosity of the materials. This resulted in positive mean values for ΔWI_D, and in reduced mechanical properties and changes in physical properties, making the materials brighter.

On the other hand, immersion in coffee solution led to a decrease in the luminosity of both resins, which may be attributed to the presence of dark-colored pigments in the solution. The staining of the resin with coffee pigments seems to occur not only on the surface of the material but also in depth, owing to dye adsorption and absorption in the resin matrix material.[6]

Regarding parameter a*, an increase was observed in the red band value for the composite resins, since the values became less negative (or positive) when immersed in coffee. It has been reported that the composition of the organic phase may favor pigment incorporation.[31] Higher pigmentation has been observed in resins containing triethylene glycol dimethacrylate (TEGDMA), which has more hydrophilic characteristics and higher water absorption capacity.[31] Both the conventional resin and the bulk-fill resin tested have hydrophilic monomers in their composition, such as UDMA. However, only conventional resin has TEGDMA, which is characterized by a more elution-prone monomer.[31] This may better explain its greater ability to incorporate pigments, although both resins have shown staining ability.

As for the conventional resin, an a* increase was also observed when it was immersed in water, probably attributed to its higher water sorption property.[32] Water sorption and solubility of composites in a specified medium are material-dependent, and highly affected by the amount of filler and properties of the polymer matrix, such as hydrophilicity/hydrophobicity.[31] Sorption values are negatively correlated with the amount of resin filler.[31] The higher the volume in weight of the filler, the lower the volume of the polymer matrix, resulting in less water absorption, thus confirming that this is a phenomenon associated with the polymer phase.[31] Sorption may also occur in composites with a high filler and low matrix interface, since it provides a means of water diffusion and progressive degradation of the material.[31,33] It is suggested that the hydrolytic degradation of the interface between resinous components and the inorganic portion may modify the way light is dissipated by filler particles.

As for the b* value, all the resins at all the distances differed significantly from the baseline after immersion in water or coffee. However, coffee immersion promoted a more significant increase in b* than water immersion. It is known that coffee has yellowish pigments, associated with the susceptibility of resin staining by these pigments, in addition to water sorption capacity and hydrophilicity of the matrix resin.[31,32] Water acts as a vehicle for pigment penetration into the resin matrix, whereas the filler particles do not absorb water; therefore, a higher amount of resinous matrix, especially that containing more hydrophilic monomers, promotes higher water sorption[24,26]; this may lead to a greater color change.[4]

Coffee also has significant amounts of gallic acid, which favors composite pigmentation.[12] The adsorption and absorption of pigments in the organic matrix of the material—not easily removed by brushing, finishing or polishing—directly impact the values obtained for the color change (ΔE_{ab}, ΔE_{00}) and for the difference in whiteness (ΔWI_D). For this reason, the first null hypothesis was rejected, since the staining solution influenced the color stability properties of the conventional and bulk-fill resins. Furthermore, when immersed in coffee, the conventional composite resin presented higher ΔE_{ab}, ΔE_{00} and ΔWI_D values than the bulk-fill resin at all light-activation distances. These differences are probably related to the organic matrix composition,[7] since TEGDMA and Bis-GMA are hydrophilic monomers, which are more susceptible to pigment incorporation. This may explain the results of ΔE_{ab}, since conventional resin has these monomers in its composition, corroborating the findings of Mansouri and Zidan.[34] The results presented values above the limit of 2.7,[22,23] which is considered clinically acceptable.[22] However, the color change obtained by the CIEDE2000 formula (ΔE_{00}) is better correlated with visual perception than the CIELAB.[22] In this study, the ΔE_{00} values for immersion in coffee solution for both the resins and the light-activation distances (all median values above 1.92) were higher than the perceptibility and acceptability thresholds,[22] showing that immersion in coffee caused clinically perceptible color changes. Furthermore, ΔWI_D mean values were also above the threshold limits for perceptibility

and acceptability when the resins were immersed in the coffee solution. However, these values were lower than the acceptable values when both resins were immersed in distilled water, and higher than the threshold limit for perceptibility when the conventional resin was light-cured at a 4-mm distance, and the bulk-fill resin, at all distances.[26]

Regarding the light-activation distances, there was no influence in the color change in the present study. This leads to the acceptance of the second null hypothesis. However, another study[12] shows that bulk-fill resins have significantly higher staining power when the thickness increases; this may influence the lower longevity of restorations. A curing unit that provides sufficient energy for activation of resin-specific primers may minimize the effects of the light-activation distance,[35] specifically at the evaluated distances, which did not exceed 4 mm.[20,21] The LED light-curing unit used herein is a high-power unit, with three blue LEDs and one violet LED on its tip. This resulted in great effectiveness in exciting various types of photoinitiators.[36] Furthermore, the total irradiance output could be the same for the three different distances, because all the light output from the light-curing unit was conserved by using black rubber matrices. These factors could influence the color difference values.

Blue LEDs are more powerful than violet ones, and provide much deeper light penetration, thus producing more complete polymerization of both conventional and bulk-fill composite resins.[37] Overall, bulk-fill resins exhibit greater translucency compared with conventional resins. Since light transmission is closely connected to the opacity of the material, the filler/matrix ratio in these resins is low, favoring light dissipation and increasing the degree of conversion.[20,21,38] However, even with no color change differences in the composite resins in relation to the light-activation distances, the light transmission rate may have affected other material properties, such as hardness and degree of conversion. Furthermore, the findings of this study are limited to the 2-mm thickness of the resin composites used, leaving unknown what the effect would be for much thicker samples, in a range up to 5 mm, as is indicated for bulk-fill resins. Similarly, only one color was

evaluated, and no finishing or polishing procedures were applied to the surface of the samples; this also could have influenced the results. Therefore, future studies should be performed to investigate these properties.

Conclusions

The conventional resin composite showed higher staining when immersed in coffee than the bulk-fill resin, regardless of the light-activation distance.

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