

COLOR STABILITY OF LIGHT-ACTIVATED
BLEACH SHADE COMPOSITES

by

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INTRODUCTION

The term "composite" refers to a three-dimensional combination of two or more chemically different materials with a distinct interface separating the components.

A combination of hard, inorganic filler particles bonded to soft dimethacrylate polymer was introduced in the 1960s. As a consequence of the bonded filler phase, these materials had mechanical properties that approached the properties of dentin and enamel better than unfilled resins.

Originally intended for use in anterior Class 3, Class 4, and Class 5 restorations where esthetics are important, improvements have included light curing, bonding to tooth structure, and reduced wear. Continued development in wear resistance, dentin bonding, and reduced polymerization shrinkage has led to their increased use in posterior restorations.

It is important for the color of all esthetic restorative materials to remain stable over a long period in the oral environment. Dental composites are known to be susceptible to varying degrees of discoloration after prolonged exposure to the oral environment because of the nature of the materials in the composite formulations. In recent years, increased esthetic awareness and the demands of patients and the dental profession have made dental bleaching procedures popular. In accordance with this surge of interest, various bleaching materials have been developed. Since most of these materials are effective, the resulting tooth shade is often lighter than the lightest Vita shade (B1). To match the shades of extremely white teeth, numerous manufacturers have

begun producing bleach shade composites. These materials lack the *in vitro* and *in vivo* evaluations necessary to determine their color stability. Previous studies have reported color changes of regular dental composites resulting from accelerated aging, exposure to various energy sources, and staining solutions, but few studies have investigated the color stability of bleach shade composites.

REVIEW OF LITERATURE

In 1978 Powers et al.¹ made one of the first attempts to test the color stability of composites. The color stability of seven commercial composite resins, an unfilled resin, and three glazes was evaluated under conditions of accelerated aging by reflection spectrophotometry and visually with Munsell color tabs. After aging for 900 h, most of the resins had lower values of luminous reflectance and excitation purity and higher values of dominant wavelength and contrast ratio compared with values at baseline.

In 1980 Powers et al.² evaluated the color stability of seven commercial composite restorative materials under conditions of accelerated aging using reflection spectrophotometry at baseline and at 300 h, 600 h, and 900 h. During early aging the composites generally became darker, more chromatic, and more opaque. Changes in color of the conventional composites during aging were influenced by erosion of the resin matrices and exposure of filler particles. Color stability of the microfilled composites under the *in vitro* conditions tested was better than that of the conventional composites and did not appear to be influenced as much by erosion.

COLOR STABILITY OF LIGHT-CURED VS CHEMICALLY CURED COMPOSITES

Also in 1980, Miyagawa et al.³ studied the color stability of five commercial composites evaluated according to a proposed modification of ADA Specification No. 27. After exposure of 24 h to a sunlamp, light-cured composites showed greater changes in color than conventional and microfilled composites.

In 1990 Chang et al.⁴ investigated the color stability of seven visible light-cured and three chemically-cured composite resins while being subjected to UV light irradiation and storage in an aqueous environment at elevated temperatures. Color shift was evaluated visually and by colorimetric measurements. Significant correlation was found between visual scoring and colorimetric readings. When subjected to UV light, a wide deviation in color change existed from brand to brand in light-cured composite resins. The color shift of chemically cured composite resins was less than, but fell within the range of, light-cured composite resins. When stored in water at elevated temperatures, light-cured resins exhibited better color stability than the chemically cured composite resins.

In 2003 Schulze et al.⁵ investigated the color and microhardness changes of five chemical and five light-cured composites as a function of accelerated aging from light exposure. For each material, five composite specimens were embedded in epoxy resin prior to determining the Knoop microhardness of the surface. For analyzing the color with a spectrophotometer, three disks per composite were prepared. After measuring the baseline for hardness and color, the same specimens were exposed to a xenon arc light and water in a Weather-Ometer machine for a total radiant energy of 150 kJ/m² and 122 h. The microhardness and the color were again determined following aging treatment. Each material showed a significant increase in hardness after aging. Comparing the hardness changes (in %) of the light-cured materials with the chemically cured materials, no significant difference could be found. Perceptible color differences could be observed for all the materials. Three brands showed small differences with $\Delta E^* = 1.6-2.2$ (ΔE is the total color change), while four composites had ΔE^* ranging from 6.2 to 15.5. A

significant correlation between hardness values and color changes could not be established. The findings suggested that given the light-cured materials' greater resistance than chemically cured materials to color changes after accelerated aging by light and water, the light-cured materials could be more esthetically acceptable. Color changes were not correlated with surface hardness changes of the materials after aging.

THE EFFECT OF EXPOSURE TO ULTRAVIOLET LIGHT ON LIGHT-CURED COMPOSITES

In 1985 Wozniak et al.⁶ evaluated the ultraviolet light color stability of seven commercial composite resins after 1 day, 8 days, and 15 days of exposure. Color differences between exposed and unexposed specimens stored for identical time periods were determined. Samples exposed to ultraviolet light showed large changes in Munsell hue and chroma with smaller but significant changes in value. Unexposed samples showed small changes in the Munsell components, in some cases opposite to those observed for the exposed samples. Statistical analysis showed that although significant color changes were observed, brands of composite resins could not be distinguished by length of storage in the dark. Time of exposure was a significant variable at 24 h and 8 days. At 15 days a number of composite resins did not undergo additional significant color change. Scanning electron microscopy (SEM) showed a significant roughening of the surface of exposed composites with resin breakdown and exposure of the composite filler.

In 1997 Leibrock et al.⁷ evaluated the color stability of six visible light-cured fine hybrid composites after 24 h and 120 h of irradiation using a xenon lamp. Discoloration of four shades of each material (A1, A2, A3.5 and B2-Vita shade guide) was measured

using a reflection spectrophotometer with the CIE-L*a*b* system (CIELAB). The discoloration after 24 h of irradiation had values of between 0.7 and 3.8 ΔE^* and was therefore clinically acceptable with the exception of Z100 (colors A1 and B2). The results showed the differences in color of all shades of Pekafill NF and Tetric tested were significantly less than those of the other products. All samples with the exception of Pekafill NF (A3.5 and B2) showed increased discoloration to values of 3.7 to 7.8 ΔE^* after 120 h of exposure to UV light. In general, all the composites tended to become more yellow (b^*), darker (L^*) and slightly greener (a^*).

In 1998 Uchida et al.⁸ evaluated the color changes in composites as a function of shade through environmental effects such as ultraviolet light exposure. Five shades of two composites were subjected to ultraviolet light exposure at 37°C for 24 h after initial storage for 24 h in distilled water at 37°C. The lightness and chromaticity values of color were measured both before and after ultraviolet light exposure with a Minolta Chromameter. The total color change as well as changes in the lightness and chromaticity values were measured with the CIELAB scale and analyzed to monitor color degradation, if any. It was found that color degradation was a significant function of shade and occurred primarily as an increase in yellowness. Color changes increased with the lightness of the shade in both composite systems. It has been concluded that the lighter shades of composites were likely to be subject to higher color degradation through the environmental effects of ultraviolet light exposure.

In 2005 Gaintantzopoulou et al.⁹ evaluated the color stability of the surface and in-depth (2 mm) layer of two resin composites, a laboratory second-generation resin composite and a compomer after 24 h and 360 h of water aging under dark and UV light

conditions. The influence of various polymerization techniques on color changes was also evaluated. Color differences (ΔE^*) showed higher color changes under UV light exposure than under dark storage, both at 24-h and 360-h evaluations. Color changes were significantly higher at the 360-h assessment in both conditions of maintenance. The compomer was the least color-stable of the materials tested. Additional polymerization significantly decreased the color change of both composite resins.

In 2006 Lu et al.¹⁰ tried to determine the differences in color and color parameters such as lightness, chroma, and hue of composite resins created by varying the amount of UV component of a pulsed-xenon source that is conditioned to approximate the Commission Internationale de l'Eclairage (CIE) standard illuminant D65.

A spectrophotometer, in which the UV component of a daylight simulator could be adjusted, was developed. Eight light-polymerized dental composite resins, A3 shade, were studied. Five disk-shaped specimens, 10 mm x 3 mm, were prepared for each material. The color of the specimen was measured on a reflection spectrophotometer over a white background relative to three illuminations, which had the same spectral power distribution of the CIE standard illuminant D65 in the visible range, but a different UV component. The D65 indicated the illumination for which the UV component of the pulsed-xenon source was adjusted, the CIE standard illuminant D65, by using a UV adjustment tile. The UV-EXC indicated the illumination for which the UV component of the source was excluded with a UV filter. The UV-INC indicated the illumination for which the UV component was included.

It was found that color differences (ΔE^*) by the amount of UV component in the illuminations ranged between 0.3 and 1.4 for D65 and UV-EXC, between 0.3 and 0.5 for

D65 and UV-INC, and between 0.2 and 1.6 for UV-EXC and UV-INC. Based on the repeated-measures analysis of variance (ANOVA), lightness was not influenced by the amount of the UV component in the illumination; however, chroma and hue were influenced by the amount of UV component.

It was concluded that though there were significant differences in color and color parameters by the amount of the UV component in the D65-simulated xenon source, color difference caused by the UV component was lower than 1.6, which is in the visually acceptable range.

In 2006 Lee et al.¹¹ evaluated the changes in opalescence and fluorescence properties of resin composites after accelerated aging for 24 hours. Changes in translucency and masking effect were also determined. Color and spectral distribution of seven resin composites (A2 shade, 1-mm thick) were measured in the reflectance and transmittance modes under ultraviolet light (UV)-included and excluded conditions. The opalescence parameter (OP) was calculated as the difference in yellow-blue (Δb^*) and red-green (Δa^*) coordinates between the reflected and transmitted colors under UV-included and excluded conditions. For the fluorescence evaluation, color differences (FL-Ref and FL-Trans) by the inclusion or exclusion of the UV-component of the standard illuminant D65 in the reflectance and transmittance modes were calculated. Under UV-included and excluded conditions, the translucency parameter (TP) was calculated, and the masking effect (ME) was calculated as the color difference between a specimen over a black tile and black tile itself. It was found that OP values in UV-included and excluded conditions did not change significantly after aging. FL-Ref and FL-Trans, TP values and ME values in UV-included and excluded conditions changed significantly after aging

($p < 0.05$). The ranges of changes after aging in ΔE units were: OP, -0.50 to 0.74; FL, -1.19 to 0.15; TP, -1.37 to 0.13; and ME, -0.49 to 0.33. Therefore, the opalescence of resin composites did not change, but fluorescence was not detected after accelerated aging with 150 kJ/m^2 . Translucency and masking effect changed significantly after aging.

THE EFFECT OF STAINING SOLUTIONS

In 1989 Satou et al.¹² published a study that tested the color stability of composites after immersing them in different solutions. The adsorption of staining materials to resin restoratives was considered to be influenced by the physico-chemical properties of the resin-based monomers. To study the effects of the surface characteristics of resins on staining, they prepared five visible-light-cured experimental resins without fillers. Staining of these resins was colorimetrically measured. The staining solutions used were Oil Orange and Food Red 3. With the Oil Orange solution, the materials with higher hydrophobicity showed higher staining. With the Food Red 3 solution, the materials with higher water sorption showed higher staining.

In 1994 Dietschi et al.¹³ evaluated the color stability of modern light-cured composites when subjected to various physico-chemical and staining conditions. Ten brands of light-cured composites were evaluated including hybrids, microfine hybrids and microfilled composites. Some universal shade samples underwent only staining tests, while others were subjected to one of the following experimental conditions: thermocycling, post-curing, polishing or a 1-wk immersion in saline, prior to staining. The coloring solutions used for the staining tests were: coffee, E 110 food dye, vinegar and erythrosin. A colorimetric evaluation according to the CIELAB system was performed after experimental periods of 1 wk and 3 wk. It was found that erythrosin

caused the greatest color change for the composites tested. A reduced susceptibility to staining was observed where surfaces had been polished. Low water sorption, a high filler-resin ratio, reduced particle size and hardness, and an optimal filler-matrix coupling system were related to improved composite resistance to discoloration. It was concluded that the resistance of modern composites to discoloration still depends on their structure and manipulation.

COLOR CHANGE BEFORE AND AFTER LIGHT CURING

In 1990 Seghi et al.¹⁴ evaluated three shades of nine light-cured composites to determine the colorimetric changes that occur as a result of the photo-polymerization reaction. A photo-electric tristimulus colorimeter was used to measure the color of a 0.5-mm-thick sample of composite on two different backgrounds before and after the polymerization process had been initiated. The results showed that each of the photo-initiated composites tested produced a visually significant change in color as a result of the polymerization reaction, regardless of the shade of the backing. In general, the light-cured composites produced a characteristic chromatic shift toward the blue region of color space, which resulted in a perceived decrease in yellow chroma. Therefore, direct shade selection of a resin composite that is more yellow or more chromatic than the tooth being restored is recommended to compensate for this characteristic immediate color shift.

In 1995 Eldiwany et al.¹⁵ tested the color stability of five composites after light-curing and recommended post-curing using reflection spectrophotometry. Samples of the composites were prepared as disks 10 mm in diameter and 1 mm thick. The pre-cured

samples were prepared with a clear plastic sheet on the top and bottom of the disk, pressed between two glass slabs to the thickness of the mold, and then removed from between the glass slabs. The color of the samples was measured with the clear plastic sheets in place. The color of the composites before curing served as the control. It was found that light-curing caused barely perceptible to perceptible color changes for all the composites from the pre-cured shade. Clearfil and TrueVitality changed color significantly more than Charisma, Conquest C&B and Herculite XRV. Once the composites were light-cured, post-curing caused no further perceptible changes in shade.

In 2002 Paravina et al.¹⁶ evaluated curing-dependent changes in color and translucency parameter (TP) values of composite bleach shades. Thirty bleach shades of microhybrid and microfill composites were analyzed. Specimens ($n = 5$) were made as disks, 10 mm in diameter and 2 mm thick, using cylindrical molds. Specimens were polymerized for 60 seconds using a light-curing unit. Data were collected before and after composite curing using a spectrophotometer and analyzed using the appropriate color-difference metric equations. It was found that $L^*a^*b^*$ values (maximum minus minimum values) for microhybrids were 17.7, 2.91, and 7.97, respectively. Corresponding ranges for microfills were 14.4, 1.26, and 4.27, respectively. Curing-dependent color differences varied from 3.7 to 12.0 ΔE^* units, whereas TP values of cured resin composites varied from 2.0 to 7.1. Light-curing caused an increase of microhybrid TP values (+0.7) and a decrease of microfill TP values (-0.7). Color differences were found to be acceptable for five of six composite pairs of the same shade designation (each of them made by the same manufacturer) in post-curing measurements against a white background. Curing-dependent color and TP changes indicated that dentists should use cured composite for

matching of shade and translucency. Tested materials became less saturated, with microhybrids becoming darker and microfills becoming lighter after polymerization. Light-curing caused an increase in translucency of microhybrids and a reduced translucency in microfills.

In 2006 Sidhu et al.¹⁷ evaluated color and translucency changes caused by light curing resin composite materials. The CIELAB parameters (L^* , a^* and b^*) of disks of A2 and opaque A2 shades of Charisma (Heraeus-Kulzer), Solare (GC) and Filtek Supreme (3M) were evaluated on the backings of black, white, and the material itself both before and after light curing to evaluate color and translucency changes (by means of calculating ΔE^* and the translucency parameter, respectively). It was found that Solare and Filtek Supreme showed significantly smaller color changes during light curing than Charisma (ΔE was 1, 0.68, and 2.76 for Solare, Filtek Supreme, and Charisma respectively); however, the value of ΔE^* of all the products/shades was still in the clinically unacceptable range. Regarding translucency changes during light curing, the A2 and opaque A2 shades of Charisma showed a statistically significant increase, although no difference was observed in the other products (translucency changes were 1.19, 0.84, and 1.58 for Solare, Filtek Supreme, and Charisma respectively). It was concluded that Solare and Filtek Supreme tended to show less changes in translucency and color during light curing compared to Charisma. Nevertheless, the changes in color during light curing were still in the range of unacceptable color change. Therefore, direct shade matching of these materials for a precise shade match should be performed by using the cured material.

Also in 2006, Kim et al.¹⁸ measured the color change of varied shades of dental resin composites after polymerization and determined the correlation among the

polymerization color changes and the changes in color parameters after polymerization. Eight light-curing resin composites, a total of 41 shades, were studied. The color of specimens (1 mm in thickness) was measured on a reflection spectrophotometer before and after polymerization over a white background. Changes in color ($\Delta E^*(ab)$), and color parameters (ΔL^* , Δa^* , and Δb^* : [value after polymerization - value before polymerization]) were calculated. It was found that the range of changes in each shade of resin composite was 1.1-7.9 for color ($\Delta E^*(ab)$); -7.5 to 2.3 for ΔL^* ; -0.9 to 1.2 for Δa^* , and -6.8 to 3.1 for Δb^* . The $\Delta E^*(ab)$, ΔL^* , Δa^* , and Δb^* were influenced by the brand and shade of resin composites, and there was a significant interaction between two independent variables ($p < 0.05$). On the basis of the multiple regression analysis, in which $\Delta E^*(ab)$ after polymerization was set as a dependent variable and ΔL^* , Δa^* and Δb^* as independent variables, the multiple correlation coefficient (r) was 0.842 and the included predictors were ΔL^* [standardized partial correlation coefficient (β) = -0.760].

This result indicated that the polymerization changes in color and color parameters were varied by the brand and shade of resin composites, and the polymerization color change was caused by the changes in lightness and chroma with a similar power of influence.

THE EFFECT OF DIFFERENT CURING UNITS

In 2005 Usumez et al.¹⁹ determined color changes in a composite cured with various types of curing units after two years. A hybrid (Clearfil AP-X) composite was cured with a conventional halogen, a high intensity halogen, a plasma arc, and a light emitting diode unit. The specimens were stored in light-proof boxes after the curing

procedure to avoid further exposure to light and stored in 37°C in 100-percent humidity. Colorimetric values of the specimens immediately after curing and after two years were measured using a colorimeter. The CIE 1976 L*a*b color system was used to determine color differences. Differences from baseline were calculated as ΔE^*ab . The values varied significantly, depending on the curing unit used. The specimens cured with a plasma-arc curing unit induced significantly higher color changes than any other specimen and the color differences were also visually appreciable by the non-skilled operator ($\Delta E^*ab > 2.5$). The specimens cured with a high-intensity halogen curing unit produced the lowest color change; however, there were no statistically significant differences among the color changes of specimens cured with conventional halogen, high-intensity halogen, and the light-emitting diode unit, and the color changes were not clinically relevant ($\Delta E^*ab < 2.5$). The results of this study suggest that composite materials undergo measurable changes due to curing-unit exposure. The specimens cured with a plasma-arc light showed the highest color changes as compared with specimens cured with other curing units. The reason behind that could be the high intensity of plasma-arc light is available at lower wavelengths compared with the other light units, and therefore, less curing ability of composite is obtained. Subsequently more color change occurred.

In 2005 Janda et al.²⁰ investigated the influence of curing devices and curing times on the color stability of filling resins by measuring the CIELAB values after performing dry storage, water storage, and a sun test (EN ISO 7491). Eight samples each of Charisma (CH), Durafill (DU), Definite (DE), and Dyract AP (DY) were light cured by using Translux Energy (TE) (Quartz Tungsten Halogen Light) for 20 s, 40 s or 60 s, or by using Apollo 95E (AP) (Plasma Arc Light) for 3 s, 10 s or 20 s. Minor color changes

occurred for all dry stored materials, devices, and curing times. The TE-cured, water-stored samples behaved similarly to the dry-stored ones, but the samples cured with AP revealed very strong color changes, mainly because of a drastic bleaching process. The bleaching of DU was significantly less than that of the other materials, but a strong white shift occurred. CH, DE, and DU showed very little (and even acceptable) discolorations after the sun test when TE-cured. DY showed a drastic discoloration. All samples cured using AP drastically bleached and shifted to white for DU and DY but to dark for DE. In conclusion, the extent of discoloration depended on 1) the material, 2) the test method, 3) curing time, and 4) the curing device. The halogen light-cured samples performed best.

Some studies have indicated the amount of residual monomer in a composite resin could affect the color stability of the composite. In 2006 Filipov et al.²¹ investigated the amount of residual monomer in a composite resin after light-curing with different sources, light intensities, and spectra of radiation. The resin specimens (4 mm in diameter; 2 mm thick) (n=5) were inserted in Plexiglass matrixes and light-cured with a halogen lamp, LED, and PAC units for 40 s, 40 s and 5 s, respectively. The polymerized specimens were ground and 25 mg of each specimen were immersed in 8 ml 96-percent ethanol for 24 h to extract the residual monomer. Data were analyzed statistically by variational dispersion analysis and a Tukey-Kramer test at a 5-percent significance level. It was observed the halogen lamp produced the smallest amount of monomer under sufficient light intensity. The spectrum of light radiation of the PAC was within the limits of 450 nm to 490 nm and was of extremely high intensity, but the amount of residual monomer recorded for the specimens cured with this device was statistically greater than the other two curing units. The LED unit had the best spectral radiation because it is in

narrower and more effective borders of light spectrum compared with the other two curing lights. An increase of light intensity was proved necessary.

In 2007 Janda et al.²² investigated the influence of a halogen light-curing device used with constant or exponential polymerization mode on the color stability of contemporary resin-based filling materials. Eight samples of Charisma (CH), Durafill (DU), Definite (DE), and Dyract AP (DY) each were light-cured with constant power or with soft-start mode (Translux Energy) for 20 s, 40 s or 60 s. The CIELAB values (L^* , a^* , b^*) were measured prior to and after performing dry aging, water aging or a sun test (EN ISO 7491) and ΔL , Δa , Δb , and ΔE values were calculated. Statistical analysis (GLM and repetition of measures) showed significant changes ($p < 0.05$) of the color values for each material's curing mode and time after each of the aging processes. Exponentially-cured DU was the most color-unstable material after aging in water followed by the 20-s exponentially cured DE and CH samples. After the sun test, DY showed significant bleaching (negative Δb) and the largest ΔE for all curing times and modes followed by the DE samples. DU and CH were the most color-stable materials in this test. So it was concluded that the extent of discoloration depends on the a) curing time, b) curing mode, c) aging condition, and d) material. For the constant curing mode, 40 s curing time for the exponential 60 s seems to be appropriate.

COLOR STABILITY IN DIFFERENT CONDITIONS

In 2000 Douglas²³ evaluated and characterized the color stability of various new-generation indirect resins (ceramic-polymers) when subjected to accelerated aging. Four new-generation indirect resin systems, one direct resin system, and one dental porcelain control were subjected to accelerated aging for a period of 300 h. Initial specimen color

parameters were determined in the Commission International de l'Eclairage Lab (CIELAB) color order system with a colorimeter. Color changes (ΔE) were calculated between baseline color measurements and measurements made after 150 h and 300 h of accelerated aging. It was found that after 300 h of accelerated aging, color changes of the indirect resins ranged between 0.62 and 3.40 ΔE units. Two of the products tested demonstrated color stability that was not significantly different from the porcelain control. It was concluded that all indirect resins tested demonstrated color stability at or below a quantitative level that would be considered clinically acceptable. Color changes of ceramic-polymers occurred because of changes in chroma, rather than alterations in lightness.

In 2007 Sarafianou et al.²⁴ evaluated the color changes and amount of remaining C = C bonds (% RDB) in three dental composites after hydrothermal- and photo-aging. The materials tested were Estelite Sigma, Filtek Supreme and Tetric Ceram. Specimens were fabricated from each material and subjected to L* a* b* colorimetry and FTIR spectroscopy before and after aging. Statistical evaluation of the ΔL^* , Δa^* , Δb^* , ΔE and % ΔRDB data was done by one-way ANOVA and Tukey's test. It was found that no significant differences existed in ΔL^* , Δa^* , ΔE and % ΔRDB among the materials tested. Tetric Ceram demonstrated a significant difference in Δb^* . All the materials showed visually perceptible ($\Delta E > 1$) but clinically acceptable values ($\Delta E < 3.3$). Within each material group, statistically significant differences in % RDB were noticed before and after aging ($p < 0.05$). Filtek Supreme presented the lowest % RDB before aging, with Tetric Ceram presenting the lowest % RDB after aging ($p < 0.05$). The % ΔRDB mean values showed statistically significant differences among all the groups tested. No

correlation was found between ΔE and % ΔRDB . Subsequently, we can conclude that the color changes are not affected by the amount of remaining C = C bonds.

After reviewing the literature, it is apparent that researchers have evaluated the change in color of different shades of composite after curing, accelerated aging, or immersing in different solutions. Some researchers have measured the change in the color of the composite after exposure to visible light, UV light, Xenon light, halogen light, plasma-arc light, and sunlight.

The results of the reported studies support the belief that curing composites using a light-curing unit (LED, PAC, or QTH) will result in a color change that is not perceptible clinically ($\Delta E < 3.3$). The major color change that can be detected clinically ($\Delta E \geq 3.3$) is a result of different aging or storing conditions (sunlamp, thermocycling, water immersion). Most studies were done on regular-shade composite resins, so that minimal evidence is available about the effect of different storing conditions on the color stability of bleach shade composites.

In addition, the effect of the sunlight on the color of these composites has not been thoroughly studied. More studies should be done on the color stability of these composites under different conditions. The hypothesis for the present study was that current commercial bleach shade composites activated by a high-intensity quartz-tungsten-halogen light source would show clinically perceptible color changes ($\Delta E \geq 3.3$)²⁵ when aged in different conditions.

MATERIALS AND METHODS

Twenty-six current commercial bleach shade composites were used in this study. These composites were: Point 4 (Kerr) shades (XL1, XL2, XL3); TPH (Dentsply/Caulk) shades (BW, XL, L); Filtek Supreme Plus (Filtek SP, 3M ESPE) shades (WE, WD, XWD, WB, XWB); Durafill VS (Kulzer) bleach shades (SL, SSL, SLO; Miris (Coltene-Whaledent) shades (WR, WB, NT, NR, IR); Tetric EvoCeram (Ivoclar Vivadent) shades (BL, BXL, BI, BM); Tescera (Bisco) shades (bleach 1, bleach 2, and bleach 3). Specifications of these composite brands are summarized in Table I.

For each test material, nine specimens were prepared at 22.0^o–22.5^oC (room temperature) and at a relative humidity of 50 percent. A white wax-coated cement-mixing pad was used to provide a consistent reflective background, and a strip of Mylar sheet with a white backing (Type D, DuPont Co., Wilmington, DE) was laid on top of the pad. A polyacetyl mold (diameter 9 mm, height 2 mm) was placed on the top of the Mylar sheet. The uncured composite paste was inserted into the open end of the mold. After slightly overfilling, a glass plate (26 x 77 x 1 mm, Fisher Scientific, Norcross, GA) was used to flatten the material to force the composite to adapt to the mold dimensions and thereby express excess material.

A high-intensity tungsten halogen (QTH) light (Optilux, Demetron Research Corp., Danbury, CT) with intensity of 900 mW/cm² to 1020 mW/cm² and an 11-mm light guide was used to cure the specimens. The specimens were irradiated from one side and in one step in constant polymerization mode for 60 s. The intensity of the curing unit was measured using a laboratory-grade radiometer (Model 100, Demetron Research

Corp., Danbury, CT). This measurement was done every two hours during the curing process to make sure the curing light had the minimum intensity required to cure the composite according to the manufacturer's guidelines. (Light intensity should be more than 800 mW/cm²) The curing tip of Optilux was held against the top of the glass slide centered over the specimen. The bottom surface of the specimen was marked after curing using a surgical scalpel to make all color measurements from the same top surface of the specimen, which was unmarked. After curing, all specimens were placed in a dry and dark plastic container.

Color measurements for all specimens were made after 90 minutes in this container to obtain baseline color values. The color measurements were made using a UV-VIS spectrophotometer (CM 2600 D, Konica Minolta Corp., Japan). After color measurement, nine specimens for each test material were subjected to different conditions; three specimens were placed in dark and dry storage using a dark plastic container that had been sealed and stored in an incubator at 37° C; three specimens were placed in distilled water in the dark using an amber glass bottle and stored in an incubator at 37° C, and three specimens were subjected to the sun test using a sunlamp of 275 watts (sunlamp style BM7, General Electric). The sunlamp specimens were placed 7 inches from the light source for 24 h in a dry environment in accordance with American Dental Association Specification No. 80 for Color Stability. Color measurements were made after 1 day, 7 days, and 90 days of storage in different conditions, and after 24 h of exposure to the sunlamp test. Three measurements were made for each specimen, and the mean value was used. One operator obtained all the color readings.

The CIELAB color system was used to determine the size of the color shift that occurred as a result of different storing conditions. The color parameters L^* , a^* , b^* were recorded for each specimen. The total color difference (ΔE) was calculated as follows:

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

SAMPLE SIZE JUSTIFICATION

It was found from reviewing the literature that the expected standard deviation for ΔE was 0.2. Assuming two-sided tests each at a 5-percent significance level, and a sample size of three specimens per storage method-composite combination (243 total specimens), the study had 80-percent power to detect a difference in ΔE of 3.0 between any two storage methods for each composite at each time.

STATISTICAL METHODS

Repeated-measures ANOVA were used to evaluate the effects of storage method, composite, and time on the color changes. Terms for storage method, composite, time, and interactions among the three factors were included in the ANOVA, as well as effects to allow for correlations among the multiple times within a specimen. A 5-percent significance level was used for all comparisons.

RESULTS

Storing bleach shade composites in distilled water, dark and dry storage, or subjecting them to the sunlamp for 24 h resulted in a wide range of readings. The ΔE values for 1 day of dark and dry storage ranged from 0.23 for Durafill (SLO) to 2.30 for Point 4 (XL2) (Table II). Values for 7 days ranged from 0.30 for Miris (NT) to 3.79 for Point 4 (XL2). Values for 30 days ranged from 0.50 for EvoCeram (BM) to 3.97 for Point 4 (XL2). Storage in H₂O for 24 hours resulted in ΔE that ranged from 0.43 for Miris (IR) to 2.57 for Point 4 (XL2) (Table III). Values for 7 days ranged from 0.31 for EvoCeram (BXL) to 3.22 for Point 4 (XL2). Values for 30 days ranged from 0.58 for Durafill (SL) to 3.65 for Point 4 (XL2). Sunlamp exposure resulted in a greater range of ΔE compared with other storage methods. Sunlamp exposure for 24 hours resulted in ΔE that ranged from 1.30 for Miris (NT) to 9.29 for Tescera 1 (Table IV). It can be said that ΔE for a specimen subjected to a certain condition or storage is directly proportional to the time elapsed while the specimen was stored in that condition.

The sunlamp exposure resulted in more composites with $\Delta E \geq 3.3$ than the other two storage methods. The following group-storage-time combinations had mean ΔE of 3.3 or higher: 1) Sunlamp: EvoCeram (BL), EvoCeram (BM), EvoCeram (BXL), Tescera 1, Tescera 2, Tescera 3. 2) Dark and dry 30 days: Point 4 (XL2); 3) Dark and dry 7 days: Point 4 (XL2); 4). H₂O 30 days: Point 4 (XL2).

On the other hand, comparing dark and dry storage with H₂O storage for the same storage time resulted in inconclusive results; for example, some composites (Durafill [SL, SLO], Miris [NT, WB, WR], Point 4 [XL1, XL2]) when stored in dark and dry storage

for 1 day had significantly less change in ΔE than when stored in H₂O for the same time period. However, other composites (EvoCeram [B1, BM], Filtek Supreme Plus [WB, WE, XWB, XWD], Miris [IR], Tescera 1, 2, 3, TPH [L, XL]) had significantly more change in ΔE (Table V and Table VIII).

For 7 days, it was noticed that fewer composite shades (Durafill (SSL), EvoCeram (BM), Miris [NT, WB] showed less change in ΔE in dark and dry storage when compared with H₂O storage, while others showed exactly the opposite (Durafill [SL], EvoCeram [BL, BXL], Filtek Supreme Plus [WB, XWD], Miris [IR, NR], Point 4 [XL1, XL2], Tescera 1, 2, 3, TPH [BW, L, XL]) (Table VI and Table IX).

For 30-day storage, it was noticed that fewer composite shades (Durafill [SLO, SSL], EvoCeram [BI, BM], Miris [WB] showed less change in ΔE in dark and dry storage when compared with H₂O storage while others (Durafill [SL], Filtek Supreme Plus [XWD], Miris [NT], Point 4 [XL1], [XL2], Tescera 1, 2, 3, TPH [BW, L, XL]) showed exactly the opposite (Table VII and Table X).

Time comparisons for specimens in the same storage medium did not yield conclusive results where it was found that some composites had significantly less change in ΔE when stored in dark and dry storage for 1 day than when stored in the same storage for 7 days (Durafill [SL, SLO, SSL], Miris [WR], Point 4 [XL1], [XL2], [XL3], Tescera 2, 3, TPH [L]), while others did exactly the opposite (EvoCeram [BI, BL, BM] Filtek Supreme Plus [WB, WE, XWB, XWD], Miris [NR, NT]) (Table V, Table VI, and Table VII).

Generally, it can be said that dark and dry storage in regard to any time comparisons (1:7), (1:30), (7:30) did not produce conclusive results. The same result

applies to storage in H₂O. Color difference (ΔE) was found to be within an acceptable clinical range ($\Delta E < 3.3$) for 25 shades of the composites tested in dark and dry or in H₂O except for Point 4 (XL2) in dark and dry storage for 30 days (Tables V through Table X). The color difference had more range and was above the threshold of 3.3 for 6 shades out of 26 shades tested after 24-h exposure of the sunlamp (Table XI).

TABLES AND FIGURES

TABLE I

Composite brands, filler content, shades, and lot numbers used in the research

<i>Composite Brand/Filler Content (% by Weight)</i>	<i>Shades</i>	<i>Lot Number</i>
Point 4 (Kerr)/77%	XL1	2955288
	XL2	2760903
	XL3	2787091
TPH (Dentsply-Caulk)/Less than 80%	BW	0706151
	XL	0709271
	L	070517
Filtek SP (3M ESPE)/72.5%	WE	8BX
	WD	7BT
	XWD	7AY
	WB	8BP
	XWB	8BG
Durafill (Heraeus Kulzer)/80.5%	SL	010303
	SSL	010126
	SLO	010301
Miris (Coltene-Whaledent)/80%	WR	0111399
	WB	0106136
	NT	0135580
	NR	0118703
	IR	0152850
Tetric EvoCeram (Ivoclar Vivadent)/82%	BL	J19095
	BXL	J26850
	BI	K15704
	BM	K08667
Tescera (Bisco)/Less than 80%	Bleach 1	0800004127
	Bleach 2	0800006561
	Bleach 3	0800006562

TABLE II

Color readings for composite groups in dark and dry storage for 1 day, 7 day, and 30 days

Dark & Dry Group	Time (days) N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Durafill(SL)	1	3	66.22	-2.19	2.11	-0.41	1.20	0.17	0.06	0.02	0.26	1.10	0.06		
	7	3	67.78	-2.30	2.51	1.16	0.22	0.05	0.05	0.42	0.37	1.28	0.10		
	30	3	67.79	-2.31	2.60	1.16	0.36	0.04	0.02	0.52	0.43	1.34	0.20		
Durafill(SLO)	1	3	74.12	-2.31	2.36	0.05	0.15	0.08	0.12	-0.10	0.14	0.23	0.08		
	7	3	74.42	-2.32	3.28	0.35	0.16	0.07	0.04	0.82	0.11	0.90	0.05		
	30	3	74.47	-2.31	3.43	0.40	0.23	0.08	0.04	0.97	0.12	1.07	0.06		
(Durafill(SSL)	1	3	75.66	-1.80	1.45	-0.02	0.59	-0.03	0.05	0.58	0.29	0.78	0.17		
	7	3	76.03	-1.75	1.84	0.35	0.27	0.02	0.02	0.97	0.03	1.05	0.08		
	30	3	76.12	-1.77	2.07	0.44	0.21	0.00	0.02	1.20	0.06	1.29	0.13		

(continued)

TABLE II (continued)

Color readings for composite groups in dark and dry storage for 1 day, 7 day, and 30 days

Dark & Dry Group	Time (days)	N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
EvoCeram(BI)	1	3	59.07	-1.26	2.42	0.69	0.33	-0.05	0.25	0.25	0.95	0.22	1.23	0.08		
	7	3	58.22	-1.14	1.33	-0.16	0.97	0.07	0.13	-0.14	0.50	0.92	0.12			
	30	3	58.79	-1.04	1.02	0.41	0.79	0.16	0.05	-0.45	0.49	0.98	0.14			
EvoCeram(BL)	1	3	65.67	-2.04	1.43	0.41	0.61	0.35	0.21	1.15	0.06	1.37	0.06			
	7	3	65.80	-2.00	0.92	0.55	0.52	0.39	0.24	0.64	0.17	1.05	0.09			
	30	3	66.28	-2.09	0.85	1.02	0.13	0.30	0.21	0.57	0.13	1.23	0.08			
EvoCeram(BM)	1	3	64.71	-1.00	3.00	-0.29	0.15	0.32	0.28	0.70	0.11	0.86	0.15			
	7	3	64.59	-0.97	2.57	-0.40	0.23	0.34	0.31	0.28	0.11	0.68	0.03			
	30	3	65.08	-1.03	2.36	0.09	0.40	0.28	0.27	0.06	0.15	0.50	0.13			

(continued)

TABLE II (continued)

Color readings for composite groups in dark and dry storage for 1 day, 7 day, and 30 days

Dark & Dry Group	Time (days)	N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
EvoCeram(BXL)	1	3	82.58	2.41	4.31	0.22	0.25	0.24	0.29	0.24	0.14	0.23	0.51	0.09		
	7	3	82.74	2.35	4.00	0.39	0.15	0.35	0.14	-0.17	0.25	0.61	0.06			
	30	3	82.99	2.47	3.91	0.64	0.32	0.23	0.15	-0.27	0.33	0.82	0.14			
Filtek SP(WB)	1	3	69.34	1.23	4.17	-1.18	0.25	0.32	0.06	1.01	0.26	1.61	0.01			
	7	3	69.62	1.06	4.04	-0.90	0.05	0.49	0.02	0.88	0.09	1.35	0.07			
	30	3	69.92	1.04	4.15	-0.60	0.30	0.51	0.02	0.99	0.06	1.28	0.13			
Filtek SP(WD)	1	3	76.69	3.49	-1.69	-0.55	0.34	0.27	0.05	0.44	0.27	0.84	0.03			
	7	3	77.05	3.24	-1.53	0.18	0.10	0.52	0.17	0.60	0.12	0.84	0.04			
	30	3	77.27	3.16	-1.76	0.04	0.22	0.60	0.07	0.37	0.16	0.74	0.06			

(continued)

TABLE II (continued)

Color readings for composite groups in dark and dry storage for 1 day, 7 day, and 30 days

Dark & Dry Group	Time (days) N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Filtek SP(WE)	1	3	61.88	-1.38	-0.02	-0.38	0.07	0.54	0.33	0.92	0.25	1.18	0.15		
	7	3	61.91	-1.34	-0.55	-0.36	0.42	0.58	0.03	0.39	0.08	0.85	0.12		
	30	3	62.28	-1.28	-0.42	0.01	0.33	0.64	0.03	0.52	0.10	0.87	0.07		
Filtek SP(XWB)	1	3	73.51	-2.33	-0.63	-0.96	0.10	0.40	0.02	0.78	0.05	1.30	0.08		
	7	3	73.79	-2.15	-1.02	-0.67	0.15	0.58	0.02	0.39	0.24	0.99	0.11		
	30	3	73.76	-2.10	-0.97	-0.71	0.15	0.63	0.01	0.44	0.19	1.06	0.15		
Filtek SP(XWD)	1	3	78.58	-1.47	4.43	-0.39	0.39	-0.12	0.22	2.01	0.07	2.08	0.03		
	7	3	78.63	-1.52	4.04	-0.34	0.08	-0.16	0.14	1.62	0.15	1.67	0.15		
	30	3	78.98	-1.48	4.24	0.01	0.13	-0.12	0.15	1.82	0.17	1.83	0.18		

(continued)

TABLE II (continued)

Color readings for composite groups in dark and dry storage for 1 day, 7 day, and 30 days

Dark & Dry Group	Time (days) N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Mirris(IR)	1	3	58.22	-0.15	7.54	0.08	0.25	0.18	1.24	0.05	1.31	0.07			
	7	3	58.68	-0.33	7.44	0.15	0.04	0.08	0.13	1.14	0.12	1.16	0.10		
	30	3	59.01	-0.37	7.74	0.48	0.21	0.03	0.21	1.44	0.24	1.55	0.15		
Mirris(NR)	1	3	60.35	0.68	3.21	0.68	0.19	0.07	0.12	0.62	0.10	0.94	0.11		
	7	3	59.97	0.63	3.08	0.30	0.25	0.02	0.12	0.50	0.10	0.62	0.12		
	30	3	60.58	0.58	3.38	0.90	0.11	-0.03	0.13	0.80	0.17	1.22	0.09		
Mirris(NT)	1	3	56.27	1.16	3.60	0.49	0.04	0.14	0.06	0.05	0.18	0.53	0.04		
	7	3	55.93	0.95	3.62	0.15	0.13	-0.07	0.17	0.07	0.22	0.30	0.05		
	30	3	56.96	0.90	3.90	1.18	0.11	-0.12	0.18	0.34	0.42	1.29	0.09		

(continued)

TABLE II (continued)

Color readings for composite groups in dark and dry storage for 1 day, 7 day, and 30 days

Dark & Dry Time	L*	a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Mirris(WB)	3	62.66	-1.53	-0.51	0.08	0.15	0.18	0.10	-0.09	0.12	0.25	0.15	
	7	62.86	-1.76	-0.31	0.28	0.11	-0.06	0.04	0.11	0.14	0.33	0.09	
	30	63.05	-1.85	0.12	0.47	0.28	-0.14	0.03	0.54	0.06	0.76	0.12	
Mirris(WR)	3	61.69	-1.38	0.31	0.09	0.11	-0.06	0.09	-0.34	0.06	0.38	0.04	
	7	62.10	-1.44	0.50	0.50	0.17	-0.13	0.13	-0.15	0.14	0.56	0.14	
	30	62.10	-1.47	0.93	0.50	0.13	-0.16	0.12	0.28	0.15	0.62	0.08	
Point4(XL1)	3	68.85	-2.79	-0.06	-0.03	0.21	-0.07	0.04	0.83	0.09	0.86	0.08	
	7	69.31	-3.20	0.89	0.43	0.49	-0.48	0.10	1.78	0.11	1.94	0.06	
	30	69.50	-3.19	1.21	0.62	0.48	-0.47	0.06	2.10	0.25	2.29	0.08	

(continued)

TABLE II (continued)

Color readings for composite groups in dark and dry storage for 1 day, 7 day, and 30 days

Dark & Dry Group	Time (days)	N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Point4(XL2)	1	3	80.06	3.57	3.89	0.42	-0.21	0.42	0.03	-0.31	0.03	2.24	0.06	2.30	0.04	
	7	3	80.38	4.01	5.33	0.11	0.55	-0.75	0.05	3.68	0.05	3.79	0.09			
	30	3	80.40	3.97	5.54	0.13	0.29	-0.71	0.04	3.90	0.11	3.97	0.09			
Point4(XL3)	1	3	89.58	2.24	5.88	0.21	0.16	0.07	0.12	1.09	0.14	1.13	0.10			
	7	3	89.54	2.41	6.99	0.17	0.21	-0.09	0.14	2.20	0.12	2.22	0.09			
	30	3	90/54	2.39	7.33	0.17	0.14	-0.08	0.13	2.54	0.06	2.55	0.06			
TPH(BW)	1	3	76.97	2.84	0.87	0.08	-0.57	0.08	-0.02	0.07	1.37	0.17	1.48	0.13		
	7	3	76.88	2.81	0.94	-0.65	0.30	0.01	0.11	1.44	0.21	1.61	0.04			
	30	3	77.31	2.88	0.98	-0.22	0.34	-0.05	0.11	1.48	0.08	1.53	0.07			

(continued)

TABLE II (continued)

Color readings for composite groups in dark and dry storage for 1 day, 7 day, and 30 days

Dark & Dry Group	Time (days)	N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TPH(L)	1	3	68.59	2.02	3.83	-0.56	0.23	0.08	-0.02	0.08	1.34	0.04	1.46	0.11		
	7	3	68.31	-1.83	4.08	-0.84	0.02	0.17	0.05	1.59	0.05	1.81	0.04			
	30	3	68.66	-1.82	4.21	-0.50	0.01	0.18	0.07	1.72	0.17	1.80	0.16			
TPH(XL)	1	3	70.57	-1.59	2.68	0.00	0.42	0.09	-0.04	0.09	1.75	0.09	1.79	0.06		
	7	3	70.31	-1.52	2.82	-0.26	0.34	0.02	0.08	1.90	0.09	1.93	0.11			
	30	3	70.43	-1.54	2.99	-0.13	0.24	0.01	0.09	2.07	0.08	2.08	0.10			
Tescera 1	1	3	79.58	-2.23	5.42	-0.60	0.15	0.11	0.08	1.68	0.09	1.79	0.07			
	7	3	79.73	-2.25	5.54	-0.45	0.18	0.09	0.09	1.80	0.03	1.87	0.04			
	30	3	80.07	-2.35	5.74	-0.11	0.27	0.00	0.08	2.00	0.03	2.02	0.01			

(continued)

TABLE II (continued)

Color readings for composite groups in dark and dry storage for 1 day, 7 day, and 30 days

Dark & Dry Group	Time (days)	N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Tescera 2	1	3	74.95	-2.18	4.63	0.61	-0.28	0.17	0.06	1.80	0.04	1.90	0.04			
	7	3	75.22	-2.21	4.98	-0.01	0.54	0.14	0.07	2.16	0.11	2.21	0.07			
	30	3	75.35	-2.33	5.33	0.12	0.64	0.02	0.08	2.50	0.13	2.56	0.14			
Tescera 3	1	3	70.78	-1.17	4.18	0.58	0.15	0.09	0.10	1.78	0.10	1.89	0.06			
	7	3	70.82	-1.25	4.35	0.62	0.18	0.01	0.09	1.95	0.11	2.05	0.09			
	30	3	71.08	-1.34	4.61	0.88	0.30	-0.07	0.10	2.21	0.16	2.39	0.11			

TABLE III

Color readings for composite groups in H₂O storage for 1 day, 7 days, and 30 days

H ₂ O Group	Time (days)	N	L*		a*		b*		ΔL*		Δa*		Δb*		ΔE*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Durafill(SL)	1	3	65.61	-2.15	2.25	-1.33	0.13	0.16	0.08	0.33	1.37	0.10				
	7	3	67.42	-2.31	2.74	0.47	0.19	-0.01	0.02	0.49	0.04	0.69	0.14			
	30	3	66.78	-2.38	2.75	-0.17	0.19	-0.08	0.13	0.50	0.13	0.58	0.05			
Durafill(SLO)	1	3	74.30	-2.67	3.22	0.11	0.07	-0.24	0.10	0.74	0.07	0.79	0.09			
	7	3	74.09	-2.15	3.20	-0.10	0.11	-0.27	0.15	0.72	0.14	0.80	0.13			
	30	3	73.98	-2.21	3.82	-0.21	0.07	0.22	0.10	1.34	0.15	1.38	0.13			
(Durafill(SSL)	1	3	75.44	-1.28	1.37	0.15	0.49	0.48	0.07	0.43	0.22	0.79	0.12			
	7	3	75.75	-1.59	2.32	0.45	0.48	0.17	0.22	1.39	0.10	1.53	0.10			
	30	3	75.69	-1.64	3.20	0.40	0.52	0.12	0.29	2.26	0.03	2.35	0.03			

(continued)

TABLE III (continued)

Color readings for composite groups in H₂O storage for 1 day, 7 days, and 30 days

H ₂ O Group	Time (days)	N	L*		a*		b*		ΔL*		Δa*		Δb*		ΔE*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
EvoCeram(BI)	1	3	59.15	1.45	-1.45	1.45	1.45	1.45	0.22	0.47	0.31	0.36	-0.17	0.62	0.80	0.14
	7	3	59.35	1.31	-1.31	1.26	1.26	0.42	0.09	0.45	0.29	-0.36	0.48	0.84	0.13	
	30	3	60.43	1.62	-1.62	2.01	2.01	1.50	0.36	0.14	0.74	0.38	0.44	1.73	0.18	
Durafill(SL)	1	3	65.61	2.15	-2.15	2.25	2.25	-1.33	0.13	0.16	0.08	0.00	0.33	1.37	0.10	
	7	3	67.42	2.31	-2.31	2.74	2.74	0.47	0.19	-0.01	0.02	0.49	0.04	0.69	0.14	
	30	3	66.78	2.38	-2.38	2.75	2.75	-0.17	0.19	-0.08	0.13	0.50	0.13	0.58	0.05	
Durafill(SLO)	1	3	74.30	2.67	-2.67	3.22	3.22	0.11	0.07	-0.24	0.10	0.74	0.07	0.79	0.09	
	7	3	74.09	2.15	-2.15	3.20	3.20	-0.10	0.11	-0.27	0.15	0.72	0.14	0.80	0.13	
	30	3	73.98	2.21	-2.21	3.82	3.82	-0.21	0.07	0.22	0.10	1.34	0.15	1.38	0.13	

(continued)

TABLE III (continued)

Color readings for composite groups in H₂O storage for 1 day, 7 days, and 30 days

H ₂ O Group	Time (days)	N	L*		a*		b*		ΔL*		Δa*		Δb*		ΔE*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
EvoCeram(BI)	1	3	59.15	1.45	-1.45	1.45	1.45	1.45	0.22	0.47	0.31	0.36	-0.17	0.62	0.80	0.14
	7	3	59.35	1.31	-1.31	1.26	1.26	1.26	0.42	0.09	0.45	0.29	-0.36	0.48	0.84	0.13
	30	3	60.43	1.62	-1.62	2.01	2.01	1.50	0.36	0.14	0.74	0.38	0.44	1.73	0.18	
EvoCeram(BL)	1	3	65.69	2.15	-2.15	0.64	0.64	0.15	0.24	0.11	0.30	0.08	0.45	0.52	0.10	
	7	3	65.75	2.11	-2.11	0.49	0.49	0.20	0.30	0.15	0.45	-0.06	0.27	0.55	0.14	
	30	3	66.06	2.12	-2.12	1.48	1.48	0.52	0.26	0.14	0.48	0.92	0.22	1.16	0.12	
EvoCeram(BM)	1	3	65.10	1.25	-1.25	2.32	2.32	-0.33	0.45	-0.07	0.37	0.01	0.23	0.61	0.04	
	7	3	65.18	1.24	-1.24	2.05	2.05	-0.24	0.86	-0.06	0.40	-0.26	0.21	0.87	0.08	
	30	3	64.80	0.95	-0.95	2.43	2.43	-0.63	0.07	0.23	0.09	0.12	0.42	0.76	0.12	

(continued)

TABLE III (continued)

Color readings for composite groups in H₂O storage for 1 day, 7 days, and 30 days

H ₂ O Group	Time (days)	N	L*		a*		b*		ΔL*		Δa*		Δb*		ΔE*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
EvoCeram(BXL)	1	3	82.71	-2.39	3.70	3.70	-0.12	0.18	0.10	0.28	0.12	0.38	0.46	0.04		
	7	3	82.79	-2.32	3.63	3.63	-0.04	0.04	0.17	0.20	0.05	0.24	0.31	0.06		
	30	3	87.76	-2.34	4.25	4.25	-0.06	0.17	0.15	0.24	0.67	0.11	0.73	0.08		
Filtek SP(WB)	1	3	69.87	-1.17	3.78	3.78	-0.67	0.19	0.41	0.01	0.85	0.10	1.17	0.13		
	7	3	70.70	-1.20	3.08	3.08	0.16	0.37	0.39	0.54	0.15	0.55	0.82	0.10		
	30	3	71.40	-1.25	3.16	3.16	0.86	0.41	0.34	0.71	0.23	0.60	1.26	0.08		
Filteak SP(WD)	1	3	77.08	-3.18	-2.28	-2.28	-0.33	0.03	0.50	0.10	0.04	0.02	0.60	0.10		
	7	3	77.50	-3.06	-3.03	-3.03	0.09	0.02	0.62	0.16	-0.72	0.31	0.98	0.17		
	30	3	77.72	-3.23	-2.73	-2.73	0.31	0.08	0.45	0.18	-0.42	0.07	0.71	0.04		

(continued)

TABLE III (continued)

Color readings for composite groups in H₂O storage for 1 day, 7 days, and 30 days

H ₂ O Group	Time (days)	N	L*		a*		b*		ΔL*		Δa*		Δb*		ΔE*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Filtex SP(WE)	1	3	62.64	0.43	-1.62	0.43	-0.42	0.05	-0.12	0.08	0.13	0.34	0.48	0.06		
	7	3	63.34	0.23	-1.37	0.23	-0.63	0.22	0.58	0.35	-0.08	0.15	0.74	0.12		
	30	3	63.31	0.31	-1.36	0.31	-0.79	0.15	0.56	0.36	-0.25	0.12	0.76	0.17		
Filtex SP(XWB)	1	3	73.97	0.01	-2.07	0.01	-1.37	0.06	-0.45	0.63	0.45	0.11	0.90	0.90		
	7	3	74.75	0.41	-2.04	0.41	-1.79	0.16	0.33	0.66	0.03	0.18	0.83	0.10		
	30	3	74.75	0.19	-1.93	0.19	-2.10	0.06	0.34	0.77	-0.28	0.13	0.91	0.05		
Filtex SP(XWD)	1	3	78.81	0.57	-1.76	0.57	3.97	0.40	-0.31	-0.25	1.06	0.03	1.26	0.15		
	7	3	79.29	0.57	-1.66	0.57	3.35	0.34	0.17	-0.15	0.44	0.13	0.74	0.08		
	30	3	79.55	0.31	-1.55	0.31	3.14	0.22	-0.43	-0.04	0.23	0.27	0.61	0.15		

(continued)

TABLE III (continued)

Color readings for composite groups in H₂O storage for 1 day, 7 days, and 30 days

H ₂ O Group	Time (days)	N	L*		a*		b*		ΔL*		Δa*		Δb*		ΔE*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Mirris(IR)	1	3	59.02	0.02	7.46	0.15	0.06	0.28	0.06	0.25	0.18	0.43	0.09			
	7	3	58.61	-0.02	7.78	-0.25	0.12	0.24	0.01	0.57	0.16	0.68	0.07			
	30	3	59.10	-0.05	8.54	0.24	0.36	0.21	0.02	1.33	0.10	1.40	0.09			
Mirris(NR)	1	3	60.14	0.96	2.99	0.70	0.12	0.17	0.22	0.37	0.11	0.84	0.05			
	7	3	59.36	0.87	2.64	-0.08	0.38	0.07	0.13	0.03	0.33	0.42	0.16			
	30	3	60.10	0.88	3.42	0.66	0.20	0.08	0.13	0.81	0.09	1.06	0.06			
Mirris(NT)	1	3	56.41	1.07	3.46	0.56	0.34	-0.10	0.21	-0.22	0.64	0.86	0.14			
	7	3	56.11	1.05	2.95	0.25	0.55	-0.12	0.08	-0.73	0.07	0.90	0.12			
	30	3	56.64	1.15	3.84	0.78	0.09	-0.01	0.13	0.16	0.39	0.87	0.04			

(continued)

TABLE III (continued)

Color readings for composite groups in H₂O storage for 1 day, 7 days, and 30 days

H ₂ O Group	Time (days) N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Mirris(WB)	1	63.53	0.10	-1.55	0.10	0.22	0.10	0.76	0.10	0.01	0.06	0.73	0.01	1.05	0.08
	7	63.06	0.91	-1.52	0.29	-0.37	0.91	0.29	0.91	0.03	0.03	0.14	0.10	0.81	0.12
	30	62.93	0.71	-1.59	0.16	0.64	0.71	0.16	0.71	-0.03	0.12	1.15	0.09	1.30	0.15
Mirris(WR)	1	62.80	0.10	-1.31	0.10	0.58	0.10	1.13	0.10	-0.03	0.14	0.05	0.29	1.17	0.11
	7	62.21	0.12	-1.31	0.54	0.49	0.12	0.54	0.12	-0.03	0.03	-0.04	0.09	0.55	0.13
	30	61.64	0.16	-1.30	-0.03	1.22	0.16	-0.03	0.16	-0.02	0.02	0.69	0.10	0.70	0.09
Point4(XL1)	1	68.79	0.02	-2.48	0.08	0.28	0.02	0.08	0.02	-0.06	0.05	1.24	0.02	1.24	0.02
	7	68.62	0.20	-2.48	-0.09	0.37	0.20	-0.09	0.20	-0.07	0.10	1.32	0.09	1.34	0.09
	30	68.72	0.02	-2.37	0.02	0.97	-0.20	0.02	-0.20	0.05	0.09	1.92	0.32	1.93	0.33

(continued)

TABLE III (continued)

Color readings for composite groups in H₂O storage for 1 day, 7 days, and 30 days

H ₂ O Group	Time (days) N	L*		a*		b*		ΔL*		Δa*		Δb*		ΔE*	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Point4(XL2)	1	3	78.32	-2.85	3.45	3.45	-1.29	0.20	0.38	0.17	2.18	0.19	2.57	0.20	
	7	3	79.88	-2.99	4.45	4.45	0.27	0.07	0.24	0.40	3.18	0.18	3.22	0.13	
	30	3	79.64	-2.95	4.88	4.88	0.03	0.32	0.28	0.37	3.62	0.21	3.65	0.20	
Point4(XL3)	1	3	89.49	-1.78	4.32	4.32	-0.06	0.09	0.05	0.17	1.08	0.08	1.09	0.09	
	7	3	89.66	-1.91	5.56	5.56	0.11	0.18	-0.07	0.08	2.32	0.11	2.33	0.11	
	30	3	89.42	-1.92	5.95	5.95	-0.14	0.36	-0.08	0.11	2.71	0.19	2.73	0.19	
TPH(BW)	1	3	77.24	-2.80	0.80	0.80	-0.32	0.59	0.04	0.08	1.27	0.10	1.40	0.05	
	7	3	77.00	-2.50	0.48	0.48	-0.56	0.21	0.34	0.08	0.94	0.03	1.16	0.09	
	30	3	77.38	-2.60	0.45	0.45	-0.18	0.12	0.25	0.08	0.92	0.09	0.97	0.09	

(continued)

TABLE III (continued)

Color readings for composite groups in H₂O storage for 1 day, 7 days, and 30 days

H ₂ O Group	Time (days)	N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TPH(L)	1	3	68.68	-1.91	3.63	0.09	0.06	0.01	0.10	0.92	0.03	0.93	0.04			
	7	3	68.78	-1.73	3.46	0.19	0.21	0.19	0.12	0.74	0.13	0.82	0.12			
	30	3	68.75	-1.76	3.73	0.16	0.25	0.16	0.14	1.02	0.24	1.07	0.19			
TPH(XL)	1	3	70.69	-1.41	2.33	-0.09	0.46	0.12	0.20	0.93	0.13	1.03	0.03			
	7	3	70.55	-1.32	2.08	-0.23	0.30	0.20	0.04	0.68	0.03	0.78	0.12			
	30	3	70.60	-1.39	2.39	-0.18	0.08	0.14	0.02	0.99	0.08	1.02	0.08			
Tescera 1	1	3	80.10	-2.00	4.34	0.39	0.03	0.23	0.03	0.41	0.09	0.61	0.05			
	7	3	79.98	-1.85	3.95	0.26	0.31	0.38	0.06	0.02	0.11	0.53	0.10			
	30	3	80.21	-1.78	3.94	0.49	0.18	0.45	0.03	0.01	0.12	0.68	0.12			

(continued)

TABLE III (continued)

Color readings for composite groups in H₂O storage for 1 day, 7 days, and 30 days

H ₂ O Group	Time (days)	N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Tescera 2	1	3	75.08	-1.93	3.85	3.85	-0.30	0.55	0.30	0.05	1.33	0.16	1.47	0.04		
	7	3	74.94	-1.76	3.46	3.46	-0.44	0.43	0.47	0.00	0.94	0.12	1.19	0.07		
	30	3	75.07	-1.68	3.55	3.55	-0.31	0.51	0.55	0.05	1.03	0.24	1.29	0.17		
Tescera 3	1	3	70.37	-0.88	3.80	3.80	0.23	0.51	0.30	0.08	0.90	0.20	1.07	0.15		
	7	3	70.28	-0.78	3.46	3.46	-0.32	0.48	0.40	0.06	0.56	0.19	0.87	0.05		
	30	3	70.35	-0.71	3.41	3.41	-0.24	0.27	0.47	0.09	0.51	0.09	0.77	0.05		

TABLE IV

Color readings for composite groups subjected to sunlamp for 24 hours

Sunlamp Group	Time (days)	N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Durafil(SL)	1	3	66.94	0.11	-2.77	0.28	3.81	0.06	0.11	-0.49	1.86	0.10	1.94	0.11		
Durafil(SLO)	1	3	73.92	0.15	-2.88	-0.03	4.93	0.05	0.15	-0.42	2.52	0.08	2.56	0.08		
(Durafil(SSL)	1	3	75.64	0.29	-2.44	0.32	4.03	0.10	0.29	-0.68	3.11	0.13	3.21	0.15		
EvoCeram(BI)	1	3	58.79	0.21	-1.75	-0.03	4.26	0.07	0.21	-0.44	2.73	0.06	2.77	0.04		
EvoCeram(BL)	1	3	65.09	0.19	-2.77	-0.34	4.23	0.15	0.19	-0.20	4.04	0.03	4.06	0.02		
EvoCeram(BM)	1	3	64.59	0.25	-1.63	-0.69	5.42	0.19	0.25	-0.32	3.23	0.12	3.33	0.10		
EvoCeram(BXL)	1	3	81.71	0.08	-3.31	-1.19	8.10	0.19	0.08	-0.59	4.32	0.08	4.52	0.07		
Filtek SP(WB)	1	3	69.30	0.15	-1.25	-1.05	5.20	0.02	0.15	0.29	1.79	0.11	2.10	0.03		
Filtek SP(WD)	1	3	76.15	0.15	-3.41	-1.09	-1.02	0.15	0.15	0.35	1.13	0.17	1.63	0.05		

(continued)

TABLE IV (continued)

Color readings for composite groups subjected to sunlamp for 24 hours

Sunlamp Group	Time (days)	N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Filtek SP(WE)	1	3	61.40	1.59	-1.59	0.69	0.69	-1.00	0.31	0.39	0.12	1.68	0.23	2.02	0.03	
Filtek SP(XWB)	1	3	73.08	2.49	-2.49	0.04	0.04	-1.16	0.10	0.16	0.06	1.15	0.27	1.66	0.12	
Filtek SP(XWD)	1	3	78.11	1.55	-1.55	5.49	5.49	-1.08	0.25	0.09	0.14	2.63	0.04	2.85	0.12	
Miris(IR)	1	3	58.33	0.55	-0.55	8.22	8.22	0.55	0.67	-0.24	0.21	1.78	0.28	1.98	0.10	
Miris(NR)	1	3	59.62	0.35	0.35	4.26	4.26	0.02	0.93	-0.28	0.16	1.93	0.21	2.10	0.14	
Miris(NT)	1	3	55.90	0.72	0.72	4.81	4.81	0.16	0.44	-0.45	0.14	1.14	0.21	1.30	0.17	
Miris(WB)	1	3	62.51	2.10	-2.10	0.87	0.87	0.20	0.25	-0.44	0.02	1.57	0.19	1.66	0.19	
Miris(WR)	1	3	61.43	1.75	-1.75	1.73	1.73	-0.02	0.18	-0.51	0.13	1.41	0.14	1.50	0.16	
Point4(XL1)	1	3	68.58	3.21	-3.21	0.29	0.29	-0.20	0.42	-0.73	0.06	1.65	0.09	1.85	0.04	

(continued)

TABLE IV (continued)

Color readings for composite groups subjected to sunlamp for 24 hours

Sunlamp Group	Time (days) N	L*		a*		b*		ΔL^*		Δa^*		Δb^*		ΔE^*	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Point4(XL2)	1 3	80.40	0.91	-3.97	0.44	4.55	0.44	0.91	-1.02	0.09	2.88	0.05	3.18	0.12	
Point4(XL3)	1 3	90.32	0.79	-2.68	1.59	5.19	0.79	0.79	-0.19	0.07	1.30	0.61	2.21	0.08	
TPH(BW)	1 3	76.50	0.03	-3.42	-0.96	1.60	0.03	0.03	-0.58	0.04	2.70	0.03	2.93	0.02	
TPH(L)	1 3	67.76	0.71	-2.25	-1.08	4.78	0.71	0.71	-0.26	0.04	2.28	0.35	2.62	0.09	
TPH(XL)	1 3	69.82	0.13	-1.99	-0.80	2.83	0.13	0.13	-0.53	0.05	1.38	0.17	1.69	0.13	
Tescera 1	1 3	78.38	0.23	-2.96	-2.20	12.44	0.23	0.23	-0.58	0.05	9.00	0.07	9.29	0.03	
Tescera 2	1 3	69.21	0.21	-1.65	-6.38	9.66	0.21	0.21	0.61	0.08	6.70	0.10	9.27	0.18	
Tescera 3	1 3	74.07	0.18	-2.96	3.27	10.49	0.18	0.18	-1.69	0.06	7.99	0.00	8.80	0.06	

TABLE V

ΔE for composite groups in dark and dry storage for 1 day,
ordered from smallest ΔE to greatest ΔE *

<u>Group</u>	<u>ΔE</u>
Durafill(SLO)	0.23
Miris(WB)	0.25
Miris(WR)	0.38
EvoCeram(BXL)	0.51
Miris(NT)	0.53
Durafill(SSL)	0.78
Filtek SP(WD)	0.84
Point4(XL1)	0.86
EvoCeram(BM)	0.86
Miris(NR)	0.94
Durafill(SL)	1.10
Point4(XL3)	1.13
Filtek SP (WE)	1.18
EvoCeram(BI)	1.23
Filtek SP(XWB)	1.30
Miris(IR)	1.31
EvoCeram(BL)	1.37
TPH(L)	1.46
TPH(BW)	1.48
Filtek SP(WB)	1.61
TPH(XL)	1.79
Tescera 1	1.79
Tescera 3	1.89
Tescera 2	1.90
Filtek SP(XWD)	2.08
Point4(XL2)	2.30

* For the group comparisons, groups not connected by lines are considered to be significantly different. A 5-percent significance level was used for all comparisons.

TABLE VI

ΔE for composite groups placed in dark and dry storage for 7 days, ordered from smallest ΔE to greatest ΔE

<u>Group</u>	<u>ΔE</u>
Miris(NT)	0.30
Miris(WB)	0.33
Miris(WR)	0.56
EvoCeram(BXL)	0.61
Miris(NR)	0.62
EvoCeram(BM)	0.68
Filtek SP(WD)	0.84
Filtek SP(WE)	0.85
Durafill(SLO)	0.90
EvoCeram(BI)	0.92
Filtek SP(XWB)	0.99
EvoCeram(BL)	1.05
Durafill(SSL)	1.05
Miris(IR)	1.16
Durafill(SL)	1.28
Filtek SP(WB)	1.35
TPH(BW)	1.61
Filtek SP(XWD)	1.67
TPH(L)	1.81
Tescera 1	1.87
TPH(XL)	1.93
Point4(XL1)	1.94
Tescera 3	2.05
Tescera 2	2.21
Point4(XL3)	2.22
Point4(XL2)	3.79

TABLE VII

ΔE for composite groups placed in dark and dry storage for 30 days, ordered from smallest ΔE to greatest ΔE

<u>Group</u>	<u>ΔE</u>
EvoCeram(BM)	0.50
Miris(WR)	0.62
Filtek SP(WD)	0.74
Miris(WB)	0.76
EvoCeram(BXL)	0.82
Filtek SP(WE)	0.87
EvoCeram(BI)	0.99
Filtek SP(XWB)	1.06
Durafill(SLO)	1.07
Miris(NR)	1.22
EvoCeram(BL)	1.23
Filtek SP(WB)	1.28
Durafill(SSL)	1.29
Miris(NT)	1.29
Durafill(SL)	1.34
TPH(BW)	1.53
Miris(IR)	1.55
TPH(L)	1.80
Filtek SP(XWD)	1.83
Tescera 1	2.02
TPH(XL)	2.08
Point4(XL1)	2.29
Tescera 3	2.39
Point4(XL3)	2.55
Tescera 2	2.56
Point4(XL2)	3.97

TABLE VIII

ΔE for composite groups placed in H₂O storage for 1 day,
ordered from smallest ΔE to greatest ΔE

<u>Group</u>	<u>ΔE</u>
Miris(IR)	0.43
EvoCeram(BXL)	0.46
Filtek SP(WE)	0.48
EvoCeram(BL)	0.52
Filtek SP(WD)	0.60
Tescera 1	0.61
EvoCeram(BM)	0.61
Durafill(SSL)	0.79
Durafill(SLO)	0.79
EvoCeram(BI)	0.80
Miris(NR)	0.84
Miris(NT)	0.86
Filtek SP(XWB)	0.90
TPH(L)	0.93
TPH(XL)	1.03
Miris(WB)	1.05
Tescera 3	1.07
Point4(XL3)	1.09
Miris(WR)	1.17
Filtek SP(WB)	1.17
Point4(XL1)	1.24
Filtek SP(XWD)	1.26
Durafill(SL)	1.37
TPH(BW)	1.40
Tescera 2	1.47
Point4(XL2)	2.57

TABLE IX

ΔE for composite groups in H₂O storage for 7 days, ordered from smallest ΔE to greatest ΔE

<u>Group</u>	<u>ΔE</u>
EvoCeram(BXL)	0.31
Miris(NR)	0.42
Tescera 1	0.53
EvoCeram(BL)	0.55
Miris(WR)	0.55
Miris(IR)	0.68
Durafill(SL)	0.69
Filtek SP(WE)	0.74
Filtek SP(XWD)	0.74
TPH(XL)	0.78
Durafill(SLO)	0.80
Miris(WB)	0.81
TPH(L)	0.82
Filtek SP(WB)	0.82
Filtek SP(XWB)	0.83
EvoCeram(BI)	0.84
Tescera 3	0.87
EvoCeram(BM)	0.87
Miris(NT)	0.90
Filtek SP(WD)	0.98
TPH(BW)	1.16
Tescera 2	1.19
Point4(XL1)	1.34
Durafill(SSL)	1.53
Point4(XL3)	2.33
Point4(XL2)	3.22

TABLE X

ΔE for composite groups in H₂O storage for 30 days,
ordered from smallest ΔE to greatest ΔE

<u>Group</u>	<u>ΔE</u>
Durafill(SL)	0.58
Filtek SP(XWD)	0.61
Tescera 1	0.68
Miris(WR)	0.70
Filtek SP(WD)	0.71
EvoCeram(BXL)	0.73
Filtek SP(WE)	0.76
EvoCeram(BM)	0.76
Tescera 3	0.77
Miris(NT)	0.87
Filtek SP(XWB)	0.91
TPH(BW)	0.97
TPH(XL)	1.02
Miris(NR)	1.06
TPH(L)	1.07
EvoCeram(BL)	1.16
Filtek SP(WB)	1.26
Tescera 2	1.29
Miris(WB)	1.30
Durafill(SLO)	1.38
Miris(IR)	1.40
EvoCeram(BI)	1.73
Point4(XL1)	1.93
Durafill(SSL)	2.35
Point4(XL3)	2.73
Point4(XL2)	3.65

TABLE XI

ΔE for composite groups subjected to sunlamp
for 24 hours, ordered from smallest ΔE to greatest ΔE

<u>Group</u>	<u>ΔE</u>
Miris(NT)	1.30
Miris(WR)	1.50
Filtek SP(WD)	1.63
Filtek SP(XWB)	1.66
Miris(WB)	1.66
TPH(XL)	1.69
Point4(XL1)	1.85
Durafill(SL)	1.94
Miris(IR)	1.98
Filtek SP(WE)	2.02
Miris(NR)	2.10
Filtek SP(WB)	2.10
Point4(XL3)	2.21
Durafill(SLO)	2.56
TPH(L)	2.62
EvoCeram(BI)	2.77
Filtek SP(XWD)	2.85
TPH(BW)	2.93
Point4(XL2)	3.18
Durafill(SSL)	3.21
EvoCeram(BM)	3.33
EvoCeram(BL)	4.06
EvoCeram(BXL)	4.52
Tescera 3	8.80
Tescera 2	9.27
Tescera 1	9.29

DISCUSSION

The color space in the CIELAB system consists of three coordinates L^* , a^* , b^* . The L^* refers to the lightness coordinate and its value ranges from 0 for perfect black to 100 for perfect white. The points a^* and b^* are chromatic coordinates in the red-green axis and the yellow-blue axis, respectively. Positive a^* values cover the red range and negative values cover the green color range. Positive b^* values cover the yellow color range while negative values cover blue color range.

The results of the present study partially supported the hypothesis that commercial bleach shade composites will have a color change of $\Delta E \geq 3.3$ as a result of aging in different conditions. This study indicated that UV light exposure of bleach shade composites for 24 hours causes significant changes in their CIELAB color space coordinates (Table 11). This is in accordance with previous results of investigators who demonstrated regular shade composite discoloration on exposure to UV light.^{1,2}

A color difference ≥ 3.3 is detectable clinically.²⁵ This study showed that for all bleach composite brands used in the study except Point 4 and TPH (XL3) shades, the color change (ΔE) caused by exposure to the sunlamp for 24 hours exceeds any color change caused by storage in H_2O or in a dark and dry container for 1 day, 7 days, and 30 days. Point 4 bleach shades were more affected by dark and dry or H_2O storage for 30 days than the sunlamp exposure for 24 hours.

The least color-stable bleach shade composites with sunlamp exposure are Tescera (Bisco) shades. Exposure for 24 hours resulted in almost three times the

threshold that people can detect ($\Delta E \geq 3.3$) with ΔE being 9.29, 9.27, and 8.80 for Tescera 1, Tescera 2, Tescera 3, respectively (Table 11).

Three out of four shades of Tetric Evo-ceram (Ivoclar-Vivadent) exceeded the detectable threshold of $\Delta E \geq 3.3$. The color changes for BL, BM, and BXL were 4.06, 3.33, and 4.52 respectively.

Certain shades from other brands showed significant color change, although they didn't reach the color change threshold of 3.3. The brands Filtek Supreme Plus (XWD), TPH (BW), Point 4 (XL2), and Durafill (SSL) showed color change (ΔE) of 2.85, 2.93, 3.18, and 3.21 respectively. These results show that certain brands are more susceptible to color change as a result of sun lamp exposure, and certain shades of other brands are susceptible to a lesser degree of a color change as well.

Storage in H₂O for 24 hours for 1 day or 7 days didn't result in a clinically detectable color change ($\Delta E \geq 3.3$) for any brand of composite tested (Table 8 and 9). The only composite that almost reached ΔE of 3.3 was Point 4(XL2), when storing this composite in H₂O for 1 day and 7 days resulted in a color change ΔE of 2.57 and 3.22, respectively. Point 4 (XL3) was less affected when storage in H₂O for 7 days resulted in ΔE of 2.33. This is the only shade of composite other than Point 4(XL2) that resulted in a color change greater than 2 ($\Delta E > 2$) in 7 days of storage in H₂O.

Placing bleach shade composites in H₂O for 30 days resulted in a detectable color change ($\Delta E \geq 3.3$) for some bleach composite shades (Table 10). Storing Point 4 (XL2) in H₂O for 30 days resulted in ΔE of 3.65, while placing Point 4 (XL3) in H₂O for 30 days resulted in ΔE of 2.73. Aside from the XL2, the Point 4 (XL3) is the only composite shade that reached this degree of color change in 30 days of storage in water. The other

brands of composite showed significant color change, although they didn't reach the threshold ($\Delta E \geq 3.3$). Durafill (SSL), Point 4(XL1), and EvoCeram(BI) showed ΔE of 2.35, 1.93, and 1.73 , respectively after immersion in H₂O for 30 days.

Storing bleach shade composites in dark and dry storage for 1 day didn't result in a detectable color change ($\Delta E \geq 3.3$) (Table 5, 6, and 7), whereas storage for 7 days resulted in ΔE of 3.79 for Point 4 (XL2). Dark and dry storage for 30 days didn't result in $\Delta E \geq 3.3$, except for Point 4 (XL2), where ΔE was 3.97. For Point 4(XL3), the color change ΔE was 2.56. Although it didn't reach the threshold of 3.3, it was the second highest color change after Point 4 (XL2).

Point 4 bleach shade composite in either dark and dry or in H₂O storage for 30 days resulted in significant color change for only one shade (XL2). Dark and dry storage for 30 days resulted in ΔE of 3.97 for Point 4 (XL2), while H₂O storage resulted in ΔE of 3.18 for this shade. Other Point 4 shades didn't break the threshold ($\Delta E < 3.3$). These results show that certain brands are more susceptible to color change as a result of H₂O storage or dark and dry storage; that certain shades from other brands are susceptible to a lesser degree of a color change as well, and that color change is directly proportional to storage time.

The color change (ΔE) resulting from exposure to the sunlamp is mainly due to the increase in the b* coordinate. The increase in b* coordinate reflects a shift to a more yellow color range (farther away from the blue color range). The change in a* was relatively minor, and toward a lower a* value (green range) in most composite brands, and this shift didn't contribute a lot in the resultant ΔE . The L* coordinate change was generally toward a lower value and a darker shade, with the exceptions of Durafill, Miris

(WR), Point 4(XL2), and Tescera 3, where ΔL^* value was either stable or had a positive value (the color shifted to a brighter color). Tescera Brand showed the most change in value among all composite shades tested. Tescera 1, Tescera 2, and Tescera 3 showed ΔL of -2.2, -6.38, and 3.27 respectively (Table 4).

Likewise, the color change (ΔE) resulting from storage in H_2O was mainly due to the increase in the b^* coordinate (yellowness) with few exceptions. Filtek Supreme Plus (WD, WE, XWB) showed the only exceptions where a decrease in Δb^* was seen. The values for a^* tended to increase slightly while those for L^* tended to decrease with few exceptions (Table 3).

The same thing can be said in the case of dark and dry storage where the b^* value is the main player. A general trend was seen of values for b^* increasing directly proportional to the time elapsed in dark and dry storage, except in the case of EvoCeram (BI, BXL), where the b^* decreased. The value for a^* tended to slightly increase toward the red color range while the L^* value tended to increase toward a lighter shade with few exceptions as well (Table 2).

We can clearly see that certain brands do not have good color stability under the sunlamp, namely Tescera and EvoCeram (Table 4). On the other hand, a brand like Miris did very well under the same conditions. Some brands have good color stability for certain shades like Filtek Supreme Plus (WD, XWB, WE, WB), but the shade XWD has ΔE of 2.85, which is relatively high.

Storing these composites in H_2O yielded less substantial performance, where we can see that no shade of Point 4 showed good color stability, but storing these composites

in dry and dark storage produced results showing Tescera and Point 4 were the lowest in terms of color stability (Tables 2 and 3).

Camphorquinone (CQ) is a yellow-colored material and the most commonly used photoinitiator in dental restorative resins. Although used in very small amounts, it significantly influences the material's color. In this study, all photoinitiator systems included CQ. Schneider et al.²⁶ evaluated the influence of the photoinitiator system on the yellowing of dental resin composites, and he found the yellowing effect increases as the photoinitiator concentration is increased, regardless of the photoinitiator system used. Other very important components of photoinitiator systems are tertiary aromatic or aliphatic amines, which act as so-called accelerators.²⁷ Amines are known to form by-products during photoreaction, and these by-products tend to cause yellow to red/brown discoloration under the influence of light or heat.²⁸ This phenomenon could explain why certain materials had less color stability under the sunlamp. These materials could have more CQ, more amine by-products, or both.

Some studies have shown the resin matrix content also influences color stability. In the case of greater matrix content, increased water sorption occurs, resulting in a whiter, opaque shade. In the case of less matrix content, the water sorption is less, making a smaller impact on the color.^{29, 30} This could explain why we see certain materials perform well in H₂O storage in terms of color stability, while others do not.

The materials' behavior during dry storage could be the result of nearly complete conversion of CQ to colorless products, and the formation of other yellow by-products from either the CQ or the aromatic amines dominating the shade.²⁷ However, because the

exact composition of these products is unknown, a correlation cannot be made between the use of these materials and the potential for leaving a residual yellow color.

SUMMARY AND CONCLUSIONS

The present study yielded the following conclusions:

- 1) The color stability of bleach shade composites depends on various factors, namely, the resin material, the shade of the resin material, the storage method, and the storage time.
- 2) This study showed that for all bleach composite shades used in the study, except Point 4(Kerr) and TPH (XL3) shades, the color change (ΔE) caused by exposure to the sunlamp for 24 hours exceeded any color change caused by storage in H₂O or in a dark and dry container for 1 day, 7 days, and 30 days.
- 3) The least color-stable bleach shade composites with sunlamp exposure were Tescera (Bisco) and Tetric Evo-ceram (Ivoclar-Vivadent) shades. Tescera shades when exposed to sunlamp for 24 hours resulted in almost three times the threshold that people can detect, while three out of four shades (BL, BM, BXL) of Tetric Evo-ceram (Ivoclar-Vivadent) exceeded the detectable threshold of $\Delta E \geq 3.3$.
- 4) When subjected to the sunlamp, certain composite shades showed statistically significant color change, although they didn't reach the color change threshold of 3.3. Those were Filtek Supreme Plus (XWD), TPH (BW), Point 4 (XL2), and Durafill (SSL).
- 5) Point 4 (Kerr) bleach shade composites were the least color stable when placed either in H₂O or in dark and dry storage. Two out of three shades (XL2) and (XL3) exceeded the detectable threshold of $\Delta E \geq 3.3$ when placed

in H₂O for 30 days, whereas all Point 4 shades had the least color stability when placed in dark and dry storage for 30 days compared with all other shades in this study.

- 6) Certain composite shades showed statistically significant color change when placed in H₂O, although they didn't reach the threshold ($\Delta E \geq 3.3$). Those were Point 4(XL1), Durafill (SSL), and EvoCeram (BI).
- 7) Certain composite shades showed statistically significant color changes when placed in dark and dry storage, although they didn't reach the threshold ($\Delta E \geq 3.3$). Those were Tescera 1, 2, 3, TPH (XL), and Filtek Supreme Plus (XWD).

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ABSTRACT

COLOR STABILITY OF LIGHT-ACTIVATED
BLEACH SHADE COMPOSITES

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OBJECTIVE: This study evaluated the color stability of bleach shade composites when activated by a high-intensity quartz-tungsten-halogen (QTH) light source after 1 day, 7 days, and 30 days of exposure to different conditions.

HYPOTHESIS: The current commercial bleach shade composites activated by a high-intensity quartz-tungsten-halogen light source would show clinically perceptible color changes ($\Delta E \geq 3.3$) when aged in different conditions.

MATERIALS AND METHODS: Twenty-six bleach shade composite specimens were polymerized using a QTH light source for 60 s. All materials contained a camphorquinone photoinitiating system. After curing, color measurements were made for all specimens. The specimens were divided into three groups. The first group was placed in dry and dark storage. The second group was placed in water storage. The third group was subjected to a sunlamp test. All groups were subjected to the different conditions at

37° C. The specimen color parameters were recorded L*, a*, and b* and color differences (ΔE^*) were determined to measure the effect of storage in different conditions on the color of the specimens.

RESULTS: Storing bleach shade composites in distilled water, dark and dry storage, or subjecting them to the sunlamp for 24 hours resulted in a wide range of readings. The sunlamp exposure resulted in the most values with $\Delta E \geq 3.3$ than the other two storage methods. The following group-storage-time combinations had a mean ΔE of 3.3 or higher:

Sunlamp: EvoCeram(BL), EvoCeram(BM), EvoCeram(BXL), Tescera 1, Tescera 2, Tescera 3.

Dark and dry for 30 days: Point4 (XL2).

Dark and dry for 7 days: Point 4 (XL2).

H₂O for 30 days: Point 4 (XL2).

CONCLUSION: The color stability of bleach shade composites depends on various factors, namely, the resin material, the shade of the resin material, the storage method, and the storage time.

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