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Effect of Tooth-Whitening Procedures on Stained Composite Resins

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Clinical Relevance

A composite resin stained by coffee or wine can be lightened to a clinically noticeable degree by some at-home tooth-whitening therapies.

SUMMARY

In this laboratory study, a composite resin was stained to a visibly discernible level using both coffee and red wine over 14 days (change was considered clinically noticeable and significant when $\Delta E_{ab}^* \geq 2.7$). Color change was measured at one, three, seven, and 14 days of staining. Although the nature of color change was different for the two staining solutions, the overall degree of staining (ΔE_{ab}^*) rendered by either coffee or wine at each time interval was not significantly different ($p \geq 0.05$). Four whitening protocols were applied to stained composites. Treatment included applications of distilled water (control), Crest Pro-Health [HD] toothpaste, Crest Whitestrips, Opalescence PF bleach (15%), and application of a fine pumice polishing (Preppies). HD toothpaste and Whitestrips were applied daily for 21 days, Opalescence was applied daily for 10 days, and polishing was applied once. Each of the whitening products, applied in a manner simulating at-home or in-office treatment, was effective in producing color improvements (lightening) over controls ($p < 0.05$), but none of the four treatments produced lightening that was significantly different from the other treatments ($p \geq 0.05$). A comparison of final composite color with that measured at baseline showed that Opalescence returned composite color to an acceptable level following exposure to both staining solutions ($\Delta E_{ab}^* < 2.7$), Whitestrips returned color close to baseline for wine-stained composites, and HD paste and polishing permitted residual stain to remain ($\Delta E_{ab}^* \geq 2.7$).

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INTRODUCTION

Various studies have described the value of an attractive smile and the positive psychological impact of teeth that are intact, properly aligned, and not discolored. The influence of dentition on positive perceptions of social attractiveness (friendliness, social class, popularity, and intelligence)[1] and overall social competence, intellectual achievement, and psychologic adjustment[2] have been reported.

One study found that job applicants with ideal dental esthetics were thought to be intellectually superior to other applicants and more likely to be hired.[3] A survey of nearly 15,000 US adults regarding the importance and value of good oral health found that low-income adults were nearly twice as likely as high-income adults to believe that their teeth affected their ability to successfully interview for a job.[4] In that same study, 25% of the respondents said they avoid smiling because of the condition of their mouth or teeth.

One of the most common concerns regarding dental appearance is tooth color. Surveys have found that approximately 25% to 55% of adults are dissatisfied with their tooth color.[5-7] Since first described in the literature in 1989, vital tooth whitening (bleaching) has become a common and popular procedure worldwide for improving tooth color.[8]

Over many years, studies have been conducted to measure staining of composite resins by multiple beverages or condiments, such as fruit juices, tea, coffee, soy sauce, and cola.[9-20] Among those studies, coffee and red wine are two commonly consumed beverages that have been shown to cause significant composite resin staining. A recent study found that red wine and coffee were the only two of six beverages tested that caused clinically visible color changes of all three categories of direct esthetic restorations tested: nanocomposites, giomers, and resin-modified glass ionomers.[21]

A 2015 survey found that 64% of US adults drank at least one cup of coffee per day.[22] Worldwide, per capita coffee consumption is led primarily by Europeans, in particular Northern Europeans. The Netherlands leads the world in per capita coffee consumption at 2.4 cups per day.[23]

Wine consumption varies greatly throughout the world, but overall, nearly 25 billion liters were consumed in 2014. The United States, France, Italy, and Germany together accounted for more than 40% of that wine consumption.[24] Given these figures for consumption of staining beverages, as well as the aforementioned concerns about tooth color, dental patients are naturally interested in finding ways to regain optimum tooth and restoration colors when beverage consumption causes discoloration.

Previous laboratory studies have been conducted to determine the lightening effects of both home-applied and office-applied tooth-bleaching products and polishing procedures on stained composite resins. Fay and others[25] found that a home bleaching product reduced stain from composite resin with or without the product's active ingredient. Villalta and others[26] also determined that bleaching improved the color of red wine– and coffee-stained composite resin to a level that was not clinically perceptible from baseline (prestain) color; however, they noted a weakness in their study was lack of a negative control group to confirm that the improvement was not a spurious result.

Studies comparing the effects of polishing to bleaching stained composite resins have had mixed results. Garoushi and others[27] found that repolishing was more effective than an in-office bleaching product (40% hydrogen peroxide bleaching gel) for improving color. In contrast, Türkün and Türkün[28] determined that another in-office bleaching product was more effective than simulated office polishing.

The purposes of this laboratory study were 1) to confirm and measure the staining of a composite resin by coffee and red wine and then 2) to determine the degree of lightening that could be regained by using contemporary self-applied at-home whitening products and an in-office polishing technique.

METHODS AND MATERIALS

A microhybrid composite resin, three staining materials, and four whitening/polishing materials were selected for this study. Details about the materials used including manufacturers or producers are listed in Table 1.

Specimen Preparation

Seventy-five composite resin specimens (13-mm diameter × 2-mm-thick discs) were fabricated using Amelogen Plus composite resin, shade A1. A split-mold Teflon (Chemours, Wilmington, DE, USA) well with 2-mm-deep holes was used to make the specimens.

Each specimen well was filled with composite resin to a depth of 1 mm, then light cured for a total of 60 seconds (light tip held in three overlapping positions for 20 seconds to cover the entire 13-mm surface). After a second increment of composite resin was placed, it was covered with a glass microscope slide and light cured for another 60 seconds in the

Table 1: *Materials Used*

Product	Code	Composition/Type	Manufacturer/Producer	Lot No.
Composite resin				
Amelogen Plus	AP	Microhybrid	Ultradent, South Jordan, UT, USA	BBLK2
Staining materials				
Distilled water	DW (negative staining control)			
Red wine	RW	Yellow Tail Cabernet	Casella Wines, Yenda, Australia 2014	
13.5% alc/vol	Sauvignon			
Coffee	CO	Pike Place Roast	Starbucks, Seattle, WA, USA	2016
Whitening and polishing materials				
Distilled water	DW (negative whitening control)			
Toothpaste	TP	Crest Pro-Health [HD]	Proctor & Gamble Cincinnati, OH, USA	4272M108
Whitestrips	WS	Supreme Professional	Proctor & Gamble Cincinnati, OH, USA	(L)5132U44
Whitening gel	BL	Opalescence PF (15%)	Ultradent, South Jordan, UT, USA	BB2QP
Pumice polish	PP	Preppies	Whip Mix, Louisville, KY, USA	5026

same manner as the prior step. A standard power VALO LED curing light (V23689, Ultradent, South Jordan, UT, USA) was used for polymerization of all specimens, and tested for output strength at the beginning and after 25 and 50 specimens were fabricated. The output exceeded 600 mW/cm^2 at each testing period.

After fabrication, each composite resin disc was numbered (1-75) on the bottom surface with an indelible pen, and the upper surface was polished with Sof-Lex XT (3M ESPE Dental Supplies, St Paul, MN, USA) fine and superfine polishing discs, using a slow-speed handpiece. Specimens were stored in distilled water at room temperature (22±1°C) for one day prior to staining.

Staining Procedure

The specimens were randomly distributed into three groups of 25 that were placed in 100 mL of each test solution in a 250-mL covered plastic specimen jar. To allow the test solutions to maximize contact, specimens were placed on a perforated plastic platform, which was elevated 0.5 mm in each jar. One group was placed in red wine (Yellow Tail Cabernet Sauvignon, Casella Wines, Yenda, Australia) at room temperature, one in coffee (Starbucks Pike Place Roast, Seattle, WA, USA) at approximately 75°C initially and then allowed to cool to room temperature, and one in distilled water (negative control) at room temperature. The coffee solution was prepared using a standard drip coffee maker and paper filter, with a ratio of one tablespoon ground coffee per six fluid ounces of water. Each solution was replaced daily for 14 days. Upon conclusion of the staining procedures and final pretreatment color testing, the specimens were stored in distilled water for 24 hours prior to the application of color improvement treatments.

Color Testing

The color of each specimen was measured at baseline (prior to staining), 24 and 72 hours, seven and 14 days to determine the rate of color change. Prior to measurement, each specimen was rinsed for five seconds with distilled water and then blotted dry with a paper towel (Envision, Georgia-Pacific, Atlanta, GA, USA). Measurements were procured with a pulsed xenon arc light spectrophotometer (Konica Minolta CM-2002, Konica Minolta, Inc, Tokyo, Japan) against a white background using CIELAB color space relative to CIE standard illuminant D65. Since it was necessary to measure color at multiple time intervals on the same specimen, it was critical to measure color at the same location every time. A positioning jig was constructed with an alignment mark so that the specimen, which also held an alignment mark on its side, could be oriented beneath the port of the spectrophotometer in an identical position each time.

Color differences ΔL^*, Δa^*, and Δb^* caused by staining were determined by subtracting L^*,a^*,b^* values measured at baseline from those measured at one, three, seven, and 14 days. Color changes rendered by whitening protocols were calculated by subtracting color index values measured after 14 days of staining from those measured after administration of whitening regimens. Overall effectiveness of whitening protocols was assessed by subtracting baseline color index values from those measured after whitening. Total ΔE_{ab}^* color change was calculated at the same time intervals according to the expression $\Delta E_{ab}^* = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2}$, where L^* is lightness (–L*=black; +L*=white), a* is green-red (–a*=green; +a*=red), and b* is blue-yellow (–b*=blue; +b*=yellow).[29] Based on a recent study of ceramic staining, perceptible discoloration was considered clinically acceptable up to the value of ΔE_{ab}*=2.7 in subjective visual evaluations made *in vitro* under optimal lighting conditions.[30]

Whitening and Polishing Treatments

Materials tested for color improvement included 1) distilled water, 2) Crest Pro-Health [HD] toothpaste, 3) Crest Whitestrips, 4) Opalescence PF bleach (15%), and 5) application of a fine pumice polishing (Preppies). This produced a sample size of five for each group. The sample size was chosen based on a power analysis[31] of data obtained from previous color measurements. The analysis was powered to detect differences between groups of 2.0 ΔE_{ab} units with 80% power, 60 degrees of freedom (three staining groups × five treatment groups × n–1 or 4 test samples per group) at $\alpha = 0.05$ level of confidence.

Each treatment was delivered according to the manufacturer's instructions simulating normal clinical or at-home application, over a period of 21 days. All specimens were stored in distilled water at room temperature between treatment applications, and that distilled water was replaced daily. The Pro-Health toothpaste and Whitestrips treatments began on day 1 and were applied twice daily for 21 days, to mimic a typical pattern of brushing by patients and the manufacturer's recommended use for Whitestrips. The distilled water test group (negative control) was placed in fresh distilled water daily. Opalescence PF bleach was applied from days 12 to 21, and the pumice (Preppies) specimens were treated on day 21.

Following is the protocol for each treatment:

1. Distilled water (negative control): Replaced daily.
2. Crest Pro-Health toothpaste: After drying specimens (cotton gauze), specimens were brushed for five seconds with step 1 paste and five seconds with step 2 paste (wiped with cotton gauze but no rinse after step 1; rinsed with tap water after step 2) using an Oral B PRO 5000 electric toothbrush. Five seconds per specimen was chosen as the typical amount of time a patient would brush a stained surface. Following treatment, the specimens were rinsed with tap water and wiped dry before replacing in distilled water.
3. Whitestrips: After drying specimens, Whitestrips were applied for a total of 60 minutes daily. Each specimen received a Whitestrip for 30 minutes, and then that Whitestrip was replaced with another. The Whitestrips user instructions direct patients to use them twice daily for 30 minutes each. Following treatment, the specimens were rinsed with tap water and wiped dry before replacing in distilled water.
4. Opalescence PF bleach: Beginning on day 12, specimens were treated for seven hours daily. The timing protocol was chosen to mimic a 10-day regimen of overnight tray application applied at bedtime. The bleach was applied to the treatment surface of each specimen with a cotton-tip applicator. Following treatment, the specimens were rinsed with tap water and wiped dry before replacing in distilled water.
5. Preppies: On day 21, these specimens were polished with Preppie paste applied via a rubber cup on slow-speed handpiece for 10 seconds at moderate pressure. The 10-second application was based on the amount of time a typical dental hygienist would polish a severely stained surface. Following treatment, the specimens were rinsed with tap water and wiped dry before replacing in distilled water.

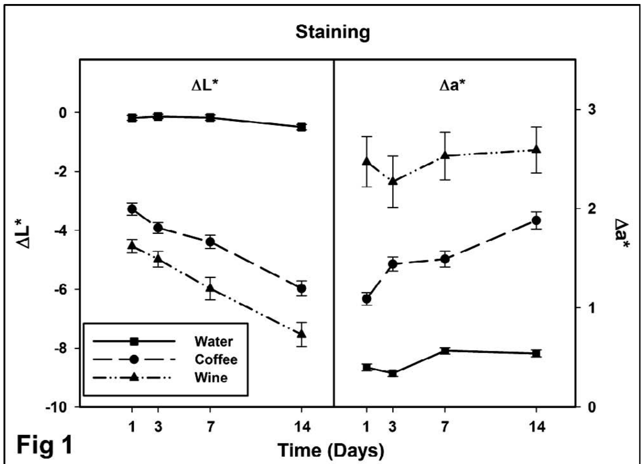
After 24 hours in distilled water, all specimens were measured for the final time using the spectrophotometer.

For statistical treatment of data, mean and standard error values were calculated for each group at each time interval for ΔL*, Δa*, Δb*, and ΔE_{ab}*. A repeated-measures one-factor generalized linear model (GLM) was employed to identify the presence of significant color changes caused by staining, and a two-factor GLM was used to assess color changes rendered by whitening protocols on stained composites ($p<0.05$). If significant differences were detected, a Tukey-Kramer post hoc pairwise comparison test was applied to assess differences between groups ($p<0.05$).[31]

RESULTS

A review of the data set revealed that for two wine-stained groups, one whitened with Crest HD paste and another with Opalescence, two samples in each group recorded unrealistically high ΔE_{ab}* values during staining. This suggested that errors in color measurement may have occurred, and a statistical test for outliers[31,32] applied to the data set resulted in removal of the data points. For the two groups, the sample sizes were reduced from five to three.

Color changes induced by staining protocols are presented in Figures 1 and 2. Both wine and coffee



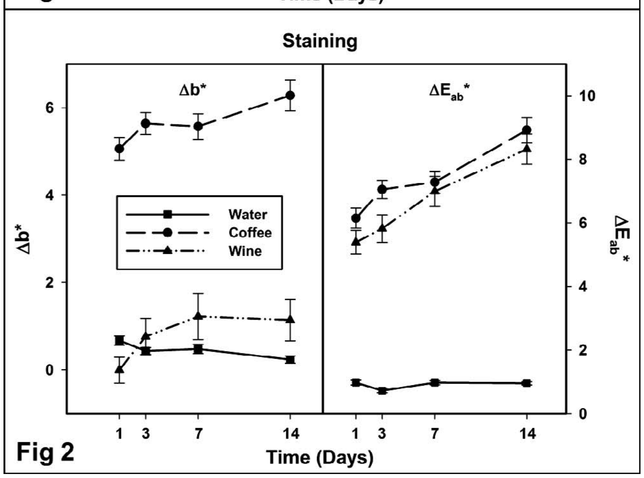


Figure 1. *Changes in ΔL* (left vertical axis) and Δa* (right vertical axis) color parameters after soaking in control and staining solutions over time. Error bars represent standard errors of means. Note differences in scale between left and right axes. For ΔL*and Δa*, all solutions are significantly different from each other at each time interval (*$p<0.05$*, GLM/Tukey).*

Figure 2. *Changes in Δb* (left vertical axis) and ΔE_{ab}* (right vertical axis) color parameters after soaking in control and staining solutions over time. Error bars represent standard errors of means. Note differences in scale between left and right axes. For Δb*, coffee is significantly different from water and wine at all time intervals (*$p<0.05$*, GLM/Tukey), whereas wine and water are not significantly different from each other at any time interval (*$p\geq0.05$*). For ΔE_{ab}*, coffee and wine are significantly different from water at each time interval (*$p<0.05$*) but not different from each other at any time interval (*$p\geq0.05$*).*

produced quasi-linear decreases in mean ΔL* values and increases in mean ΔE_{ab}* values over the 14-day period. The composite was darkened most by red wine, and continuous exposure to the beverage lowered the mean ΔL* value from −4.5 to −7.5 between days 1 and 14. Darkening by coffee was significantly less ($p<0.05$), as ΔL* values changed from −3.3 to −6.0 over the same time period. The nature of discoloration for the two staining solutions was different, as red wine significantly reddened the composites more than coffee ($2.3\leq\Delta a^*\leq2.6$ vs $1.1\leq\Delta a^*\leq1.9$, respectively), and coffee caused significantly greater yellowing than red wine ($5.1\leq\Delta b^*\leq6.3$ vs $0\leq\Delta b^*\leq1.2$, respectively, all $p<0.05$). Although the nature of color changes imparted by the two staining solutions was different, the calculated total color changes were similar, as their ΔE_{ab}* values were not significantly different at any time point ($p\geq0.05$). Control groups soaked in water underwent minimal color change at all time intervals, as mean ΔE_{ab}* values ranged from 0.7 to 1.0 units.

Tables 2, 3, and 4 show color parameter changes that were measured after the four whitening methods were applied to stained and control composites. For wine- and coffee-exposed composites (Tables 2 and 3), whitening procedures significantly changed color parameters over those measured for control groups ($p<0.05$). However, no significant differences were noted among the different whitening methods for any color parameter, regardless of storage media ($p\geq0.05$). Data presented in Tables 2 and 3 demonstrate that the effects from staining mostly were reversed, as the various whitening methods increased color value (ΔL* positive), reduced reddening caused by wine (Δa* negative), and lowered yellowing caused by coffee (Δb* negative). Interestingly, Crest HD Paste and Whitestrips increased yellowness in wine-stained composites by nearly 2.5 Δb* units (Table 2). For composites soaked in water, the four whitening methods did not significantly change any color parameter over those measured for the control group ($p\geq0.05$; Table 4).

To assess the overall color deviation from baseline after staining and whitening, ΔE_{ab}* values were calculated, and the results are shown in Figure 3. A horizontal line drawn at $\Delta E_{ab}^*=2.7$ identifies the 50%:50% threshold for maximum acceptable visual color change.[30] Although overall color changes delivered by the four whitening methods to stained composites were not statistically different from one another ($p\geq0.05$), only Opalescence was effective in returning composites to baseline color following exposure to both wine and coffee ($\Delta E_{ab}^*<2.7$). Whitestrips reduced the effects caused by wine staining to an acceptable level but left excess residual stain from coffee. Brushing with Crest HD paste and polishing with Preppies partially removed the two stains, but excess residual stain remained on composite surfaces ($\Delta E_{ab}^*>2.7$).

DISCUSSION

When composite discoloration renders an unsightly restoration, clinical intervention is required to either

Table 2: *Composite Color Changes Imparted by Whitening Treatments After Storage in Wine (Mean ± SE)†*

Whitening Treatment	ΔL*	Δa*	Δb*	ΔE_{ab}*
Water	−0.4 ± 0.31[a]	−2.5 ± 0.18[a]	1.0 ± 0.60[a]	3.0 ± 0.30[a]
HD Paste	4.8 ± 0.59[b]	−3.2 ± 0.39[a]	2.5 ± 0.34[a]	6.3 ± 0.48[b]
Opalescence	5.8 ± 0.15[b]	−3.4 ± 0.012[a]	0.4 ± 0.41[a]	6.7 ± 0.17[b]
Whitestrips	5.6 ± 0.49[b]	−3.3 ± 0.71[a]	2.4 ± 1.31[a]	7.2 ± 1.26[b]
Polish	5.8 ± 1.81[b]	−3.5 ± 0.86[a]	−1.2 ± 1.16[a]	7.4 ± 1.95[b]

† Groups with different superscript letters denote significant differences at the 0.05 probability level (GLM/Tukey). Comparisons are vertical only.

Table 3: *Composite Color Changes Imparted by Whitening Treatments After Storage in Coffee (Mean ± SE)†*

Whitening Treatment	ΔL*	Δa*	Δb*	ΔE_{ab}*
Water	−0.6 ± 0.11[a]	−0.6 ± 0.11[a]	−1.5 ± 0.23[a]	1.7 ± 0.26[a]
HD Paste	3.3 ± 0.38[b]	−1.8 ± 0.20[a]	−5.8 ± 0.52[b]	7.1 ± 0.42[b]
Opalescence	3.9 ± 0.46[b]	−1.8 ± 0.20[a]	−7.8 ± 0.80[b]	8.9 ± 0.86[b]
Whitestrips	2.9 ± 0.41[b]	−1.4 ± 0.16[a]	−4.8 ± 0.39[b]	5.8 ± 0.49[b]
Polish	2.9 ± 0.36[b]	−2.0 ± 0.22[a]	−7.2 ± 0.61[b]	8.0 ± 0.63[b]

† Groups with different superscript letters denote significant differences at the 0.05 probability level (GLM/Tukey). Comparisons are vertical only.

Table 4: *Composite Color Changes Imparted by Whitening Treatments After Storage in Water (Mean ± SE)†*

Whitening Treatment	ΔL*	Δa*	Δb*	ΔE_{ab}*
Water	−1.2 ± 0.15	−0.3 ± 0.14	−0.3 ± 0.40	1.6 ± 0.18
HD Paste	−0.3 ± 0.26	−0.7 ± 0.20	−0.9 ± 0.29	1.2 ± 0.39
Opalescence	0.1 ± 0.15	−0.4 ± 0.10	−1.4 ± 0.09	1.5 ± 0.08
Whitestrips	−0.2 ± 0.14	−0.4 ± 0.08	−1.5 ± 0.20	1.6 ± 0.21
Polish	−0.7 ± 0.14	−0.6 ± 0.06	−0.8 ± 0.16	1.3 ± 0.14

† No significant differences among whitening treatments for any color parameter ($p \geq 0.05$, GLM/Tukey).

counteract the discoloration or replace the restoration. Composite discoloration has been reported to occur at three levels: surface (or external), subsurface, and body (or intrinsic).[13] While accumulated food, beverages, and plaque typically serve as surface stains, subsurface stains are attributed to surface stains diffusing into superficial resin layers, with pigments attaching to and potentially reacting chemically with the composite. Intrinsic stain mostly is ascribed to physico-chemical reactions occurring deep within the composite. Stain chemistry, exposure time, composite composition and handling, and environmental conditions (eg, pH and temperature) contribute to the staining process.

Coffee and red wine were chosen as staining agents because of their propensity to stain esthetic restorative materials. Coffee stain originates from the roasting process, which thermally degrades monosaccharides into a brown caramel substance that reacts with chlorogenic acids to produce brown-black pigments. When brewed, the pigments become dispersed into acidic media (pH 4.5-6.5), either as water-soluble or colloidally dispersed compounds.[33] For this study, the primary result from coffee exposure was darkening and yellowing of the composite, which was observed as a lowering of ΔL* values and an increase of Δb* values continuously over the 14-day period (Figures 1 and 2). For red wine, its observed color is derived from the presence of multiple anthocyanins, which are based on the flavonoid molecule that contains one three-membered and two six-membered ring structures.[34,35] When deposited onto composite surfaces, the pigments cause the composite to redden, which in this study was observed as an increase in Δa* by 2.5 units after one day. Interestingly, Δa* did not remarkably change thereafter, with continued color change being mostly caused by composite darkening (negative ΔL*). Wine also demonstrates low pH (3.0-4.5), and its alcohol content ranges from 12 to 14 volume percent. Low pH enhances water diffusion, and alcohol plasticizes the resin matrix, which releases residual stresses caused by polymerization shrinkage and creates regions of microcracking that have been observed along filler-resin

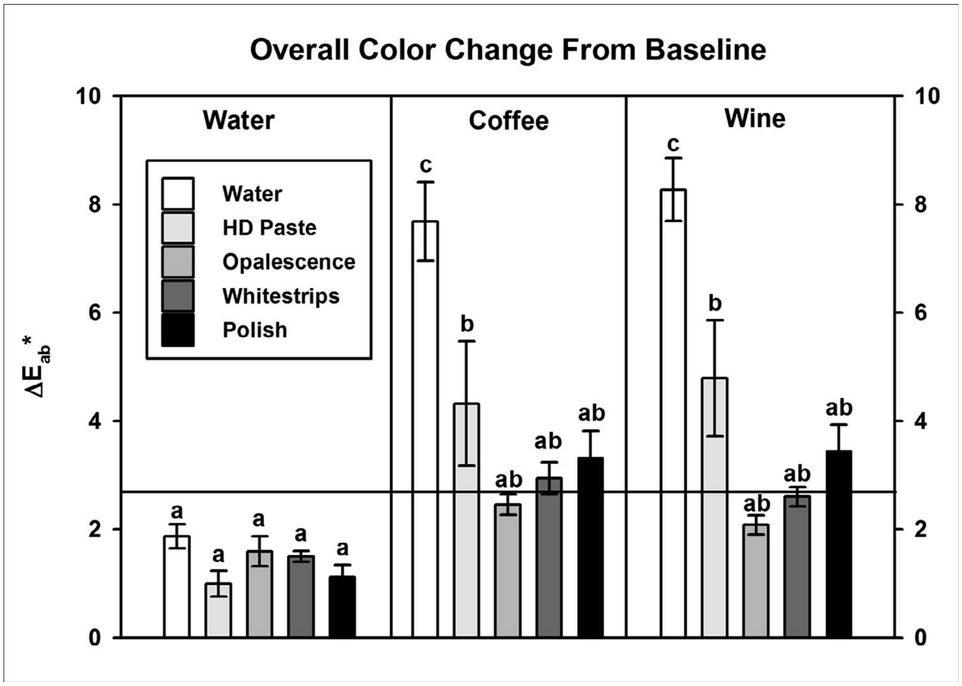


Figure 3. *Bar chart of overall mean ΔE_{ab}* color change from baseline for the four whitening agents. Error bars represent standard errors of means. Groups labeled with the same lower-case letter are not significantly different at the α=0.05 level of confidence (GLM/Tukey). The horizontal line drawn at ΔE_{ab}*=2.7 represents the 50%:50% threshold for maximum acceptable visual color change.*

interfaces.[36] This promotes deeper stain penetration into the composite.

The staining method employed for this study involved soaking test samples over time and measuring color change. This method does not truly mimic the *in vivo* condition, in which stain exposure time is shorter and oral surfaces are periodically rinsed and exposed to other compounds. However, the soaking method provides an avenue for conducting accelerated staining experiments, and it permits the study of stain accumulation over time. The observation that stain accumulation was continuous over the 14-day period supports the contention that the staining process is partially tied to water diffusion into the composite.[27] Amelogen contains a Bis-GMA/TEGDMA (triethylene glycol dimethacrylate) copolymer system, and classic work conducted by Kalachandra and Turner[37] demonstrated that for Bis-GMA/TEGDMA systems, increases in TEGDMA content from 0 to 100 weight percent produced a three to six weight percent increase in water uptake over a 14-day period. The presence of TEGDMA imparts hydrophilicity to the polymer system, which enhances composite stainability, particularly when contrasted to a hydrophobic polymer system, such as a silorane-based composite.[38,39]

The LED curing light used in this study was a standard dental curing light that is used in both dental schools and dental practice. Although the light was expected to deliver sufficient intensity and wavelength to ensure adequate polymerization of the composite resin, it is noteworthy that previous investigations that compared various halogen and LED curing units reported both significant[40,41] and nonsignificant[42] differences in degree of conversion when polymerizing resin-based composites. One study showed that for Amelogen Plus, the percentage degree of conversion ranged from 56.5% to 62.6% among one halogen and three LED curing units.[40] Vandewalle and others,[41] in their study of one halogen and five LED curing lights, demonstrated that curing lights with the least dispersion of light and lowest diversion angles produced the highest degrees of conversion at greater curing distances. Since degree of conversion can affect water sorption[43] and water sorption is tied to stainability, different curing lights may render a composite with different degrees of stainability, particularly when greater thicknesses of composite are polymerized.

The results obtained from staining experiments most closely follow those reported by Manojlovic and others,[44] in which three days of soaking in coffee and wine produced similar numerical changes in ΔL*, Δa*, Δb*, and ΔE_{ab}*. Data trends for the four color parameters after seven days' immersion in coffee and wine are similar to those reported by Tan and others,[21] but Tan's results showed nearly two times greater change for each color parameter. ΔE_{ab}* values reported by Ertas and others,[16] Villalta and others,[26] Fujita and others,[36] Catelan and others,[45] Al-Kheraif and others,[46] and Yu and others[47] at matching immersion times for either coffee or wine were 1.5 to 3.0 times lower than those observed here, and ΔE_{ab}^* values reported by Polli and Arossi,[48] Schmitt and others,[49] and Tonetto and others[50] were 1.3 to 5.5 times higher. In nearly every study, different composite systems were evaluated. Since resin matrix chemistry,[13,51] filler loading,[51,52] filler particle size,[53] and degree of conversion[43] are known to affect water sorption of the composite, it can be concluded that the nature and severity of composite staining are expected to be different for each manufacturer's product. Therefore, it is not reasonable to extrapolate staining experiment results obtained from one composite system and deduce potential stain susceptibility for another composite system.

This study sought to evaluate the effectiveness of four whitening methods in removing stain from Amelogen Plus following exposure to red wine and coffee. The return-to-baseline results demonstrated that for this composite, the passive application of two at-home peroxide-based systems were more effective in restoring baseline color than were two systems relying primarily on surface brushing or polishing. The observation that peroxide-based systems performed better can be attributed to the ability of their components to penetrate the composite subsurface and chemically react with pigment molecules. Brushing and polishing, on the other hand, rely on removal of composite surface layers, with the depth of stain removal being limited by the amount of material loss produced by typical brushing and polishing activities. Crest HD paste contains sodium hexametaphosphate for reducing stain and calculus formation,[54] but the results presented here suggest that it is less effective in removing stain that has penetrated the composite subsurface than are diffusible peroxide-based systems.

Of the peroxide agents used in this study, Opalescence contains 15% carbamide peroxide and Whitestrips contain 6.0% to 6.5% hydrogen peroxide. When activated by heat, light, or pH, hydrogen peroxide (H_2O_2) dissociates via cleavage of O-H and O-O bonds to produce $H^\bullet$, $^\bullet OOH$, and $2^\bullet OH$ radicals that are capable of decomposing conjugated double bonds and ring structures present within stain. Carbamide peroxide breaks down into hydrogen peroxide and urea, with urea further dissociating into carbon dioxide and ammonia. This creates an alkaline environment capable of producing the perhydroxyl anion (HO_2^-), a compound shown to further the whitening effect.[55,56] For this study, it is reasoned that the presence of urea and higher peroxide concentration in Opalescence produced a more aggressive environment for whitening than did Whitestrips, which resulted in nearly complete stain removal for both coffee and wine.

CONCLUSION

Although Amelogen Plus underwent different types of color change when stained with coffee or red wine, four whitening methods reversed the color changes in manners that were not significantly different from one another ($p \geq 0.05$). However, only the carbamide peroxide-based system was capable of returning color to a baseline level that was below the threshold of maximum acceptability for color change ($\Delta E_{ab}^* \leq 2.7$).

Acknowledgements

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Note

While reviewing the literature during this article's preparation, it was noted that a number of publications incorrectly reported Kalachandra and Turner's[37] results for water diffusion into Bis-GMA/TEGDMA copolymer systems, either through direct citation or through citation of articles incorrectly reporting the results.[16,17,57-65] The publications incorrectly stated that water uptake increased 3-6 weight percent for TEGDMA weight increases between 0 and 1 weight percent, when instead the range of studied TEGDMA weight increases were between 0% and 100%. Part of the confusion may lie in incorrectly interpreting the abstract, where it was stated that the *proportion* of TEGDMA increased from 0 to 1.0. However, a review of results presented in table I clearly show that five Bis-GMA/TEGDMA weight percentage ratios were studied by Kalachandra and Turner (100/0, 70/30, 50/50, 30/70, and 0/100) and that 6 weight percent water uptake was achieved with the 0/100 formulation, which corresponds to 100 weight percent TEGDMA.

Conflict of Interest

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

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