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Effects of Carbamide Peroxide on the Staining Susceptibility of Tooth-colored Restorative Materials

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Clinical Relevance

The staining susceptibility of esthetic restorative materials is significantly affected by the use of 15% carbamide peroxide. The effects of bleaching on the surface morphology and color of restorative materials are material dependent.

SUMMARY

This study investigated the effects of an at-home bleaching gel containing 15% carbamide peroxide on the susceptibility of tooth-colored restorative materials to different staining solutions. The tooth-colored restoratives used in this study were a nano resin composite (Filtek Z350), a packable resin composite (Filtek P60), a poly-acid-modified composite (Dyract AP) and a glass-ionomer cement (Ketac Molar Easymix). Each material was equally divided into two groups (n=34): the bleaching group and the control group. This study included two treatment segments. In the first part (days 1-14), the specimens of the bleaching group were bleached with 15% carbamide peroxide gels for eight hours daily, while the specimens in the control group were stored in deionized water. Subsequently, four specimens from each group were randomly selected for observation under an environmental scanning electron microscope. In the second part (days 15-42), the samples were not bleached. Instead, they were stored in five different kinds of solutions. Color measurements for each sample were taken at six different time periods using a spectrophotometer. The data was then analyzed using SPSS statistical software. After two-

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weeks of bleaching, all the specimens showed statistically significant color changes compared with the control specimens. Furthermore, the bleaching agents seriously affected the surface morphology of Dyract AP and Ketac Molar Easymix. Following exposure to the staining solutions, it was found that the bleached restorative materials exhibited greater staining susceptibility than the control materials. Filtek Z350 and P60 exhibited the best color stability, while Dyract AP exhibited the least color stability.

INTRODUCTION

Color stability is considered an important factor in the success of an esthetic restoration.[1-2] In the literature, color stability has been defined as the ability of a material to retain its color over a period of time and in a specified environment.[2] To maintain excellent esthetic properties, tooth-colored restorative materials should have good color stability. It has been shown that both extrinsic and intrinsic factors contribute to color changes of restorative materials. Intrinsic factors influencing color changes involve chemical changes of the materials. The causes for such chemical discoloration have been identified as the oxidation of monomer or catalysts, exposure to various energy sources and immersion in water for a long period.[3-6] Extrinsic factors influencing color changes include staining by adsorption or absorption of colorants, a result of contamination from exogenous sources, such as coffee, tea, other stain-producing beverages and colored solutions.[7-9] In recent years, many tooth-colored restorative materials have been introduced into the market. The staining susceptibility of these materials has been widely investigated.[1-2,7,9]

In addition to the staining susceptibility of new restorative materials, the effects of different bleaching approaches have also received attention from researchers. Dentists are experiencing an increased demand for tooth bleaching from patients. This demand has led to bleaching systems, such as nightguard vital tooth bleaching, which uses custom trays and carbamide peroxide- (CP) or hydrogen peroxide- (HP) based bleaching gels. These gels are becoming increasingly popular in modern dentistry. Meanwhile, daily clinical practices frequently encounter tooth-colored restorations in teeth planned for bleaching. Therefore, studies investigating the effects of bleaching agents on the surface properties of tooth-colored restorative materials have been conducted. Kim and others[10] and Moraes and others[11] reported an increase in the surface roughness of restorative materials following exposure to bleaching agents. Turker and Biskin[12] observed alterations in the surface morphology of resin composite and resin-modified glass-ionomer cement due to bleaching treatment. Likewise, Jung and others[13] found surface degradation of polyacid-modified composites (compomer) after exposure to bleaching gels. However, other studies have reported conflicting results, which show that the surface morphology was not altered following exposure to bleaching agents.[14-15]

Despite these somewhat conflicting findings, it has been well documented that the relative degradation and roughness of the surface of dental materials has a direct influence on their susceptibility to staining.[16-18] Therefore, given that the findings indicate that bleaching treatment can alter the surface texture of restoratives, it is possible that increased roughness caused by the bleaching treatment could make the surface more prone to staining. However, currently, no published research has evaluated the susceptibility of restorative materials to staining after bleaching. The current study investigated the effects of bleaching gels containing 15% CP on the susceptibility of the tooth-colored restorative materials to different staining solutions. The null hypothesis was that the bleaching treatment has no effect on staining susceptibility of the restorative materials.

METHODS AND MATERIALS

Four types of tooth-colored restorative materials were tested. Of the four types, two were light-cured resin composites, one was a light-cured compomer and one was a chemical-cured glass-ionomer cement. The materials tested in this study are listed in Table 1.

For each type of restorative material, 68 disk-shaped specimens were made with customized silicone molds (diameter 10 mm, 2.2 mm thick, shade A3). The specimens were fabricated in accordance with the manufacturers' recommendations. Subsequently, all the specimens were stored in deionized water at 37°C for 24 hours.[19] They were then polished by the same operator using medium, fine and superfine discs (Sof-Lex, 3M ESPE, St Paul, MN, USA) rotating in one direction. The thickness of the polished specimens was 2 ± 0.05 mm, which was controlled with a micrometer (Mitutoyo, Tokyo, Japan). The specimens were then cleaned in deionized water in an ultrasonic cleaner for one minute to remove any debris. Finally, all the specimens were stored in 37°C deionized water for seven days.[20-21]

Study Design

This experimental regimen is shown in Figure 1. Specimens of each type of restorative material were divided into two groups (n=34): the bleaching and control group. All the specimens were submitted to two treatment parts. In the first part (days 1-14), the bleaching group specimens were bleached with 15% CP gel (Opalescence PF 15%, Ultradent Products Inc, South Jordan, UT, USA) for eight hours daily. The control group specimens remained stored in deionized

Table 1: *Restorative Materials Used in This Study*				
Materials	**Type**	**Main Composition**	**Manufacturer**	**Code**
Filtek Z350	Nanocomposite resin	Combination of aggregated zirconia/silica cluster filler, Bis-GMA, UDMA, TEGDMA and Bis-EMA	3M ESPE, St Paul, MN, USA	Z350
Dyract AP	Polyacid-modified composite	UDMA, TCB resin, strontium fluoride, alkanoyl-poly-methacrylate, photo initiators, strontium-fluoro-silicate glass, butyl hydroxy toluene, iron oxide pigments	Dentsply DeTrey GmbH, Konstanz, Germany	DY
Filtek P60	Packable resin composite	Zirconia/silica filler, Bis-GMA, UDMA and Bis-EMA resins	3M ESPE, St Paul, MN, USA	P60
Ketac Molar Easymix	Conventional glass-ionomer cement	Aluminium-calcium-lanthanum fluorosilicate glass, polycarboxylic acid	3M ESPE AG, Seefeld, Germany	KM

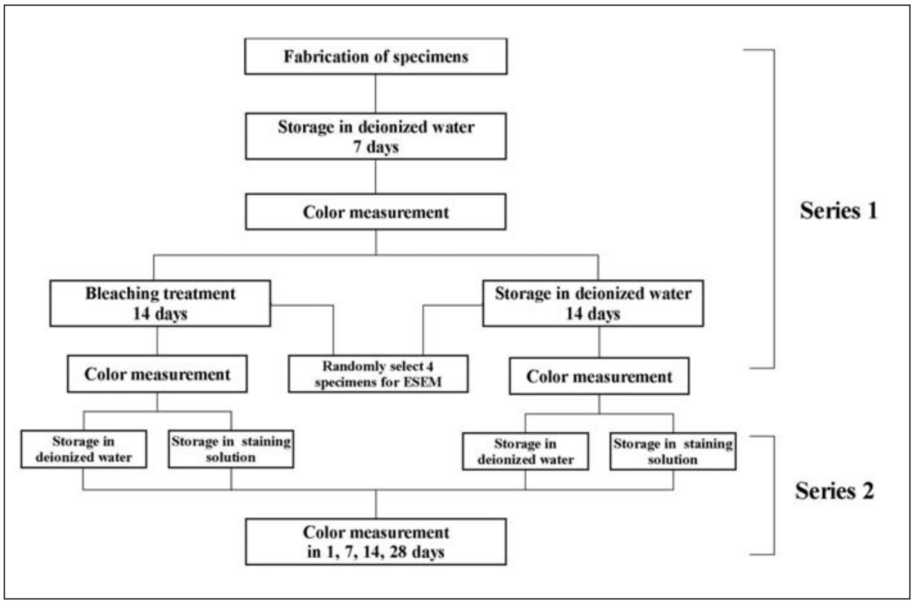

Figure 1. *Experimental regimen of the current study.*

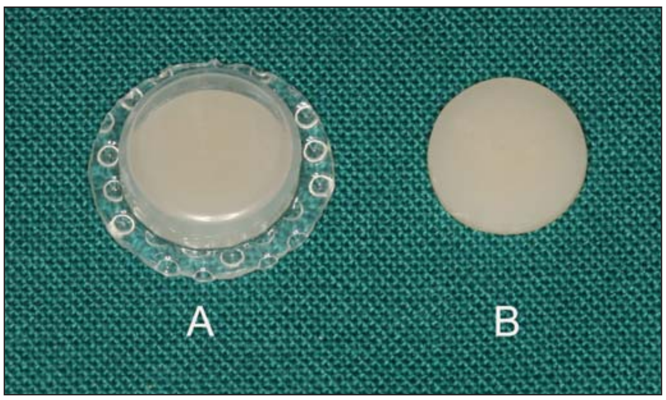

Figure 2. *A-P60 specimen with a custom-fabricated appliance; B-P60 specimen without a custom-fabricated appliance.*

water throughout the first part of the study. After part 1 of the treatment, four specimens were randomly selected from each treatment group. A total of 32 specimens were analyzed in high vacuum conditions using an environmental scanning electron microscope (ESEM) (Quanta 200, FEI Co, Eindhoven, The Netherlands) at 30 kV. Four images at two different magnifications (200x and 2000x) were taken from the representative areas of each specimen. In part 2 of the treatment (days 15-42), the samples were not bleached; however, they were stored in five different kinds of solutions.

Bleaching Procedure

The specimens of the bleaching group were treated with bleaching gels for 8 hours daily for 14 days in 37°C humidity. During this period, the control group specimens were stored in deionized water. Custom-fabricated appliances with a 0.5 mm-thick reservoir, using 0.035-inch thick soft tray sheets (Ultradent Products Inc), were made for all specimens of the bleaching group (Figure 2). The bleaching gel was applied on the top surface of each specimen of the bleaching group. After placement of the appliance, the excess gel was removed using wet tissue paper. After the eight-hour bleaching procedure, the samples were fully cleaned, then stored in deionized water for the remaining time (16 hours).

Staining Procedure

After randomly selecting specimens for the ESEM, the remaining bleaching and control group specimens were divided into five subgroups (n=6): Group A, immersed in red wine (China National Cereal and Food Stuffs Co, Yantai, China); Group B, exposed to herbal tea

Table 2: *Means and Standard Deviations (SD) for ΔL, Δa, Δb and ΔE Values for Each Material After Bleaching*

Material		ΔL	Δa	Δb	ΔE
Z350	Bleached	3.39(0.86)*	0.75(0.28)*	0.58(0.52)*	3.59(0.78)*
	Control	-0.62(0.32)	0.28(0.12)	-0.69(0.21)	1.01(0.25)
P60	Bleached	3.06(0.84)*	0.56(0.21)*	0.87(0.41)*	3.29(0.71)*
	Control	-0.52(0.47)	0.37(0.11)	-0.50(0.20)	0.94(0.28)
Dyract AP	Bleached	4.16(1.22)*	0.51(0.29)	-2.47(1.00)*	4.94(1.31)*
	Control	-1.04(0.61)	0.43(0.22)	-0.83(0.37)	1.42(0.41)
Ketac Molar	Bleached	2.99(0.82)*	0.23(0.13)	-2.61(1.04)*	4.04(1.11)*
	Control	-0.92(0.79)	0.18(0.14)	0.81(0.37)	1.51(0.22)

(Guangzhou Wanglaoji Pharmaceutical Co, Guangzhou, China); Group C, immersed in Coca Cola (Coca Cola Co, Wuhan, China); Group D, placed in coffee (Nescafé Inc, Wuhan, China); Group E, stored in deionized water. The samples were then stored in their respective solutions at 37°C. For Group A-D, each specimen was placed in a vial containing the staining solution for three hours daily. During this period, the vial was covered with a glass plate. After immersion in the solutions, each specimen was rinsed with deionized water and brushed to remove loosely attached stains for 10 seconds using an electrical toothbrush (HP235, Philips Inc, Republic of Austria). The specimens were then stored in deionized water for the remainder of the day (21 hours). With respect to Group E, the specimens were stored in deionized water for 24 hours. These 24-hour protocols were repeated daily for 28 days. The staining solutions and deionized water were changed every day, and the pH values of the staining solutions were measured using a pH-meter (PB-20, Sartorious AG, Goettingen, Germany).

Color Measurement

The color was measured with the CIE L*a*b* color space on a spectrophotometer (PR-650 Spectra Scan, Photo Research Inc, Chatsworth, CA, USA) against a dentin shade disk with a standard illuminant D65. The spectrophotometer was equipped with an MS-75 and SL-0.5X lens at 380 to 780 nm with 2 nm intervals. The measurements were set to a 0°/45° measuring arrangement and a 2° observer angle. The background disk was 20 mm in diameter and 8 mm thick (CIE L*=66.81, a*=1.99 and b*=11.48). Before the color measurement, the spectrophotometer was calibrated with a white reflectance standard tile supplied by the manufacturer. For the color measurement, the specimens were blotted dry with tissue paper and the index of refractive liquid (n=1.50, Suzhou Chemical Inc, Suzhou, China) was placed between the specimen and the background so that an optical connection was achieved.[10,22] Color measurements were obtained on the top surface of each specimen at the following time periods: baseline (T1), after the part 1 treatment (T2), after 1 day (T3), 7 days (T4), 14 days (T5) and 28 days (T6) of immersion in the different solutions. CIE L*a*b* values were measured at each time period, and the color differences induced by bleaching and staining were calculated using the formula: $\Delta E = [(L_I - L_O)^2 + (a_I - a_O)^2 + (b_I - b_O)^2]^{1/2}$ (Commission Internationale de L'Eclairage, 1978).[23]

When calculating the color difference resulting from the part 1 treatment, I= the readings at T2; O= the readings at T1. For part 2, I= the readings at each testing interval (T3-T6), O= the readings at T2. At each testing period, five measurements were performed for each specimen, and the mean color parameters of each specimen were calculated.

Statistical Analysis

The data was analyzed using the SPSS statistical software package (SPSS 13.0 for Windows, SPSS Inc, Chicago, IL, USA). All statistical analyses were carried out at a significance level of 0.05. Normal distribution of the data was checked with Kolmogorov-Smirnov. To evaluate the relative color changes of each material at each time period between the bleaching and control group, one-way analysis of variance (ANOVA) was executed. The repeated measures ANOVA was applied for analysis of the data resulting from the staining procedure.

RESULTS

There was no statistically significant difference in L*, a* and b* values between the bleaching group and the control group for each type of material at baseline ($p>0.05$). The ΔL, Δa, Δb and ΔE values of all the materials caused by bleaching treatment are presented in Table 2. After bleaching, there were statistically significant increases in L* values of the four types of restorative materials. The b* values showed an increase for resin composites and a decrease for the other materials. The two-week CP bleaching resulted in greater color differences for each of the four types of materials relative to the control group. DY showed the greatest color changes due to exposure to 15% CP. The ΔE values of the control groups ranged from 0.94 to 1.51.

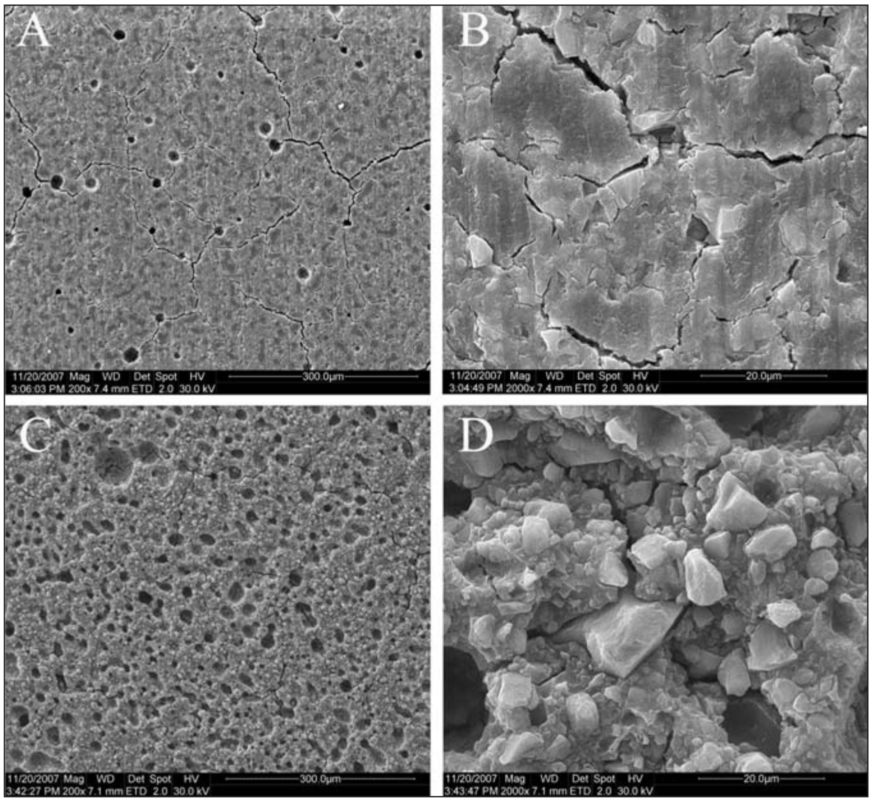

Figure 3. *ESEM images of Ketac Molar Easymix; A-control, 200x; B-control, 2000x; C-15% carbamide peroxide bleaching, 200x; D-15% carbamide peroxide bleaching, 2000x.*

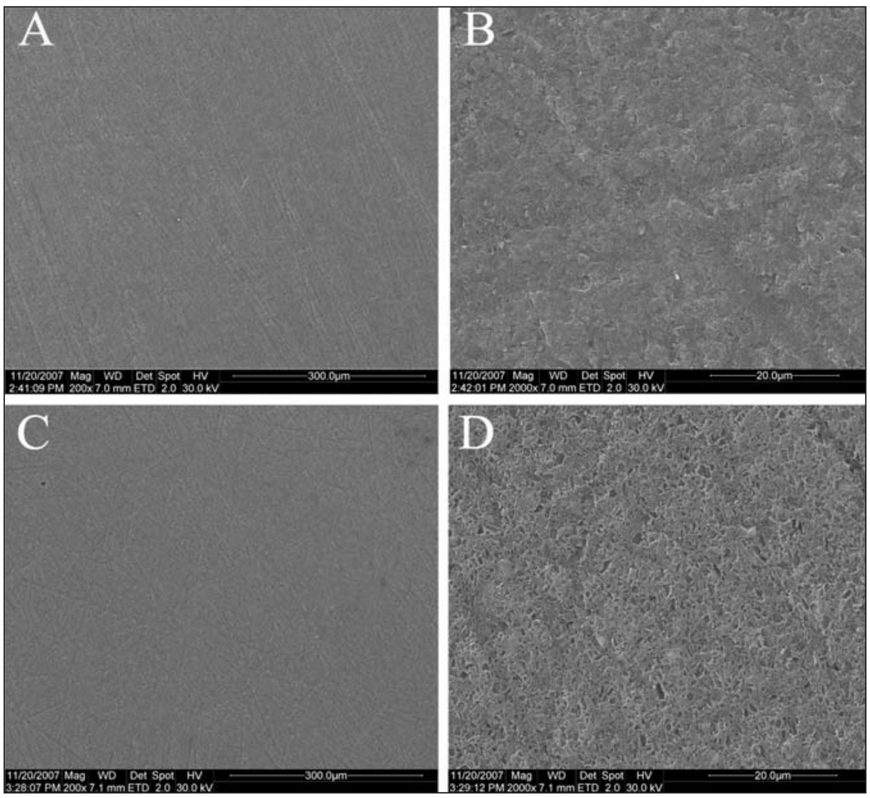

Figure 4. *ESEM images of Dyract AP; A-control, 200x; B-control, 2000x; C-15% carbamide peroxide bleaching, 200x; D-15% carbamide peroxide bleaching, 2000x.*

The ESEM observation of the glass-ionomer cement specimens, including control specimens, revealed cracking areas. However, the bleached samples showed far more cracks and pits on the surface when compared with the controls (Figure 3). The micrographs showed an increase in surface porosity for the compomer compared to the specimens stored in deionized water. (Figure 4) No differences were observed in the ESEM images between the control and bleached specimens of the tested resin composites (Figures 5 and 6).

The average pH of red wine, herbal tea, Coca Cola and coffee was 3.73, 4.91, 3.01 and 6.25, respectively. The pH values of each stain remained stable for the entire staining period. In the second part of this study, each of the staining solutions produced color changes in each of the materials. The ΔE values varied for all groups within the four experimental weeks. After four-week storage in staining solutions, all the samples showed significantly greater ΔE values than the specimens immersed in deionized water. The ΔE values caused by exposure to different staining solutions ranged from 2.32 to 21.86. Table 3 lists the ΔE values of each type of tooth-colored material at different time periods during immersion in the different solutions. All the materials showed gradual increasing color changes due to storage in the staining solutions. Generally, all the materials showed a large decrease in L^* value and a moderate increase in a^* and b^* value. The four staining solutions caused similar changes in b^* values for the four materials tested. The specimens exposed to red wine showed the most significant increases in a^* values. In most cases, after immersion in the stains, the bleached specimens had a greater decrease in L^* values compared to the control specimens. DY demonstrated the greatest changes in L^*, a^* and b^* values in the four types of materials. Compared with the other two materials, Z350 and P60 showed fewer changes in color parameters.

According to the repeated measures ANOVA, there was significant interaction between the surface treatment and staining solution ($p<0.001$) and between the staining solution and material ($p<0.001$).

Statistically significant differences in ΔE values between the bleached and control samples were found in most cases after immersion in the staining solutions (Table 4). After bleaching, most of the materials showed differences in stain resistance from the controls. However, the bleached and control specimens of Z350, P60 and DY demonstrated the same color stability following immersion in herbal tea. In general, the bleached specimens were equal to or more susceptible to stains except for P60 to red wine.

Table 5 shows significant differences in ΔE values in terms of staining solution for each material. The color change produced by each stain was different for each material. For all materials, both the bleaching and control groups, immersion in red wine produced the greatest ΔE values, while exposure to coffee induced the least.

A comparison of the staining susceptibilities of the four materials to different solutions is shown in Table 6. Overall, resin composites had better stain resistance (with lower color changes) than compomer and glass-ionomer cement. Different stains also had varied staining ability to the bleached and control samples. DY showed the least stain resistance in both the bleaching and control groups. Soaking in deionized water for four weeks produced the same color changes in both the bleached and control samples of all the materials tested.

Based on the above results, the null hypothesis that the bleaching treatment has no effect on staining susceptibility of the dental materials was therefore rejected.

DISCUSSION

Visual color assessment is a combination of physiological and psychological responses to radiant-energy stimulation. Alterations in perception can occur as a result of a number of uncontrolled factors, such as fatigue, aging, emotions, lighting conditions and metamerism.[22] The use of spectrophotometers and colorimeters to quantify tooth color could potentially eliminate the subjective aspects of color assessment.[24]

In assessing chromatic differences, the most frequently used color system is the

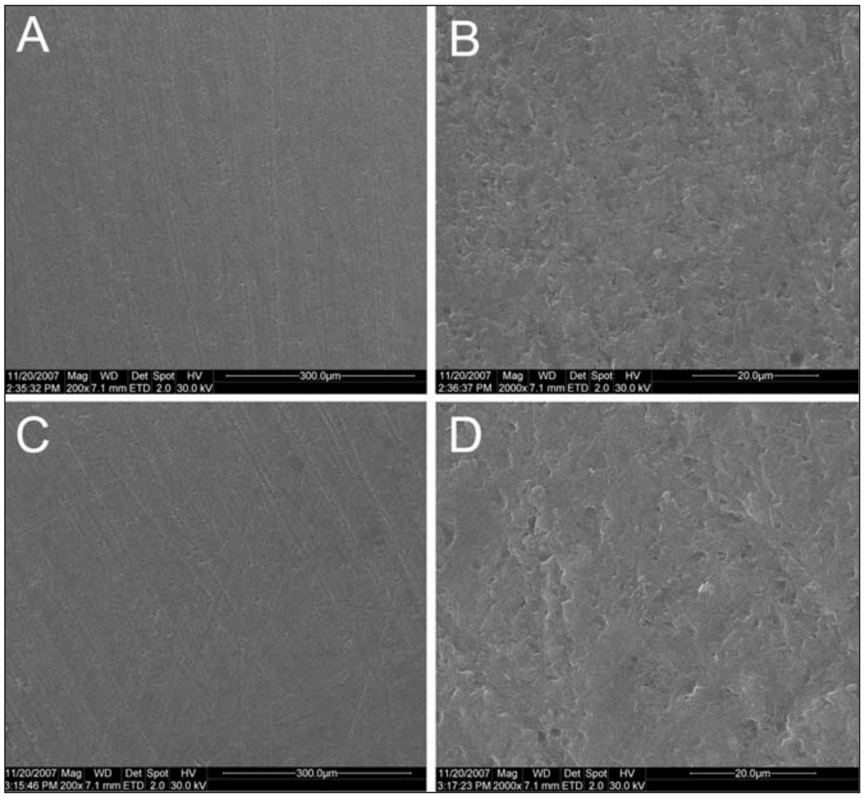

Figure 5. *ESEM images of Z350; A-control, 200x; B-control, 2000x; C-15% carbamide peroxide bleaching, 200x; D-15% carbamide peroxide bleaching, 2000x.*

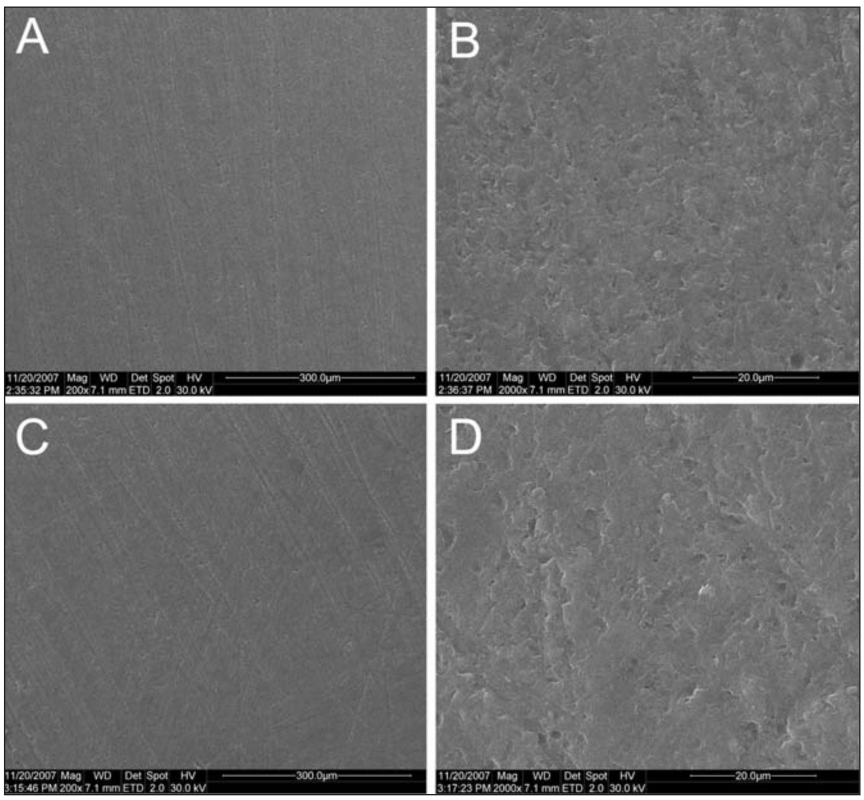

Figure 6. *ESEM images of P60; A-control, 200x; B-control, 2000x; C-15% carbamide peroxide bleaching, 200x; D-15% carbamide peroxide bleaching, 2000x.*

Table 3: *Means and Standard Deviations (SD) for ΔE Values for Each Material at Each Staining Period*

Time	Material	Red Wine		Herbal Tea		Coca Cola		Coffee		Deionized Water	
Period		Bleached	Control	Bleached	Control	Bleached	Control	Bleached	Control	Bleached	Control
T3	Z350	6.54(2.23)*	2.56(0.29)	3.00(1.91)	3.23(0.42)	4.00(1.98)*	1.30(0.59)	2.42(0.81)*	1.03(0.35)	0.14(0.05)	0.13(0.02)
	P60	5.95(1.82)	7.34(0.87)	2.68(1.10)	3.50(0.32)	2.34(0.45)*	1.45(0.17)	2.16(0.50)*	1.26(0.27)	0.16(0.09)	0.18(0.10)
	DY	8.37(1.23)	7.58(0.47)	5.18(1.54)	5.93(0.95)	5.28(0.93)*	2.90(0.71)	4.21(0.69)*	1.38(0.18)	0.19(0.05)	0.22(0.07)
	KM	7.46(1.07)*	3.85(0.53)	5.23(0.68)*	3.11(0.63)	3.02(0.96)*	1.45(0.33)	3.41(0.65)*	1.62(0.18)	0.23(0.10)	0.20(0.10)
T4	Z350	12.47(2.12)*	6.75(0.71)	5.79(1.04)	6.29(1.23)	4.84(1.57)*	1.96(0.52)	4.53(0.83)*	2.34(0.78)	0.45(0.13)	0.48(0.06)
	P60	10.82(0.74)	11.58(1.56)	5.96(1.00)	5.21(0.64)	4.52(1.14)*	2.41(0.26)	3.91(1.09)*	1.40(0.22)	0.45(0.18)	0.44(0.11)
	DY	14.48(0.77)*	16.77(0.41)	8.73(1.64)	8.47(1.32)	7.79(1.12)*	3.33(0.29)	6.09(1.19)*	2.68(0.89)	0.64(0.23)	0.49(0.16)
	KM	13.30(2.99)*	9.64(1.85)	8.87(1.42)*	6.60(0.85)	5.01(0.78)*	2.57(0.38)	5.02(1.29)*	2.36(0.46)	0.63(0.17)	0.54(0.28)
T5	Z350	14.39(1.16)*	17.03(0.57)	6.21(0.59)*	7.94(0.68)	4.87(1.09)*	3.47(0.82)	5.46(1.06)*	3.26(0.37)	0.58(0.11)	0.65(0.19)
	P60	12.88(1.00)*	15.09(1.00)	7.13(0.48)	6.55(1.02)	5.12(0.65)*	3.12(0.61)	4.10(1.30)*	1.91(0.31)	0.45(0.11)	0.60(0.13)
	DY	16.73(1.24)*	18.69(0.29)	10.51(2.19)	11.76(1.75)	9.14(1.15)*	3.98(0.66)	6.96(1.45)*	3.60(1.30)	0.55(0.18)	0.56(0.29)
	KM	18.93(2.60)*	14.55(2.59)	14.85(0.98)*	7.43(0.84)	5.73(0.84)*	3.59(0.68)	5.81(1.77)*	3.04(0.34)	0.62(0.17)	0.66(0.24)
T6	Z350	18.54(1.76)	18.70(0.93)	7.73(0.56)	8.41(0.77)	5.83(0.87)*	4.80(0.65)	6.93(1.06)*	4.73(0.87)	0.68(0.15)	0.50(0.23)
	P60	15.92(0.41)*	18.27(1.07)	8.40(0.41)	7.83(0.48)	6.28(0.59)*	3.80(0.44)	5.82(1.11)*	2.32(0.48)	0.65(0.10)	0.73(0.23)
	DY	20.97(1.47)	20.84(0.73)	12.39(2.56)	13.69(1.27)	10.74(1.58)*	5.05(0.87)	8.64(1.56)*	5.12(1.16)	0.71(0.28)	0.63(0.23)
	KM	21.86(3.08)*	17.33(2.75)	16.41(1.03)*	8.55(0.62)	6.72(1.12)*	5.29(1.06)	7.24(1.69)*	4.80(0.54)	0.65(0.27)	0.79(0.25)

**indicates statistically significant differences between the bleaching and control group at the same time period (p<0.05).*

Table 4: p-*values of Comparison of ΔE Values Due to Immersion in Different Solutions Between the Bleaching Group and Control Group for Each Material*

Material	Red Wine	Tea	Cola	Coffee	Water
Z350	0.040	0.066	0.004	0.001	0.827
P60	0.014	0.346	<0.001	<0.001	0.937
DY	0.022	0.428	<0.001	<0.001	0.095
KM	0.006	<0.001	<0.001	0.001	0.755

Commission Internationale de L'Eclairage (CIE) L*a*b* color space. L* represents the value of an object, ranging from white at the top (100) and black at the bottom (0); a* and b* are chromaticity coordinates along the red-green and yellow-blue axes, respectively.[24-27] The ΔE value represents relative color changes that an observer might report when evaluating aesthetic restorative materials. In dentistry, it has been reported that values of ΔE in the range 2–3 were just perceptible[28] and that ΔE of 3.3 is the critical value for visual perception.[29]

The baseline L*, a* and b* values reported here revealed no statistically significant difference between the bleaching and control groups for the four types of materials, which guaranteed a homogenous distribution of the samples. Following the initial two-week exposure to 15% CP, color changes of tooth-colored restorative materials were all clinically perceptible except for P60 (ΔE =3.29). Both a shift of the L* value to positive values (more brightness) and the b* value to negative values (less yellow and more blue) indicate a perceptible lightening of colored materials.[30] According to the results of the current study, the application of 15% CP resulted in a lightening effect on the specimens relative to the unbleached controls. This finding was highlighted by the distinct shift of those samples to higher L* values. The changes in a* and b* values of the bleached samples were inconsistent. Compomer was found to have the greatest ΔE values after bleaching, due to the greatest changes in L* and b* values in the four types of restorative materials. However, resin composite showed less color changes than compomer and glass-ionomer cement. This finding was in agreement with previous studies.[31-32] Deionized water caused no visible color change for all the materials (ΔE <3.3). The mechanism of color changes of the restorative materials induced by bleaching is still not clear. Possibly, the bleaching agents could induce oxidation of the surface pigments and amine compounds of the restoratives.[33-34] Kugel and others[35] reported that extracted human teeth exhibited great changes in L* and b* values after bleaching with 15% CP for two weeks. In that study, ΔL value was 5.7 and Δb value was -7.8. This indicated that the whitening effect of 15% CP bleaching (producing positive ΔL values and negative Δb values) on compomer and glass-ionomer cement was similar to its effect on teeth, although the effect was much smaller. This finding may suggest that restorations using compomer and glass-ionomer cement may have a better color match with natural teeth after bleaching than resin composite. However, it is important to note that the treatment time in their study was two hours per day. It is possi-

Table 5: *Results of Comparisons Based on Materials*

Material	Color Differences (ΔE)	
	Bleaching Group	Control Group
Z350	Red wine>Herbal tea, Coca Cola, coffee	Red wine>Herbal tea>Coca Cola, coffee
P60	Red wine>Herbal tea> Coca Cola, coffee	Red wine>Herbal tea>Coca Cola>coffee
DY	Red wine>Herbal tea, Coca Cola>coffee	Red wine>Herbal tea>Coca Cola, coffee
KM	Red wine>Herbal tea>Coca Cola, coffee	Red wine>Herbal tea>Coca Cola, coffee

>indicates statistical significance.

Table 6: *Results of Comparisons Based on Solutions*

	Color Differences (ΔE)	
Solution	Bleaching Group	Control Group
Red wine	KM,DY>Z350, P60	DY>P60>KM, Z350
Herbal tea	KM>DY>Z350, P60	DY>KM, P60, Z350
Coca Cola	DY>KM, Z350, P60	DY>KM, P60, Z350
Coffee	DY>KM, Z350, P60	Z350, DY, KM>P60
Deionized water	No significant difference	

>indicates statistical significance.

ble that greater changes in L* and b* values would have been found if the current study's eight-hour regimen was used.

The four staining agents used in the current study were selected on the basis of their common consumption in China. Numerous other studies have already established the strong potential for these agents to stain tooth-colored restorative materials.[9,18,36] Thus, apart from the control specimens of P60 immersed in coffee, all the materials used in the current study showed clinically perceptible discoloration after four-weeks of storage in the staining solutions. Moreover, in general, the bleached specimens showed more severe discoloration than the control specimens following exposure to staining agents. Bleaching treatment significantly impacted the susceptibility to staining of all the materials tested except for the susceptibility of resin composite and compomer to herbal tea. Given the importance of color stability, this may indicate that, even if the esthetic appearance of the bleached restoration is acceptable, it may still require replacement due to its degraded color stability. A possible reason for the deterioration in color stability of bleached restoratives was that 15% CP bleaching changed the surface properties of the four types of restorative materials. The ESEM observation adds some support to this hypothesis. After the bleaching treatment, the ESEM observation showed an increase in cracks and pits on the surfaces of both compomer and glass-ionomer cement relative to the controls. Previous studies have already noted that an increase in surface porosity and cracks allows stain penetration and discoloration.[18,37] Therefore, the findings of the current study, that bleached compomer and glass-ionomer cement were more prone to stains, are consistent with their greater porosity following bleaching. However, it is important to note that the control specimens of the glass-ionomer cement were also found to have extensive cracking. This result was in accordance with the previous study that showed the glass-ionomer cement to be very sensitive to desiccation.[38] Therefore, this phenomenon could be due to dehydration occurring during the ESEM procedure when the specimens were kept in the desiccator before being sputter-coated.[12] In most cases, the bleached specimens of resin composite also demonstrated more staining susceptibility. Possibly, the resin matrix of resin composite was chemically degraded by the application of 15% CP, although it was not detected by the ESEM. Moreover, it is interesting to note that the bleached P60 specimens showed better stain resistance to red wine than the control specimens. Further studies are needed to explain this result.

In the current study, the contribution of changes in L*, a* and b* values was different for each stain and for each material. In general, all materials had a similar trend of discoloration with positive Δb and Δa values and negative ΔL values. Furthermore, immersion in red wine produced the most significant increase in a* values in all four materials. The possible explanation could be the high proportion of red pigment contained in red wine. For resin composites, ΔL, Δa and Δb values were smaller when contrasted with values obtained for compomer and glass-ionomer cement. The major parameter causing the color change was found to be the L* values rather than the a* and b* values, which is consistent with previous findings.[37,39] Staining susceptibility of restorative materials might be attributed to their degree of water sorption and hydrophilicity of the matrix resin; the water presumably acting as a penetration vehicle.[40] In the literature, hydrophobic materials (resin composite) are believed to exhibit greater stain resistance and color stability than hydrophilic materials (glass-ionomer cement and compomer).[2,41] The results of the current study also add support to this conclusion. Both bleaching and the control groups of resin composites showed less susceptibility to stains compared with compomer and glass-ionomer cement. Luce and Campbell[42] reported that most of the staining took place within the first 7-10 days, during which time most of the water sorption occurs. This would account for the significant increase in discoloration for all the specimens observed in the first week.

The discoloration of restorative materials is dependent on various parameters, such as the pH value of the staining solution. The lower pH value of staining solutions is reported to increase staining as compared with chlorhexidine, which is less acidic.[43] Similar results were found in the current study. Coffee, having the greatest pH in the four staining solutions used in the current study, induced the least color changes on both bleached and control specimens. Red wine (Average pH=3.73) produced more severe discoloration than herbal tea (Average pH=4.91). However, Coca Cola, which had the lowest pH, did not produce as much discoloration as red wine and herbal tea. This result may be due to the lack of yellow colorant in Coca Cola, which can be found in tea and coffee.[44] Exposure to red wine led to massive discoloration, which could be observed on all specimens with the naked eye, regardless of whether or not the specimen has been bleached. It is possible that the alcohol contained in red wine tends to degrade the surface of restorative materials.[45] Following exposure to red wine, the resin matrix and resin-filler interface may be affected, thus leading to more severe discoloration. Coffee has been shown to have a strong staining effect on dental materials in previous studies.[2,18,28,36,44] However, coffee showed the least staining ability in the current study. The different chemistry and pH value of coffee might contribute to its poor staining ability.

Apart from the ΔE values, the corresponding NBS units (NBS units=ΔE x 0.92) obtained in the current study can be regarded as a visual assessment means to evaluate the color changes induced by bleaching and staining.[46] According to the NBS rating, after bleaching, all the materials showed "appreciable" color changes. Following immersion in red wine for four weeks, both the bleached and control specimens showed "very much" color changes; whereas, storage in other staining solutions resulted in color changes ranging from "noticeable" to "very much." Furthermore, most of the samples showed a "slight" color change while stored in deionized water.

All of the specimens were brushed after the staining procedure. This was done to evaluate the color changes without the interference of superficially adsorbed stains. Moreover, in daily life, brushing is a common procedure, and it is recommended that the teeth be cleaned thoroughly after drinking a beverage. The current study also utilized custom-fabricated appliances to control the amount of bleaching gel used. This approximates the clinical situation that the bleaching tray is usually fabricated with a 0.5 mm-thick reservoir according to the manufacturer's instructions. The eight-hour period of bleaching was chosen to simulate the overnight wearing of a custom tray filled with the bleaching agent.

There were some limitations in the current study that should be noted. Undoubtedly, three hours of exposure time is highly unlikely to be reached during the normal consumption of drinks. However, with this *in vitro* study, it was important to simulate the worst possible situation to obtain reliable data that would allow findings and recommendations applicable to a broad spectrum of patients. Furthermore, the three-hour staining protocol has been adopted in the previous study.[47] The need to simulate the worst possible conditions was also the basis on which the current study chose the different staining solutions used herein. These solutions have been shown to have a greater tendency to stain dental materials than other solutions. Under clinical conditions, the pattern of staining solutions on restorative materials may be different. Therefore, further *in vivo* or *in situ* studies are necessary.

CONCLUSIONS

Based on the results of this *in vitro* study, the following conclusions can be drawn:

1. Fifteen percent CP bleaching had an effect on the staining susceptibility of restorative materials. In most cases, bleached, tooth-colored restorative materials showed worse stain resistance than the controls.
2. The effects of bleaching agents on the color change of esthetic restoratives were material-dependent.
3. Fifteen percent CP bleaching had a significant erosion effect on the surface of compomer and glass-ionomer cement.
4. Resin composite had better color stability than compomer and glass-ionomer cement in both groups.

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