

The effect of surface finishing and storage solutions on the color stability of resin-based composites

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Advancements in resin-bonding technology have resulted in resin-based composite, or RBC, materials with lifelike characteristics, making these products the primary choice of dentists striving to meet patients' esthetic needs. The success of these restorations depends largely on their color stability.¹

Discoloration of RBC restorations may be caused by factors related to the surface treatment of the material, as well as the composition of the RBC (for example, intrinsic coloration). Previous studies have reported that the color stability of composite restorations may be influenced by different surface-finishing treatments.²⁻⁴

Finishing treatments and storage solutions significantly affect the surface staining of resin-based composite materials.

The surface finishing affects many aspects of the final restoration, including staining, plaque accumulation and wear resistance.^{5,6} Discoloration and marginal degradation are two reasons why restorations are replaced.⁷ Restoration failures may result in secondary caries, especially because of the greater tendency for plaque to accumulate on rough surfaces.^{8,9} The surface finishing of restorations located near the gingiva also influences periodontal health.¹⁰

Oral habits such as tobacco use and certain dietary patterns (for example, caffeine intake) may exacerbate the external discoloration of RBC materials.^{11,12} An RBC restoration also may become discolored as a result of its

Background. The authors tested the hypothesis that surface-finishing treatments and the type of storage solutions significantly affected the staining of resin-based composites, or RBCs, and unfilled resins, or URs.

Methods. Fifty-four RBC and 54 UR disks were polymerized through a polyester film strip (Mylar, DuPont, Wilmington, Del.) and polished in one of three groups: 1-micrometer aluminum oxide, 15- μ m diamond plate and no treatment (polyester film). All specimens were immersed in water for two days and then in coffee, cola or red wine for seven more days at 37 C. The authors recorded tristimulus color measurements before the immersions; after one and two days in water; and after one, two, three and seven days in the storage solutions.

Results. Most of the color changes occurred between day 2 in water and day 7 in the staining solution. Analysis of variance showed that the finishing treatment and storage solution significantly influenced the overall color change (ΔE), and interactions occurred between the finishing treatment and the storage solution ($P < .0001$) for both materials. RBC specimens generally exhibited greater color changes than did UR specimens. The polyester film finishing exhibited the greatest amount of color change, while the diamond finishing exhibited the least amount of color change. Immersion in wine caused the greatest color change for both materials; cola and coffee resulted in the smallest color change for RBC and UR specimens, respectively.

Conclusions. Finishing treatments and storage solutions significantly affect the surface staining of RBC materials. Polyester film finishing and red wine produced the greatest color change after seven days for RBC specimens.

Clinical Implications. Clinicians should remove the polyester film-finished surface and advise patients that drinking wine could intensify surface staining on RBC restorations.



vulnerability to certain intrinsic factors. The resin matrix, which is a major component of RBC materials, has been reported to be critical in color stability¹³ and is affected by different pH solutions^{1,14} and alcohol concentration.^{15,16} Ferracane and Marker¹⁵ and Ferracane and colleagues¹⁶ described that alcohol can plasticize the resin matrix, making it soft and prone to degradation. In addition, Dietschi and colleagues¹³ showed that the staining may be related to a high resin content and water absorption.

Although a high-gloss surface generally is considered less susceptible to staining,^{3,13,17} other surface states, such as incomplete polymerization of the resin matrix, may contribute to surface staining of RBCs. Micro-cracks, microvoids or interfacial gaps located at the interface between the filler and the matrix are the most likely penetration pathways for stains.^{18,19}

The discoloration of RBC systems appears to be related to multiple factors. Therefore, the purpose of our research was to evaluate the color stability of resin-based dental materials using three different surface-finishing treatments. The primary hypothesis tested was that finishing treatments significantly affect the surface staining of the resin-based dental materials (that is, different finishing techniques significantly alter the ability of the RBC to stain). The second hypothesis was that the resin component of the material is most vulnerable to staining. The third hypothesis was that surface staining of the material depends on the types of storage solution used.

MATERIALS AND METHODS

One of us (S.P.) prepared the experimental specimens using an RBC (Filtek Z-250, 3M shade A-1, batch number 6020A1, 3M ESPE, St. Paul, Minn.) and the unfilled activated resin, or UR, from the same batch.

We used a polyethylene frame (16.7 millimeters in diameter and 2.4-mm thick) to fabricate 108 disks (54 RBC and 54 UR). A 0.051-mm-thick transparent polyester film strip (Mylar, DuPont, Wilmington, Del.) was placed against both the bottom and the top layers of the disks. Each disk was built incrementally; the first layer was polymerized for 20 seconds and the second layer was polymerized for 40 seconds (through the polyester film strip) with a light-curing unit (SDS

Demetron, Orange, Calif.). We used a curing radiometer (SDS Demetron) to measure the output of the light unit daily to ensure a constant value of at least 470 milliwatts/square centimeter.²⁰

On completion of light curing, we randomly divided the specimens into three surface-finishing treatment groups (n = 18); specimens were polished through 1-micrometer aluminum oxide or 15- μ m diamond plate, or were left with no further treatment (polyester film). One of us (S.P.) polished the aluminum oxide specimens in water using 400, 600, 1,200 and 2,000 grits of silicon carbide abrasive (Mark V Laboratory, East Granby, Conn.). The final finishing was achieved using 1- μ m aluminum oxide slurry.

We first polished the specimens in the diamond-plate group in water with 400-grit silicon carbide abrasive (Mark V Laboratory) and then polished them with 30- and 15- μ m diamond plates (MB Diamond Plates, Mark V Laboratory). In the polyester film strip group, the top and bottom surfaces were left as polymerized.

We recorded the CIE L*, a*, b* baseline color measurements²¹ for the dry specimens (that is, before they are placed in water) using a colorimeter with an 8-mm aperture (CR-300 tristimulus, Minolta, Ramsey, N.J.). L* represents the value (that is, the amount of white [100] or black [0]). Hue (color) and chroma (saturation level) are represented by the chromatic axes a* (+ a* red/ - a* green) and b* (+ b* yellow/- b* blue).

We placed each specimen on a neutral gray background (Munsell N-7, Macbeth, New Windsor, N.Y.). This background was used for all color measurements. Neutral gray is represented midway on the L* axis, and has the least amount of influence on the value measurements. We recorded the color measurements using the D₆₅ illuminant on the colorimeter. D₆₅ is the standardized CIE illuminant that approximates natural, outside daylight.

We placed the specimens in individual vials containing 20 milliliters of distilled water and kept them immersed for two days. Throughout the immersion, the individual vials were stored in an Eviron-Shaker (Lab-Line Instruments, Melrose Park, Ill.) at 37 C. After the water immersion, we divided the specimens from each surface treatment group into three subgroups (n = 6) and

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TABLE 1

L*, a* AND b* VALUES* FOR RBC† AND UNFILLED RESIN SPECIMENS BEFORE AND AFTER SEVEN-DAY IMMERSION IN STAINING SOLUTIONS.								
MATERIAL	SURFACE FINISHING	BEFORE OR AFTER IMMERSION	L*		a*		b*	
			Mean (SD‡)	Range	Mean (SD)	Range	Mean (SD)	Range
RBC	Aluminum oxide	Before	67.1 (0.8)	65.8 - 68.0	0.4 (0.2)	0.2 - 0.7	12.7 (0.2)	12.4 - 13.2
		After	66.0 (1.1)	63.4 - 67.8	0.6 (0.4)	0.2 - 0.7	13.8 (0.6)	12.9 - 15.4
	Diamond plate	Before	66.7 (1.0)	64.3 - 67.4	0.4 (0.2)	0.2 - 1.9	12.8 (0.8)	12.4 - 3.8
		After	64.8 (0.9)	61.5 - 66.6	1.0 (0.4)	0.3 - 2.0	14.4 (1.0)	13.2 - 16.5
	Polyester film (Mylar§)	Before	66.6 (0.5)	65.3 - 67.4	0.2 (0.1)	0.0 - 0.3	12.8 (0.5)	11.1 - 13.2
		After	63.9 (1.9)	59.8 - 66.8	0.6 (0.4)	0.2 - 1.9	18.0 (4.1)	13.4 - 26.6
UR¶	Aluminum oxide	Before	62.5 (0.7)	60.3 - 63.2	-1.7 (0.2)	-1.3 - -2.1	7.8 (0.6)	6.6 - 9.2
		After	62.8 (1.2)	57.9 - 63.9	-1.0 (0.2)	-0.4 - -1.4	6.9 (1.4)	4.9 - 9.9
	Diamond plate	Before	59.0 (1.1)	57.8 - 61.6	-1.2 (0.2)	-0.8 - -1.6	7.2 (0.6)	5.8 - 8.7
		After	58.1 (1.5)	55.9 - 61.0	-0.5 (0.2)	-0.2 - -0.9	8.2 (1.7)	5.1 - 10.5
	Polyester film (Mylar)	Before	61.6 (0.6)	60.1 - 62.8	-2.3 (0.2)	-1.9 - -2.7	10.3 (0.8)	9.0 - 11.7
		After	61.9 (0.6)	60.1 - 62.9	-2.1 (0.5)	-1.5 - -3.1	11.0 (2.8)	7.9 - 17.1

* Source: CIE Colorimetry Committee.²¹
 † RBC: Resin-based composite.
 ‡ SD: Standard deviation.
 § Mylar is manufactured by DuPont, Wilmington, Del.
 ¶ UR: Unfilled resin.

then submersed each subgroup into one of the following three solutions: coffee, red wine or cola.

We measured the pH of the coffee, wine and cola solutions before immersing the specimens in them. The specimens were kept in individual vials containing 20 mL of each staining solution; they were stored at 37 C for a total of seven days. Tristimulus color measurements were recorded for the disks after one and two days' water immersion (W1, W2), as well as after one, two, three and seven days in the staining solution (S1, S2, S3, S7). The dry baseline measurement served as the control for each specimen, which enabled us to calculate any color change with greater accuracy.

The individual color parameter differences, ΔL*, Δa* and Δb*, were determined by subtracting the parameter variable at one immersion period from that at another, thereby identifying the changes in value (ΔL*) and hue (Δa* and Δb*). We used the following CIE formula to determine the total color difference (ΔE), which in this study indicates the overall color changes from one immersion period to another:

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

We used one-way and two-way analyses of vari-

ance, or ANOVA, and the Duncan multiple range test for statistical analysis.

RESULTS

This experimental design consisted of the following three material-related variables: filler particles, finishing treatments and staining solutions, which yielded 18 experimental groups. Table 1 shows the L*, a* and b* values recorded before and after the seven-day immersion for both the RBC and UR specimens in each of the three surface-finishing groups. One-way ANOVA showed that for each experimental group, the greatest change in ΔE values occurred during the seven-day immersion (between W2 and S7). Because changes that occurred during this period are relevant to a clinical situation, we have shown only the results for this period.

Table 2 shows the ΔL*, Δa*, Δb* and ΔE values for the RBC and UR specimens during the seven-day storage period for each surface-finishing treatment (that is, aluminum oxide, diamond plate or polyester film) in each staining medium (that is, cola, coffee or wine). Two-way ANOVA

TABLE 2

ΔL*, Δa*, Δb* AND ΔE FOR RBC* AND UNFILLED RESIN SPECIMENS AFTER SEVEN-DAY IMMERSION IN STAINING SOLUTIONS.†												
SURFACE FINISHING	MEAN (SD) ΔL*			MEAN (SD) Δa*			MEAN (SD) Δb*			MEAN (SD) ΔE		
	Cola	Coffee	Wine	Cola	Coffee	Wine	Cola	Coffee	Wine	Cola	Coffee	Wine
RBC												
Aluminum Oxide	-0.3 (0.3)	-1.5 (0.4)	-1.5 (0.6)	0.0 (0.0)	0.3 (0.1)	0.5 (0.4)	0.5 (0.3)	1.6 (0.5)	1.2 (0.6)	0.7 (0.3)	2.2 (0.6)	2.1 (0.3)
Diamond Plate	-0.7 (0.4)	-2.4 (0.6)	-2.6 (0.8)	0.2 (0.1)	0.7 (0.2)	1.3 (0.3)	0.9 (0.4)	2.7 (0.5)	1.1 (1.0)	1.3 (0.4)	3.7 (0.7)	3.2 (0.8)
Polyester Film (Mylar§)	-0.6 (0.8)	-3.4 (2.0)	-4.1 (1.4)	0.1 (0.1)	0.6 (0.5)	0.6 (0.4)	1.0 (0.5)	4.1 (0.8)	10.5 (1.7)	1.3 (0.7)	5.4 (1.9)	11.3 (1.7)
Unfilled Resin												
	0.9 (0.4)	0.3 (0.3)	-0.5 (0.7)	0.7 (0.1)	0.6 (0.2)	0.7 (0.2)	-2.3 (0.2)	-1.0 (0.4)	0.6 (0.8)	2.6 (0.3)	1.2 (0.4)	1.4 (0.6)
Aluminum Oxide	1.2 (0.7)	-2.5 (1.2)	-1.3 (0.7)	0.7 (0.1)	0.7 (0.2)	0.8 (0.2)	-1.4 (0.3)	2.3 (0.5)	2.0 (1.0)	2.1 (0.6)	3.5 (1.1)	2.7 (0.9)
Diamond Plate	1.1 (0.4)	0.3 (0.4)	-0.6 (0.5)	0.7 (0.1)	0.3 (0.2)	-0.5 (0.2)	-2.4 (0.3)	0.0 (0.2)	4.5 (1.1)	2.8 (0.4)	0.6 (0.3)	4.6 (1.1)

* RBC: Resin-based composite.
 † Source: CIE Colorimetry Committee.²¹
 ‡ SD: Standard deviation.
 § Mylar is manufactured by DuPont, Wilmington, Del.

indicated that both the finishing treatment and staining medium demonstrated a statistically significant influence on the ΔL*, Δa*, Δb* and ΔE values ($P < .0001$), and we found combined influences (that is, interactions) between the finishing treatment and staining medium for both the RBC and UR specimens.

Because of these interactions, we used a one-way ANOVA to analyze the effect of the staining medium on the color changes (ΔE) for each combination of material (RBC or UR) and surface finishing treatment; in addition, we conducted the Duncan multiple range test of the staining medium (Figure). The results show that the medium exhibited a statistically significant influence on the ΔE values for all material/finishing combinations ($P < .0001$).

With the exception of UR specimens finished with aluminum oxide, immersion in wine produced the greatest color change among staining solutions. Within the wine groups, we found the effect of the surface-finishing technique to be in the following increasing order of significance: aluminum oxide, diamond plate and polyester film. Cola caused less color change with RBC speci-

mens than it did with UR specimens. The effect of the finishing procedure within the cola groups for the RBC or UR specimens appeared to be minimal ($P > .05$). The results show that the effect of coffee on the color change was similar to that of the wine, except for the polyester film–finishing group, in which the effect of coffee was significantly less than that of the wine (Figure).

In most cases, the value (L^*) of the surface decreased after the seven-day immersion, except for the UR specimens with diamond finishing, in which we observed a slight increase in L^* (Table 2). The changes for Δa* (red-green axis) were relatively small and would not contribute significantly to the overall color changes (ΔE). The changes for Δb* (yellow-blue axis) were the greatest among the three color axes. One-way ANOVA and Duncan’s grouping of the Δb* values yielded virtually the same results as those of ΔE values (Figure).

Although we did not incorporate the pHs of the three staining solutions as variables in the statistical analysis, we did record them at 37 C. The pH values were 2.4, 5.1 and 3.7 for cola, coffee and wine, respectively.

DISCUSSION

Surface finishing is a critical step in achieving an esthetically acceptable restoration, and different materials and instruments may be used. Clinically, disks, pastes and burs of varying textures are used commonly on RBC materials to achieve a high-gloss, enamellike surface appearance. In this study, different finishing treatments significantly affected the color stability of both RBC and UR specimens (that is, different finishing techniques significantly changed the staining capacity of the RBC and UR materials). Thus, we accepted the primary hypothesis of this study.

High-gloss surface. A high-gloss surface generally is considered less susceptible to staining than are other surfaces.^{3,13,17} Although this study did not measure surface roughness as influenced by the polishing procedure, Pratten and Johnson²² and Stoddard and Johnson²³ found that polyester film finishing produced the smoothest surfaces for both RBC and UR materials. One should expect a polyester film–finished surface to exhibit the least amount of staining, followed by the aluminum oxide– and diamond–finished surfaces. However, polyester-film finishing exhibited the greatest color change in this study, followed by diamond finishing and then aluminum oxide finishing (Figure) (with the exception of the UR specimens immersed in the coffee solution).

It is well-known that all acrylate-based resin used in dentistry exhibits an oxygen-inhibited surface layer when cured in air. The use of a polyester film strip not only results in a smooth surface finish, but also eliminates the presence of an uncured layer on the surface. However, the surface beneath the polyester film strip does not appear to have the same degree of polymerization as the bulk of the RBC material, which has not been exposed to oxygen during placement of the material. A surface that has a lower degree of polymerization can exhibit increased discoloration.²⁴

Incomplete polymerization. In fact, de Gee and colleagues²⁵ identified incompletely polymerized portions of restorations via absorption of color dye on the surface of composite materials. In addition, recent studies^{26,27} have shown that, compared with other finishing treatments, polyester film finishing results in surfaces with the lowest hardness, which is evidence of a lower degree of polymerization on the surface. Therefore, the influence of surface finishing on surface staining

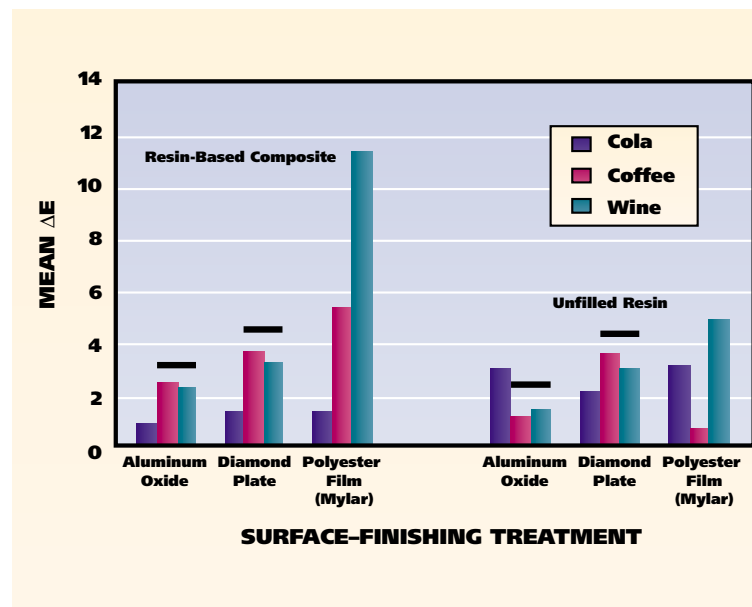


Figure. Effect of the surface-finishing treatment and staining medium on the overall color change (ΔE) of unfilled resin and resin-based composite specimens. Horizontal bars indicate that the mean values of each column represented are not statistically significantly different at $\alpha = .05$, according to the Duncan multiple range test. Mylar polyester film is manufactured by DuPont, Wilmington, Del.

becomes secondary if a lower degree of polymerization or incomplete curing is present on the surface.

Several studies also have established that curing RBC materials against a polyester film strip yields a smooth, resin-rich surface.^{4,13,22,23,28-31} The surface of RBC materials cured under a polyester film strip should have the same staining characteristics as those of UR materials. However, the results of our study show that RBC specimens with a polyester film finish exhibited substantially greater color changes than did UR specimens with a polyester film finish after immersion in wine and coffee solutions. In the case of the cola solution, UR specimens with a polyester film finish exhibited greater color changes than did RBC specimens.

Reflection of light. It is important to point out that the colorimeter analyzes the light reflected from the surface. If the specimen is translucent, as is the case for the UR specimens, the light may travel through the entire thickness of the specimen (≈ 2.4 mm) before it is reflected from the background. For RBC materials, the toothlike color is the result of fillers and pigment additives, which contribute to the higher L^* , a^* and b^* values (Table 1). In addition, these addi-

tives attenuate the intensity of the light as it travels through the specimen, so that the portion of the light reflected from the neutral gray background will not be as significant as it is for the UR specimens.

In other words, color measurement with UR materials is dominated by the bulk of the specimen, while that of RBC materials is highly influenced by the material near the surface. We included UR specimens in this study under the assumption that they would be the main source of absorbing colors. That assumption remains valid, and the influence of the bulk material on the measurement of color cannot be ignored.

Resin-rich layer. Many articles have discussed the presence of a resin-rich layer, but they do not indicate the actual thickness of the layer. A study of the surface layer by electron spectroscopy for chemical analysis; scanning electron microscopy, or SEM; and X-ray diffractometry showed that the resin content began to signal a significant decrease at a depth of 1.2 μm , and the thickness of the surface layer according to SEM micrographs was about 5 μm .³⁰

Assuming that all specimens took in the same amount of staining agent with respect to the immersion solution used, the longer light pathway within the UR material would reduce the effect of the stain on the colorimeter reading, while the shorter pathway within the RBC material could enhance the effect on color changes. Therefore, the resin-rich layer of RBC specimens with any of the three surface-finishing treatments exhibited greater color changes than did the polyester film-finished UR specimens in most cases. Therefore, we accepted the second hypothesis that the resin component of the material is most vulnerable to staining.

Finishing with 1- μm aluminum oxide and 15- μm diamond plate should remove the surface layer that was responsible for the large color change in specimens finished with a polyester film strip. One should expect specimens finished with 15- μm diamond plate to exhibit medium color changes (because of the larger particle size), while specimens finished with aluminum oxide should exhibit the least amount of color changes. This expectation was confirmed by the experimental data, with the exception of the UR specimens immersed in coffee and cola solutions (Figure).

Red wine. In our study, red wine produced the most consistent results with all surface-finishing techniques. We selected a cabernet sauvignon, which is a dark burgundy color and is 12 percent alcohol by volume. Several studies have reported that alcohol facilitates staining by softening the resin matrix.^{1,15,16,32} Apparently, the quantity of alcohol in the wine played a significant role in the staining of the polyester film-finished surface of the specimens. We should point out that long-term immersion in staining solution is used as a substitute for the cumulative effect of a staining solution.

Coffee. The effect of the coffee solution on the color change was similar to that of the red wine, except for polyester film-finished UR specimens. It is not clear why immersion in the coffee solution resulted in almost no effect on the polyester film finish of UR specimens ($\Delta E = 0.6$). The complexity of coffee chemistry may have played a

role in this deviation.

Cola. The color changes induced by the cola solution were independent of the surface finish (Figure), and the three UR groups exhibited greater changes than did the RBC groups. Cola gains its color through the addition of caramel color; red wine and coffee acquire their colors mainly from the grapes used and the coffee-bean roasting process. Caramel exhibits colors ranging from palest yellow to deepest brown and is made by heating sugar or glucose in the presence of alkali or mineral acid.³³ The negative b^* values for the UR specimens immersed in the cola solution indicate that the specimens may have become more translucent. Therefore, we accepted the third hypothesis that staining depends on the type of storage solution.

Lower pH has been shown to negatively affect wear resistance of RBC materials.³⁴ The sensitivity of water absorption and solubility behavior of RBC materials as influenced by time and pH seem to be closely related to the hydrophilicity of the resin matrix.^{35,36} However, we did not examine any effect of pH on color change in this study.

Color change perceptibility. The clinical relevance of our study results depends on how much color change (represented by ΔE values) is considered perceptible. Kuehni and Marcus³⁷ reported that a $\Delta E < 1$ was not considered perceptible to most subjects with normal color vision.

In this study, red wine produced the most consistent results with all surface-finishing techniques.

Two other studies showed that some observers did not believe that restorations with a ΔE as high as 3.3 and 3.7 required replacement, although the color differences definitely were perceptible.^{38,39} Considering that color acuity can vary considerably among people,³⁹⁻⁴³ the latter results probably would represent the color perception reality of the general population, for whom the color difference probably would be visually detected, but it also may be clinically acceptable.⁴⁴



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CONCLUSIONS

This *in vitro* study showed that finishing treatments and storage solutions significantly affect the surface staining of resin-based dental materials. The polyester film finish produced the greatest color change (ΔE) in RBC and UR materials immersed in a red wine solution for seven days. Both coffee and cola solutions caused statistically significant color changes after seven days of immersion. Although the degree of change may be perceptible to the human eye, the restorations might be considered clinically acceptable if one adopts the conclusion that there is no need for replacement when ΔE is less than 3.3.³⁸

Even though UR has more resin matrix present than does RBC, UR specimens generally exhibited smaller color changes than did RBC specimens, with the exception of specimens immersed in cola solution. This deviation also demonstrated the critical role of the composition of the staining solution on the color changes.

When placing Class III and Class IV restorations, clinicians still need to use a polyester film strip for proper interproximal contact. However, the clinician must remove the resin-rich surface layer by polishing it with interproximal strips for better color maintenance of these restorations. ■

The authors thank 3M ESPE, St. Paul, Minn., for donating the unfilled resin and resin-based composite materials used in this study.

The authors thank the Center for Dental Biomaterials at the University of Florida, College of Dentistry, Gainesville, for their contribution to the study.

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