Effect of Bleaching and Repolishing Procedures on Coffee and Tea Stain Removal from Three Anterior Composite Veneering Materials

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ABSTRACT

Discolored teeth can be treated with resin veneers, but their color changes when confronted with staining solutions. Polishing procedures can provide a remedy for highly stained composites, but they tend to remove some materials as well. However, bleaching procedures are an effective, nondestructive method for solving the problem. The aim of this study was to compare the color change of three veneer composites exposed to staining solutions and to evaluate the effectiveness of a 15% hydrogen peroxide bleaching agent and three polishing systems to remove the stain.

Forty-five disks (12 × 2 mm) each of Clearfil ST® (Kuraray Co. Ltd., Osaka, Japan), Esthet-X™ (Dentsply/Caulk, Milford DE, USA), and Filtek A110™ (3M ESPE, St. Paul, MN, USA) were prepared. The specimens were polished with Sof-Lex™ (3M ESPE), Enhance® (Dentsply/Caulk), or PoGo® (Dentsply/Caulk). Five specimens for each material–polishing system combination were immersed in coffee (Nescafe® Classic, Nestle SA, Vevey, Switzerland) or tea (Earl Grey, Lipton, Blackfriars-London, England) for 7 days. The remaining disks were stored in water. Color measurements were made with a spectrophotometer (X-Rite® Seroice SP78, Loaner, Köln, Germany) at baseline; after 1, 3, 5, and 7 days; and after bleaching and repolishing. After 1 week, one side of the specimens was bleached with Illuminé-office® (Dentsply De Trey GmbH, Konstanz, Germany) for 1 hour, and the other side was repolished for 30 seconds. All comparisons of color change for the polishing systems, times, and staining solutions were subjected to repeated measurements of analysis of variance. Paired *t*-test was used to examine whether significant color differences (ΔE^*) occurred during immersion at the specified time intervals ($p \leq .05$).

Filtek A110 was the least stained resin composite. Its color remained under a ΔE^* value of 2 during the study. Clearfil ST exhibited the most color change after 1 week. All specimens polished with Enhance showed less staining, whereas those polished with the Sof-Lex system demonstrated the most color change. Water did not cause a variance in the ΔE^*. There was no difference in the staining potential of coffee and tea. Bleaching and repolishing were effective in removing the stains. The resin composites tested reversed nearly to baseline color with the bleaching and to less than values at 1 day of staining with repolishing.

The coffee and tea brands tested stained the composites used in this study equally. In-office bleaching was found to be more effective than repolishing in the restitution of the color.

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CLINICAL SIGNIFICANCE

The results of this study suggest that the discoloration of resin veneers can be partially removed by in-office bleaching and repolishing procedures.

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Patients often seek solutions for esthetic problems such as discolored teeth. Methods including porcelain veneers and ceramic crowns have been developed to treat discolored teeth. However, these treatments are costly, and resin composite veneers remain the treatment of choice in most cases for unacceptable color match in the anterior region.[1] The major disadvantage of these resin-veneering materials is their color instability.

Three types of resin composite discolorations have been described[2,3]: (1) external discolorations owing to the accumulation of plaque and surface stains; (2) surface or subsurface color alterations, implying a superficial degradation or a slight penetration and reaction of staining agents within the superficial layer of resin composites (adsorption); and (3) body or intrinsic discolorations owing to physicochemical reactions in the deeper portions of the restoration. External and surface discolorations are closely related to hygiene, diet, and smoking habits.[4] Numerous studies have demonstrated the coloring effect of staining solutions, especially coffee and tea (Table 1). Spectrophotometry and colorimetry, applied in both in vitro and in vivo, have made it possible to study the numerous parameters related to resin composite color stability.[5–9]

The structure of the resin composite and the characteristics of the particles have direct impact on the surface smoothness and the susceptibility to extrinsic staining.[3,10–12] Besides the composition of the materials, the finishing and polishing procedures may also influence the composite surface quality and can therefore be related to the early discoloration of the resin composites.[12,13] The roughening of the surface caused by wear and chemical degradation may also affect gloss and consequently increase the extrinsic staining.[14]

Once staining has occurred, brushing with toothpaste, repolishing, and bleaching procedures can remove the stains partially or even totally. Polishing procedures can remedy highly stained composites, but they remove material from the composite surface. Modern dentifrices advertised as "whitening" preparations are attractive, but their abrasive particles might detrimentally affect the composites. Therefore, bleaching procedures appear to be a nondestructive method of solving the problem. There are many studies indicating that polishing procedures remove surface discolorations, but there are few reports of how bleaching agents affect resin composite restorations that have been stained. In-office and night guard vital bleaching are widely used because of their conservative approaches. Modern bleaching agents used for tooth discolorations contain hydrogen peroxide or carbamide peroxide (an adduct of hydrogen peroxide and urea) as active ingredients.[15–22] These peroxides penetrate the dental hard tissues and oxygenate both the dye substances (chromophores) adsorbed to the enamel surface and those in the enamel and dentin tissues. In the process of bleaching, the peroxides attack unsaturated double bonds of the chromophores, which results in colorless oxygenated molecules and particles. The chromophores lose their coloring capacity, and the natural white tooth color is restored.[16–18]

In-office and night guard vital bleaching are widely used because of their effectiveness in removing tooth discolorations. Numerous studies have shown bleaching to be effective in whitening certain

TABLE 1. SOME KEY STUDIES OF STAINING OF RESIN COMPOSITES.

Study	Materials Tested	Staining Solutions	Results
Crispin and Caputo, 1979[29]	8 resin composites	Coffee, tea, grape solution	The tea and coffee solutions caused greatest darkening than did the grape solution.
Chan et al, 1980[30]	2 resin composites	Coffee, tea, cola, soy sauce, distilled water	The staining intensity of coffee and soy sauce was greater than that of tea and cola.
Khokhar et al, 1991[35]	4 indirect resin composites	Chlorhexidine, coffee, tea (with or without saliva)	Tea stained more than did coffee. The addition of chlorhexidine and saliva increased the staining of tea.
Dietschi et al, 1994[28]	10 resin composites	Coffee, E110 food dye, vinegar, erythrosine	Erythrosine and coffee produced the most intense discolorations. Staining owing to E110 was minimal.
Yannikakis et al, 1998[27]	6 provisional resins	Coffee and tea	Coffee solution resulted in unacceptable discoloration for all materials.
Fay et al, 1999[31]	3 tooth-colored restorative materials	Juice, tea, chlorhexidine, water	The color changes caused by chlorhexidine and water was imperceptible. Juice and tea stained perceptibly in all 3 materials.

types of discolored teeth, but there has been no consensus on the effect of peroxide bleaches on resin composite restorative materials.[15–21] Friend and colleagues demonstrated a slight change in color when a microfilled resin composite was exposed to 10% carbamide peroxide for 45 days.[15] Cullen and colleagues investigated the effect of peroxide bleaches on the tensile strength and color of resin composites.[18] They found a dramatic color change with microfilled composites immersed in 30% hydrogen peroxide for 1 week and concluded that it was the result of an increase in value of opacity of the specimens.

Hunsaker and colleagues investigated the effect of seven brands of bleaching gels on dentin, enamel, and restorative materials.[19] Upon observation with a scanning electron microscope, they found no major changes in tooth structure or restoratives. In a follow-up study, Monaghan and colleagues found no differences in resin composite color after exposure to carbamide peroxide with water as the control.[21]

The stain resistance of a restorative material in the oral environment is important because one wants the restoration to retain its natural appearance with surrounding tooth structure over its life span. Resistance to staining effects caused by staining media such as coffee, tea, and juice are measured with a spectrophotometer and are expressed in ΔE^* units, with the lower values indicating less staining. The value of ΔE^* represents relative color changes that an observer might report for the materials after treatment or between time periods. However, there is some confusion about the acceptable ΔE^* value. The human eye can usually not detect ΔE^* values of < 1.5, although this value is measurable using a color spectrophotometer. Upon direct viewing of a sample, a person trained in color recognition may be able to detect a ΔE^* value of 1.5 to 2.5 units, whereas a person with average color-matching ability can recognize a shift in ΔE^* of 2.5 to 3.5 units.[23,24]

Kuehni and Marcus and Seghi and colleagues reported that a ΔE^*

value equal to 1 was considered visually detectable 50% of the time with a spectrophotometer, whereas a ΔE* value > 2 is detectable 100% of the time.[23,24] The literature indicates that with visual inspection, there is another threshold regarding color stability of the materials. This threshold is considered to be at higher levels of ΔE* and justifies the clinical acceptability of stained materials.

Johnston and Kao evaluated the assessment of appearance match by visual observation and clinical colorimetry and stated that the average color difference between compared teeth noted as a match in the oral environment was 3.7 (ΔE*).[25] Seghi and colleagues also presumed that an acceptable color difference could often be two or three times greater than the detectable limits.[24] The upper limit of acceptability in subjective visual evaluations has been confirmed by Ruyter, Um, and colleagues, who suggested that color difference is acceptable up to the value ΔE* = 3.3.[7,9] The alpha rating according to the United States Public Health Service (USPHS) clinical evaluation system proved to correspond to ΔE* values ranging between 2.2 and 4.4.[25] In accordance with all these results, in our study discoloration below or above the value ΔE* = 3 is referred to as acceptable or unacceptable, respectively.

The aim of this study was to compare the color change of three veneering resin composites when exposed to staining solutions, and to evaluate the effectiveness of a 15% hydrogen peroxide bleaching agent and three different polishing systems to remove stains.

MATERIALS AND METHODS

Specimens of three composites were fabricated, polished with one of three different systems, and then stained in coffee or tea. Using spectrophotometry, the degree of reversible surface staining was measured as ΔE* to compare bleaching versus polishing effects. The materials tested were Clearfil ST® (Kuraray Co. Ltd., Osaka, Japan), Esthet-X™ (Dentsply/Caulk, Milford, DE, USA), and Filtek A110™ (3M ESPE Dental Products, St. Paul, MN, USA), as described in Table 2. For Esthet-X and Filtek A110, the universal shade or A3 of the Vitapan® shade guide (Vita Zahnfabrik, Bad Säckingen, Germany) was selected, and for Clearfil ST, the universal light shade was selected.

One hundred thirty-five specimens (45 of each resin composite) were prepared. The specimens (12 × 2 mm disks) were made by condensing the resin composite in a polytetrafluoroethylene ring between glass slides and Mylar® (DuPont, Wilmington, DE, USA) strips and curing them on each side for 40 seconds with a light-curing unit (The Max®, Dentsply/Caulk), which had been tested for 450 mW/cm^2 output with a light meter (Curing Radiometer®, Demetron/Kerr, Danbury, CT, USA). The resin composite disks were placed in plexiglass holders (12 × 2 mm) and were roughened with silicone carbide paper (1,200 grit) and then polished dry, as recommended by the manufacturers of the three systems used: Sof-Lex™ disks (3M ESPE Dental Products), Enhance® polishing system with fine and superfine polishing pastes (Dentsply/Caulk), and PoGo® one-step microdiamond polisher (Dentsply/Caulk), as described in Table 2. Every disk was polished by the same handpiece at a low speed. For the Sof-Lex system, the medium, fine, and ultrafine disks were each used for 30 seconds. The aluminum oxide disk of the Enhance system was used for 30 seconds, and each paste was applied for another 30 seconds. The one-step polisher, PoGo, was used for only 30 seconds. For every resin composite, 15 specimen–polishing system combinations were randomly selected. The specimens were then incubated in 100% humidity at 37°C for 24 hours before baseline measurements were taken.

Five randomly selected specimens for each material and polishing system were immersed in staining solutions of coffee (Nescafe® Classic, Nestle SA, Vevey, Switzerland) or tea (Earl Grey, Lipton, Blackfriars-London, England) for 7 days. The coffee and tea brands chosen are among widely used products in the European market. They were obtained from a general department store and

TABLE 2. COMPOSITION, MANUFACTURERS, AND LOT NUMBERS OF RESIN COMPOSITES AND POLISHING SYSTEMS USED.

	Composition*	Manufacturers	Lot No.
Resin composite			
Clearfil ST	Colloidal silica, borosilicate glass, BIS-GMA, TEGDMA	Kuraray Co. Ltd.	00019A
Filtek A110	Colloidal silica, BIS-GMA, TEGDMA	3M ESPE	2BP
Esthet-X	Barium fluoroaluminoborosilicate glass, BIS-GMA, TEGDMA, UDMA	Dentsply/Caulk	001206
Polishing System			
Sof-Lex	Coarse (55 μm), medium (40 μm), fine (24 μm), and ultrafine (8 μm) aluminum oxide disks	3M ESPE	P020403
Enhance	Aluminum oxide disk (40 μm), fine (1 μm) and extrafine aluminum oxide paste (0.3 μm)	Dentsply/Caulk	001228 001031
PoGo	Microdiamond-coated disk	Dentsply/Caulk	020409

BIS-GMA = dimethacrylate; TEGDMA = tetraethyleneglycoldimethacrylate; UDMA = urethane dimethacrylate.
*Information was taken from the technical manuals of the products.

prepared fresh daily with hot tap water. Fifteen grams of coffee were poured into 500 mL of hot water and filtered after 10 minutes, prior to being poured into the containers. Five tea bags were dipped in 500 mL of hot water for 10 minutes and were filtered before being poured into the containers. The remaining specimens from each composite served as controls and were stored in distilled water during the study period (pH = 6.65). The initial pH values of the solutions were 5.99 for the coffee and 6.34 for the tea (WTW GmbH Inolab® pH meter, Sen Tix® 41 electrode, WTW GmbH, Weilheim, Germany). The specimens were kept in the dark, immersed in 20 cc of the staining solutions in groups of five in covered glass containers at 37°C ± 1°C for 7 days. The solutions were not agitated, and the disks were placed vertically in plastic holders with holes of 12 × 4mm and were suspended in the solutions. At the end of 1 week, one side of the samples immersed into the staining solutions was bleached with Illuminé-office® (Dentsply De Trey GmbH, Konstanz, Germany) for 1 hour, and the other side was repolished for 30 seconds with the polishing system used earlier. Color measurements were made after these procedures to visualize if the original color could be restituted.

The Illuminé-office (marketed as Illuminé in the United States) bleaching system is an innovative whitening system introduced into the European market in late 2001 and that sets, according to its manufacturer, new standards in bleaching therapy. A unique combination of 30% hydrogen peroxide and a gelating powder (containing sodium/calcium salts of polymethyl vinyl ether/maleic anhydride, which is a copolymer) is contained in a coupled syringe set. The mixed material for application comprises 15% active hydrogen peroxide and is semisolid. According to Kihn and colleagues, within only 30 to 60 minutes, whitening of six to nine shades can be achieved without any heat, light, or gingival isolation in clinical use.[26] We chose this material because it has a semisolid consistency that helps in the application procedure, and because the bleaching could be performed quickly in comparison with other bleaching systems. The results indicated that after a 1-hour application, the ΔE* values had returned nearly to their baseline values.[26]

Color measurements were made just before immersion (baseline) and after 1 day (T1), 3 days (T2), 5 days (T3), 7 days (T4), bleaching procedures (T5), and polishing (T6). Before each measurement, the specimens were cleaned ultrasonically (Ultrasonic cleaner ME 4.6®, Mettler Electronics Corp., Anaheim, CA, USA) in distilled water for 1 minute and dried with air spray.[26]

The color and the color difference of each specimen were measured by a spectrophotometer (Seroice Loaner, SP78, X-Rite®, GmbH, Köln, Germany). The testing apparatus had a measuring head aperture diameter of 12 mm. The measuring characteristics of the spectrophotometer were standard illuminant D65, illuminating/viewing geometry d/8°, and standard observer 10°. Before each measurement session, the colorimeter was calibrated according to the manufacturer's recommendations by using the supplied white and dark calibration standard. The disks were mounted at 90° relative to the light source. Color measurements were made under daylight conditions, in air, and at the same time of day.

Values were recorded in the Commission Internationale de l'Eclairage (CIE) CIELAB color system relative to CIE standard illuminant A (incandescent light) against a white background on a reflection spectrophotometer. The CIELAB system is an approximately uniform color space with coordinates for lightness, namely, white/black (L*), red/green (a*), and yellow/blue (b*). L*, a*, and b* values of each specimen before immersion (baseline) and after all procedures were measured six times by placing each specimen on the measuring head. The values of ΔL*, Δa*, and Δb* after six measurements were automatically calculated by the colorimeter and were recorded. Thus, ΔE* was more meaningful than were the individual L*, a*, and b* values. Resistance to staining effects is expressed in ΔE* units and was calculated from the mean ΔL*, Δa*, and Δb* values for each specimen with the following formula:

$$\Delta E* = [(L_0^* - L_1^*)^2 + (a_0^* - a_1^*)^2 + (b_0^* - b_1^*)^2]^{\frac{1}{2}}$$

The color changes (ΔE*) observed between the different resin composites, the various polishing systems, and the staining media during the study were subjected to analysis of variance (ANOVA). Possible differences among products or experimental conditions, as well as products by experimental condition interactions, were explored by a post hoc test using a Bonferroni correction. For all resin composites tested, the comparison of the colors (ΔE*) of disks subjected to various polishing systems and different solutions was analyzed with paired *t*-test with a p value set at .05. The ΔE* value was set at 3 for all possible combinations and permutations.

RESULTS

The specimens stored in water did not exhibited significant variance in the ΔE* value during the 7-day period ($p \geq .05$). There was no difference in the staining potential of coffee and tea solutions ($p \geq .05$). After being immersed in either coffee or tea, all the products became darker, redder, and more yellow.

The mean ΔE* values and ANOVA test results at the end of the staining period for the three resin composites, polishing systems, and staining solutions are shown in Table 3. All the combinations and permutations of comparisons that were made with the paired *t*-test for individual resin composite groups are listed in Tables 4 to 6.

Filtek A110 was found to be the most color-stable resin composite. This material's color remained under a ΔE* value of 2 during the test period. Clearfil ST exhibited the greatest color change ($p = .05$). All specimens polished with the Enhance system and the polishing pastes showed the least amount of staining, whereas those polished with the Sof-Lex system

TABLE 3. COMPARISON BETWEEN MATERIALS, POLISHING SYSTEMS, AND STAINING SOLUTIONS.*

Resin Composite	Resin Composites Compared	Mean Difference	p Value†
Clearfil ST	Esthet-X	0.40	.00
	Filtek A110	0.66	.00
Esthet-X	Clearfil ST	−0.40	.00
	Filtek A110	0.26	.00
Filtek A110	Clearfil ST	−0.66	.00
	Esthet-X	−0.26	.00
Polishing System	**Polishing Systems Compared**	**Mean Difference**	**p Value†**
PoGo	Sof-Lex	−0.20	.00
	Enhance	0.17	.00
Sof-Lex	PoGo	0.20	.00
	Enhance	0.38	.00
Enhance	PoGo	−0.17	.00
	Sof-Lex	−0.38	.00

*With analysis of variance and Bonferroni correction ($p < .05$).
†The mean difference is significant at the .05 level.

demonstrated the greatest color change (see Tables 3–6) ($p \leq .05$).

The mean ΔE* values for Clearfil ST, Esthet-X, and Filtek A110 and for all three polishing systems were statistically different ($p \leq .05$). ΔE* values for the resin composites were < 2.1 and were < 2 for the polishing systems tested. Figures 1 and 2 show the color difference of the materials exposed to staining solutions, bleaching, and repolishing.

After staining of the resin composites, both the bleaching and the repolishing treatments were able to reduce the color change ($p \leq .05$).

TABLE 4. RESULTS OF PAIRED *t*-TEST ACCORDING TO MATERIALS, PERIODS, POLISHING SYSTEMS, AND STAINING SOLUTIONS FOR CLEARFIL ST ($n = 5$).

Stage	With Sof-Lex Mean (SD)	[p Value]	Stage	With Enhance Mean (SD)	[p Value]	Stage	With PoGo Mean (SD)	[p Value]
	Coffee			Coffee			Coffee	
0–Day 1	2.48* (0.06)	[.00*]	0–Day 1	2.57 (0.55)	[.16]	0–Day 1	2.72* (0.12)	[.00*]
0–Day 3	0.59* (0.24)	[.00*]	0–Day 3	1.36* (0.08)	[.00*]	0–Day 3	2.26* (0.09)	[.00*]
0–Day 5	2.50* (0.07)	[.00*]	0–Day 5	2.47 (0.53)	[.09]	0–Day 5	2.94 (0.12)	[.40]
0–Day 7	1.75* (0.06)	[.00*]	0–Day 7	1.53* (0.51)	[.00*]	0–Day 7	2.59* (0.08)	[.00*]
0–Repolish	2.20* (0.07)	[.00*]	0–Repolish	1.53* (0.43)	[.00*]	0–Repolish	2.04* (0.08)	[.00*]
0–Bleaching	1.58* (0.07)	[.00*]	0–Bleaching	1.25* (0.29)	[.00*]	0–Bleaching	1.80* (0.13)	[.00*]
	Tea			Tea			Tea	
0–Day 1	2.50 (0.41)	[.05]	0–Day 1	2.47* (0.17)	[.00*]	0–Day 1	3.11 (0.27)	[.39]
0–Day 3	1.41* (0.65)	[.00*]	0–Day 3	0.94* (0.25)	[.00*]	0–Day 3	1.46* (0.29)	[.00*]
0–Day 5	3.04 (0.40)	[.81]	0–Day 5	2.54* (0.12)	[.00*]	0–Day 5	2.47 (0.48)	[.07]
0–Day 7	2.85 (0.42)	[.49]	0–Day 7	2.24* (0.15)	[.00*]	0–Day 7	2.88 (0.18)	[.23]
0–Repolish	2.01* (0.51)	[.01*]	0–Repolish	2.25 (0.49)	[.05]	0–Repolish	2.61* (0.28)	[.04*]
0–Bleaching	2.11* (0.51)	[.01*]	0–Bleaching	1.93* (0.61)	[.00*]	0–Bleaching	2.11* (0.28)	[.00*]

*ΔE must be < 3 and significant (two-tailed) p values must be < .05, otherwise the color change is not significant.

TABLE 5. RESULTS OF PAIRED *t*-TEST ACCORDING TO MATERIALS, PERIODS, POLISHING SYSTEMS, AND STAINING SOLUTIONS FOR ESTHET-X (n = 5).

Stage	With Sof-Lex Mean (SD) [p Value]	Stage	With Enhance Mean (SD) [p Value]	Stage	With PoGo Mean (SD) [p Value]
	Coffee		Coffee		Coffee
0–Day 1	3.20 (0.53) [.43]	0–Day 1	1.82* (0.20) [.00*]	0–Day 1	3.03 (0.61) [.89]
0–Day 3	5.30 (0.83) [.00*]	0–Day 3	1.64* (0.20) [.00*]	0–Day 3	0.55* (0.21) [.00*]
0–Day 5	3.02 (0.21) [.78]	0–Day 5	2.23* (0.37) [.01*]	0–Day 5	1.75* (0.22) [.00*]
0–Day 7	2.96 (0.55) [.89]	0–Day 7	2.02* (0.18) [.00*]	0–Day 7	1.18* (0.13) [.00*]
0–Repolish	1.88* (0.12) [.00*]	0–Repolish	1.12* (0.19) [.00*]	0–Repolish	1.56* (0.13) [.00*]
0–Bleaching	2.54* (0.09) [.00*]	0–Bleaching	1.01* (0.22) [.00*]	0–Bleaching	0.56* (0.14) [.00*]
	Tea		Tea		Tea
0–Day 1	3.08 (0.60) [.75]	0–Day 1	2.36* (0.49) [.04*]	0–Day 1	2.92 (0.10) [.18]
0–Day 3	0.88* (0.44) [.00*]	0–Day 3	0.51* (0.19) [.00*]	0–Day 3	0.78* (0.13) [.00*]
0–Day 5	2.25* (0.37) [.01*]	0–Day 5	1.64* (0.12) [.00*]	0–Day 5	1.50* (0.14 [.00*]
0–Day 7	2.00* (0.14) [.00*]	0–Day 7	1.54* (0.18) [.00*]	0–Day 7	1.47* (0.14) [.00*]
0–Repolish	0.69* (0.12) [.00*]	0–Repolish	1.13* (0.21) [.00*]	0–Repolish	0.40* (0.08) [.00*]
0–Bleaching	0.67* (0.13) [.00*]	0–Bleaching	0.89* (0.09) [.00*]	0–Bleaching	0.42* (0.09) [.00*]

*ΔE must be < 3 and significant (two-tailed) p values must be < .05, otherwise the color change is not significant.

TABLE 6. RESULTS OF PAIRED *t*-TEST ACCORDING TO MATERIALS, PERIODS, POLISHING SYSTEMS, AND STAINING SOLUTIONS FOR FILTEK A110 (n = 5).

Stage	With Sof-Lex Mean (SD) [p Value]	Stage	With Enhance Mean (SD) [p Value]	Stage	With PoGo Mean (SD) [p Value]
	Coffee		Coffee		Coffee
0–Day 1	2.49* (0.20) [.00*]	0–Day 1	2.48* (0.23) [.00*]	0–Day 1	2.18* *(0.48) [.02*]
0–Day 3	1.36* (0.29) [.00*]	0–Day 3	0.46* (0.27) [.00*]	0–Day 3	0.55* *(0.29) [.00*]
0–Day 5	1.53* (0.14) [.00*]	0–Day 5	1.27* (0.28) [.00*]	0–Day 5	2.75 *(0.40) [.24]
0–Day 7	0.91* (0.11) [.00*]	0–Day 7	1.09* (0.40) [.00*]	0–Day 7	2.15* *(0.48) [.01*]
0–Repolish	0.75* (0.41) [.00*]	0–Repolish	1.49* (0.18) [.00*]	0–Repolish	1.39* *(0.17) [.00*]
0–Bleaching	0.39* (0.15) [.00*]	0–Bleaching	0.88* (0.08) [.00*]	0–Bleaching	0.80* *(0.16) [.00*]
	Tea		Tea		Tea
0–Day 1	2.68* *(0.20) [.02*]	0–Day 1	2.41* (0.17) [.00*]	0–Day 1	1.53* *(0.25) [.00*]
0–Day 3	1.19* *(0.33) [.00*]	0–Day 3	0.76* (0.15) [.00*]	0–Day 3	0.47* *(0.10) [.00*]
0–Day 5	2.13* *(0.37) [.00*]	0–Day 5	2.56* (0.23) [.01*]	0–Day 5	2.56* *(0.10) [.00*]
0–Day 7	1.55* *(0.19) [.00*]	0–Day 7	1.33* (0.18) [.00*]	0–Day 7	2.78* *(0.10) [.00*]
0–Repolish	1.62* *(0.25) [.00*]	0–Repolish	0.98* (0.21) [.00*]	0–Repolish	0.53* *(0.08) [.00*]
0–Bleaching	1.16* *(0.09) [.00*]	0–Bleaching	0.88* (0.23) [.00*]	0–Bleaching	1.11* *(0.10) [.00*]

*ΔE must be < 3 and significant *(two-tailed) p values must be < .05, otherwise the color change is not significant.

Figure 1. The color changes of Filtek A110, Esthet-X, and Clearfil ST (Cl. ST) observed after immersion in coffee for 1 week, after bleaching, and after repolishing.

All of the resin composites tested reverted to a color similar to that of baseline with the bleaching treatment and to a color less than the 1-day staining values for repolishing. However, repolishing with the same system decreased the ΔE^* value for the resin composites less than the bleaching did ($p \leq .05$). The bleaching procedure decreased the ΔE^* value to < 1 for Esthet-X and Filtek A110, whereas the Clearfil ST ΔE^* value remained at 1.8. Bleaching and repolishing with PoGo or Enhance system resulted in similar ΔE^* values (1.1 and 1.4, respectively) ($p \geq .05$).

Figure 2. The color changes of Filtek A110, Esthet-X, and Clearfil ST (Cl. ST)observed after immersion in tea for 1 week, after bleaching, and after repolishing.

DISCUSSION

There are several ways to remove superficial stains from resin composites: toothbrushing, repolishing, and bleaching. Of these, toothbrushing procedure is highly dependent on the dentifrice type and the pressure applied by the patient during brushing. Because of these factors, removal of discolorations with toothbrushing is a slower process. In our study we preferred to use more rapid methods, independent of the patient, to remove the stains. For this purpose, we used repolishing and in-office bleaching procedures and evaluated the color change of the resin composites with instrumental colorimetry.

After the disks had been immersed for 1 day, most color differences caused by the staining solutions were perceptible. After 1 week of immersion in coffee or tea, all materials exhibited color changes with no specific differences. Paired *t*-tests showed that as immersion time increased, color changes became more intense. These results were in agreement with those reported by Yannikakis and colleagues,[27] Dietschi and colleagues,[28] Crispin and Caputo,[29] Chan and colleagues,[30] and Fay and colleagues.[31]

After being polished with the same system used prior to staining, the resin composites showed a decrease in the ΔE^* to a level less than the color change after 1 day of staining. It was hypothesized that the stain on the composites was about

3 μm to 5 μm deep. Polishing was less effective than bleaching but still removed some of the stain. The discolorations observed in this study proved to involve stain adsorption and subsurface absorption (ie, some of the stain remained on the surface and some penetrated into the resin composite). In our opinion, resin composite restorations in clinical situations cannot be restored to their original color with polishing, probably because of the penetration of the staining substances. Dietschi and colleagues compared the color stability of 10 polished and 10 unpolished composites, including hybrid, microfine hybrid, and microfilled composites.[28] They found that polishing with Sof-Lex disks was effective in reducing the discoloration in most of the materials tested.

Monaghan and colleagues found that there were significant color changes in composite specimens after 37% phosphoric acid etching and bleaching with 30% hydrogen peroxide with infrared light for 30 minutes.[22] We found similar results in our study with 15% hydrogen peroxide bleaching.

The structure of the composite and characteristics of the particles have a direct impact on the surface smoothness and the susceptibility to extrinsic staining.[3,10–12] In addition, the finishing and polishing procedures may influence the composite surface quality and can therefore be related to the early discoloration of composites.[12] In our study the Enhance system, which includes an additional step involving polishing pastes, likely resulted in a surface less susceptible to staining because the polishing pastes created the smoothest surfaces on the composite disks.

It has been shown that most of the water sorption of the resin composites took place during the first week. Therefore, as stain absorption seems to be closely related to water sorption,[8,9,32,33] specimen discoloration tended to follow the evolution of water sorption. The higher staining susceptibility of microfilled composites could be attributed primarily to their relatively high resin content and the related water sorption values. However, it has also been demonstrated that the diffusion coefficients of water sorption in microfine composites are within the range reported for conventional resin composite filling materials,[32] suggesting that the difference in staining resistance between both types of materials was not due to the structure of the composite.

The nature of the resin may also account for some difference in staining potential. According to Lefebvre and Khokhar and colleagues, resin materials incorporating urethane dimethacrylate seemed to be more stain resistant than were resin materials using dimethacrylate as a matrix.[34,35] In our study the universal resin composite Esthet-X was the only material having urethane dimethacrylate in its composition. The color stability of this material was better than that of Clearfil ST but worse than that of Filtek A110.

Color differences of esthetic restorations presenting a $\Delta E^* > 1$ are visually perceptible and are considered acceptable up to a ΔE^* of 3.3.[9] The alpha rating meaning an excellent color match in the USPHS clinical evaluation system proved to correspond to ΔE^* values ranging between 2.2 and 4.4.[25] In our study none of the anterior resin composites tested exhibited a ΔE^* value over 3.2 with any of the polishing systems and staining solutions. Clearfil ST and Filtek A110 did not exhibit a ΔE^* value > 3 after the 1-week period of testing. This means that none of the resin composites tested will stain at an unacceptable level in clinical situations. However, this in vitro study did show that the color change of anterior restorations can be restituted to nearly original values with in-office bleaching, which is a nondestructive and quick procedure.

The results of this study suggest that to achieve long-lasting esthetics in resin composite restorations, special attention should be paid to obtaining an optimal resin polymerization and a perfect surface finish by polishing. However, further studies are needed to determine whether the color of the tested resin composites would be stable in long-term clinical situations. Furthermore, the staining potential of these materials with other beverages and the effects of different bleaching procedures should be tested.

CONCLUSIONS

Within the limitation of this experiment, the following conclusions can be drawn:

- Most of the staining observed on resin composites is superficial and can be removed partially by repolishing and bleaching procedures. However, residual staining, which may be cumulative over time, was recorded.
- Of the resin composites tested, Clearfil ST showed the most discoloration ($p \leq .05$) and Filtek A110 the least when exposed to the staining solutions for 1 week ($p \geq .05$).
- Bleaching with Illuminé-office has been found to be more effective than repolishing procedures in the restitution of original color ($p \leq .05$).

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COMMENTARY

EFFECT OF BLEACHING AND REPOLISHING PROCEDURES ON COFFEE AND TEA STAIN REMOVAL FROM THREE ANTERIOR COMPOSITE VENEERING MATERIALS

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The entire concept of this manuscript should stimulate a much closer look at what we really know about how esthetic restorative materials (such as composites) acquire stain. My first impression of this research project was that it was ill conceived, but I quickly changed my mind. The study begs answers to several important questions regarding esthetic changes and mechanisms of action beyond its initial testable hypothesis.

An interesting observation of many who have conducted bleaching trials of stained and discolored teeth always has been that there is a small reversion after the initial bleaching treatment.[1] Without real evidence for our interpretation, we have described the process of bleaching as affecting both acquired extrinsic and acquired intrinsic staining. For teeth, acquired extrinsic stain is relatively easy to remove and easily reforms—thus, the small reversion. Acquired intrinsic stain takes much longer to form and to remove. Other types of intrinsic staining such as tetracycline staining are deferred from the present discussion.

One can certainly apply these proposed explanations to composite restorative materials as well. Acquired extrinsic stain on composite should be a strong function of the surface finish of the material. Composites with small filler particles (microfiller) and ones that are smoothened with fine particle finishing systems will have far fewer or much smaller surface defects into which to accumulate surface stains. These trends seemed to permeate the results of this study. At the same time, composites also may permit diffusion of stains through the surface into shrinkage pores or microchannels that may exist within the restoration. The source of the staining materials (eg, coffee, tea, cola, cigarettes) should influence the extent of this effect. Importantly, the active components of tooth-whitening (bleaching) systems should be able to penetrate into the same channels and act on those stains. What the authors of this article propose is that bleaching as an alternative could be a far easier and less expensive management for discolored restorations than either replacement or veneering with new material. Little work has been conducted on understanding the time-dependent mechanisms of esthetic change over time, despite the elegance of much of the engineering that has gone into design of composite restorations.

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