Scientific Article

Color Changes of Restorative Materials Exposed In Vitro to Cola Beverage

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Abstract: *Purpose:* The purpose of this in vitro study was to evaluate the color stability of restorative materials when exposed to a cola beverage. *Methods:* Color changes in restorative materials caused by exposure to a cola beverage were studied using a split-plot experimental design. Three restorative materials (composite, resin-modified glass ionomer cement, and compomer) and 3 shades of each material under 2 surface conditions (polished and unpolished) were studied. Using a chromameter, color changes were determined as the difference between color dimensions before and after cola exposure. Scanning electron microscopy was used to characterize the surface morphology of all materials before and after polishing. *Results:* 72-hour cola exposure resulted in significant changes in color, including gray level and chromaticity, both as a function of materials and their shades. Clinically, these changes compromised both color stability and esthetics in the resin-modified glass ionomer cement in all shades and in composites and compomers in the darkest shade. *Conclusions:* To avoid color degradation through cola, the lighter shades of composites and compomers should be favored over darker C shades to restore anterior and more visible lesions. Resin-modified glass ionomer cement is not recommended in esthetically critical areas due to its tendency to discolor due to cola exposure. (Pediatr Dent 2008;30:309-16) Received July 19, 2007 | Last Revision September 8, 2007 | Revision Accepted September 14, 2007

Many new restorative materials have been manufactured to meet the demands of a growing global concern for esthetic dental results. Dentists and patients alike have developed a more discerning eye and a preference for proper shade match and more esthetic results. A well-recognized factor in esthetically pleasing results is an accurate initial color match by the operator. Beyond the initial color match, however, the susceptibility for color degradation of restorations over time also is of critical concern from an esthetic point of view. Since many new materials have been developed, the ability to prevent intrinsic and extrinsic stains of restorations has become an important challenge. Esthetic materials such as composites, compomers, and resin-modified glass ionomer cements (**RMGICs**) have been developed to meet restorative applications. Among these candidate materials, RMGICs and compomers were developed to possess fluoride-leaching traits that are believed to help prevent secondary caries.[1,2]

The oral environment, however, is exposed to a variety of media on a daily basis—many of which may stain or alter the surfaces of dental restorations, potentially causing esthetic degradation. It is, therefore, important to know not only whether long-term exposure to many daily beverages changes the restorative material's color, but also whether it is a change that is perceptible to the human eye.

While many studies exist on the staining effects of beverages on composite restorations, the beverages used in most of these studies were coffee, tea, and wine, which are normally associated with adult tooth stains.[3-19] A few studies have evaluated the effects of common beverages ingested by children and their staining effects on restorative dental materials,[7,9] but the effect of important factors such as differences in shades, sample polish, etc, have not been previously reported.

In a recent study, it was shown that 56% of 6- to 17-year-old US children consume soft drinks.[20] Other studies have also confirmed the use of widespread use of soft drinks by children.[21-26] In particular, the Bogolusa Heart Study examined eating patterns of 1,562 US children and reported that most consumed sweetened beverages, with nearly 58% predominantly using soft drinks such as cola.[26] Cola is, therefore, recognized as a common beverage consumed by young children.[26] Such widespread use of cola may cause discoloration of restorations—since extended exposure to cola is known to cause color changes in restorative materials.[7,9]

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The CIE 1976 L* a* b* scheme, usually noted as CIELAB 1976, is a color representation system for color measurements introduced in 1976 by the Commission Internationale de l'Eclairage (CIE).[27] In this scheme, color is measured in 3 coordinate dimensions of L*, a*, and b*. L* represents gray level changes, and a* and b* represent changes in red-green and yellow-blue chromaticity dimensions. Color shifts to more reddish or greenish chromatic saturation are represented by changes in positive and negative directions, respectively, in the a* coordinate. Similarly, changes in positive and negative directions of the b* coordinate represent shifts to more yellowish and bluish chromatic changes, respectively. The total color score E* is computed from all 3 spectral values of color and is obtained via the formula:

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

The overall color change during a treatment is described by Delta E* (ΔE^*), which represents the total color change. The ΔE^* value is the square root of the sum of the squares of the changes in L*, a*, and b* during environmental exposure. The formula for ΔE^* (ie, total color change during an environmental exposure) is as follows:

$\Delta E^* = [\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}]^{1/2}$, where $\Delta L^* = L^*_i - L^*_f$, $\Delta a^* = a_i - a_f$, and $\Delta b^* = b_i - b_f$, in which the subscripts i and f represent the initial and final values corresponding to "before" and "after" environmental exposures, respectively.

Color measurement in CIELAB is conveniently done using color spectrometers or chromameters. Minolta chromameters (Minolta Corp., Osaka, Japan) are especially useful for such studies because of their simple and somewhat miniature design with portability that facilitate their use for both in vitro and in vivo measurements. In previous studies, they have been the popular choice for measuring color changes in restorations[28,29] Minolta's chromameters are typically composed of 2 portions: 1) the measuring head to measure color of a specimen; and 2) the data processor which computes and displays the color coordinates L*, a*, and b* in the CIELAB color space.

Although the CIELAB color system is not designed to directly measure color changes for visual differences of interest clinically, measured total color changes (ΔE^*) have been shown in the past to display good correlation with visual discoloration. While differences of even 1 or 2 units in ΔE^* may indicate some perceptible stain,[30] a detailed study by Ruyter et al[3] has shown that a shift in ΔE^* value of >3.3 reflects a change that is a clinically significant visual discoloration. The computed value of ΔE^* is, therefore, traditionally used to assess color changes. The ΔE^* value for each material-shade-surface condition subset can, therefore, be used to assess whether the changes are visually and clinically significant between the subsets. Additionally, it is often equally important to understand the relative changes in the individual color components (ie, ΔL^*, Δa^*, Δb^*) for a full understanding of the complex changes of color in restorative materials under environmental attrition.

The purpose of this study was to evaluate color change in composites, resin-modified glass ionomer cements, and compomers when exposed to a cola beverage. This study was focused on the total color change (ΔE^*) and changes in the 3 individual color components (ie, ΔL^*, Δa^*, Δb^*).

Methods

The experimental design was a blinded, split-plot type selected because the independent variables of surface condition, materials, and shades could be conveniently allotted in a whole plot-subplot layout. Repeated measures under 2 time points (before and after exposure to cola) were used for the analysis.

Three dental restorative materials were investigated:
1. RMGIC (Fuji II LC, GC Corp, Tokyo, Japan);
2. Compomer (Dyract AP, Dentsply International, Inc, Milford, Del); and
3. Total Performance Hybrid (TPH) composite (Spectrum, Dentsply International, Inc).

Each material was studied in 3 different shades, from lighter A/B shades to darker C shades. The material's initial shades were all standardized to match the Vita shade guides (H. Rauter GmbH Co., Bad Säckingen, Germany) made for porcelain restorative materials. Shades A2, B1, and C2 were used for the composite and compomer. Shades A2, B2, and C2 were used in the RMGIC samples (shade B1 was not available for Fuji II LC). The soaking media used was a cola beverage (America's Choice, A & P Company, Montvale, NJ). The ingredients in America's Choice cola are carbonated water, high fructose corn syrup and/or sugar, caramel color, phosphoric acid, caffeine, and natural flavor.

Specimens (1 cm diameter x 2 mm thick) were made in a stainless steel mold. The material was packed in the mold between 2 glass slides and cured with a standard light emitting diode (**LED**) curing light (Smartlite IQ, model no. 100, Dentsply International, Inc) through glass slides on both sides of the mold for 20 seconds each. The LED curing light was calibrated before and after each curing to ensure that all samples were cured with approximately the same intensity of light (500 mW/cm^2). The light was held at the same distance for each episode of curing to ensure that all samples are cured under uniform conditions.

The color dimensions of samples were measured using a Minolta chromameter model CR 221. The chromameter had a probe diameter of 3 mm that facilitates color measurement in small samples. The chromameter was placed flush on all the samples during measurement. The samples were kept against a white background during all measurements. This ensured that the chromameter was used with a consistent background for each sample and prevented variability due to absorption or any other confounding color effects. The chromameter was calibrated prior to each measurement. The calibration was done against a white standard (supplied with the instrument) with known color dimensions.
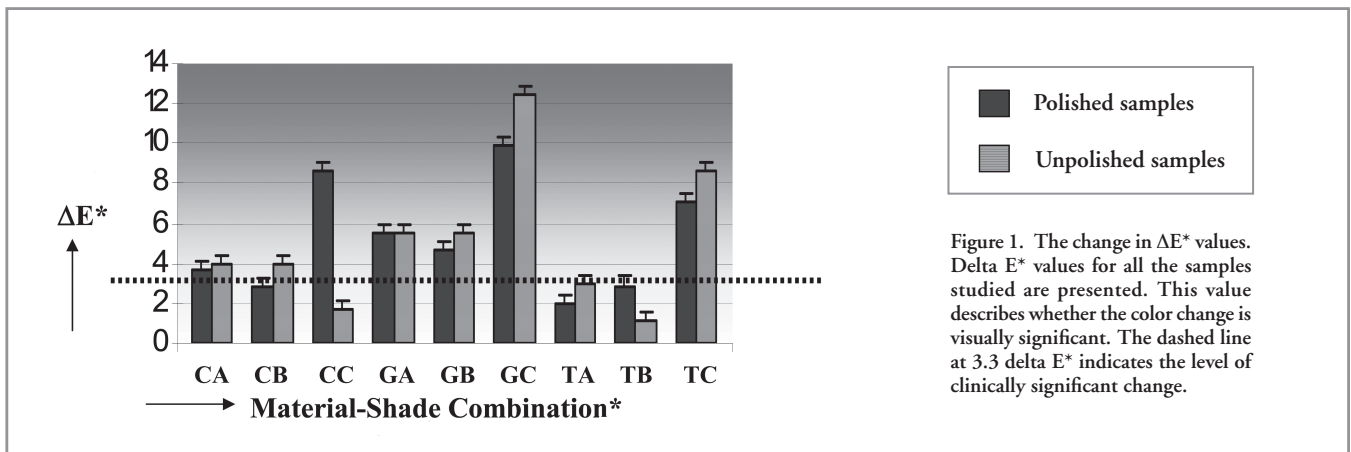
Figure 1. The change in ΔE* values. Delta E* values for all the samples studied are presented. This value describes whether the color change is visually significant. The dashed line at 3.3 delta E* indicates the level of clinically significant change.

* The material-shade combination designation uses the first letter to represent the material (C=Compomer, G=Glass ionomer and T=Total performance hybrid composite) and the sencond letter to represent the shades A, B and C. Thus CA, CB and CC represent compomers of shades A, B and C, respectively.

Sample size was selected based on power analysis calculations stipulating a minimum of 80% power. Ten samples of each material in each shade were tested (ie, the total number of samples [N]=3 materials x 3 shades x 10 samples each=90). The samples were placed under sterile water for 24 hours in a humidity chamber at 37°C to ensure stabilization of monomer conversion and to mimic oral conditions. After the initial storage, the samples were air-dried and examined using the chromameter. Measurements were taken at 2 time points (before and after soaking in cola) for all samples. Three initial readings were documented for each sample. Initial measurements were taken at 3 separate non-overlapping areas of each sample to ensure a proper examination of all the samples in their entirety.

One side of each sample was polished using a ECO-MET 4 polisher (Buehler, Lake Bluff, Ill) with 400 grit emery paper and water spray at 20 rpm for 5 seconds each. Then, the samples were placed in a chilled, open, full can of cola and left within the humidity chamber at 37°C for 72 hours. Each sample was then removed, rinsed with sterile water, and dried. Next, each sample was evaluated using the chromameter on 3 locations on each side to ensure that all areas of each sample were examined.

Scanning electron microscopy (**SEM**) analysis was done to evaluate the surfaces of representative samples of all materials. The sample surfaces were sputter coated with gold, and all polished and unpolished samples were examined at multiple magnifications before cola exposure. This examination was intended to help clarify possible surface morphological features that may potentially influence the measured color parameters.

Statistical analysis. The dependent variables included the values of: 1) L^*, a^*, and b^* measured directly by the chromameter; and 2) the computed ΔL^*, Δa^*, Δb^*, and ΔE^*. The independent variables included: 1) material type; 2) shade differences; 3) whether the material had been polished or not;

and 4) time of measurement (before or after soaking in cola). Statistical analysis employed 3- and 4-way mixed model analysis of variance (ANOVA) to examine differences due to the main effects and interactions among the independent variables in parallel tests of the dependent variables. In cases where significant omnibus F-effects were obtained, post-hoc comparisons used Bonferroni corrections to maintain experiment-wise error rates at the .05 level; this necessitated per-comparison P-levels of .0013, corresponding to a 3 standard deviation difference between means (±3 SD). All differences between selected comparison pairs were considered significant or nonsignificant based on this ±3 SD difference criterion. All analysis was done using SPSS statistical software (v. 12, SPSS, Chicago, Ill).

Preliminary analyses were carried out to confirm that intrasample color differences were not significant. This was done to ensure that color dimensions were similar at the 3 points selected for measurement of color in each sample. Repeated measurements showed high levels of consistency/reproducibility in each set of measurements within each sample, and all further analyses used the averaged data from 3 measurements in each sample.

Results

The pattern of total color change ΔE^* is shown in Figure 1, as a function of material, shade, and surface polish condition. The Ruyter criterion of a visually detectable color change at $\Delta E^* > 3.3$ is also indicated by the horizontal dashed line at the ΔE^* value of 3.3. The split-plot ANOVA showed a 4-way interaction ($P < .001$) for E^* values due to changes in material, shade, surface polish condition, and time point of measurement. This indicated significant color differences due to material-shade subset combinations in both polished and unpolished subgroups. Analysis using the 3 SD criterion showed that the differences between ΔE^* in RMGICs of all shades and in compomer and composite materials of C2 shade were statistically significant color changes. In addition,
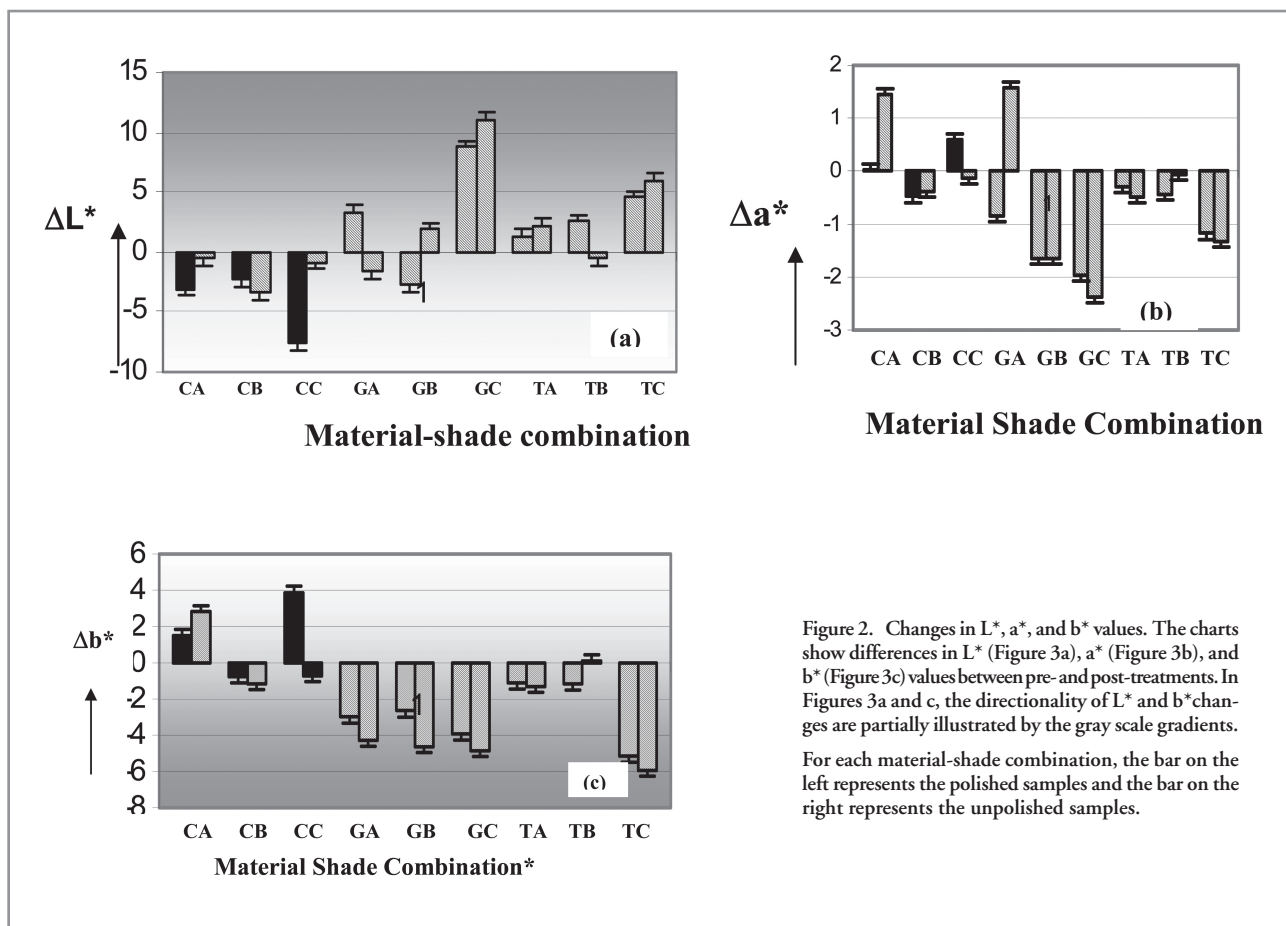
Figure 2.   Changes in L*, a*, and b* values. The charts show differences in L* (Figure 3a), a* (Figure 3b), and b* (Figure 3c) values between pre- and post-treatments. In Figures 3a and c, the directionality of L* and b* changes are partially illustrated by the gray scale gradients.

For each material-shade combination, the bar on the left represents the polished samples and the bar on the right represents the unpolished samples.

*   The material-shade combination designation uses the first letter to represent the material (C=Compomer, G=Glass ionomer and T=Total performance hybrid composite) and the second letter to represent the shades A, B and C. Thus CA, CB and CC represent compomers of shades A, B and C, respectively.

however, they also represented clinically significant changes, as was evident from the visual discoloration in the samples. The actual ΔE^* values (>3.30) in these cases also conformed to Ruyter's criterion. On the other hand, although the ΔE^* values in A2 and B2 shades of the compomer and composite were statistically significant under the ±3 SD criterion, no visual discoloration was observed in these samples, and the ΔE^* values were <3.3.

Since the total color change is the cumulative effect of changes in the 3 color dimensions L*, a*, and b*, we also analyzed the changes in these individual parameters (Figure 2). The values for L*, which indexes color on the white-black scale, ranged between a minimum of 58 and a maximum of 75. This range was expected, since most esthetic dental materials are predominantly white-yellow in color (typically in the range of 50<L*<100). The a* values varied in the range between −1.72 to +2.1, which indicated only slight changes within the red-green continuum. This small range was also expected, since most dental restorative materials are not truly red or green but may have small hints of these hues. For the b* value, the materials displayed values within the range from 1.67 to 11.23,

which indicates that all the observations were on the yellow side of this color continuum. Since dental materials mimic natural tooth structure, this reflects the variety in yellow seen in nature and the dental materials constructed to mirror these natural shades.

Statistical analysis revealed that gray level (L*) and chromaticity values (a*, b*) varied highly interactively by combinations of material, shade, polish, and cola exposure, as indicated by a highly significant 4-way interaction effect of these factors in the split-plot ANOVA (P=.001 for each dependent variable L*, a*, and b*). To evaluate these effects, further analyses first computed differences between pre- and post-treatments for all 3 parameters, $\Delta L^* = L^*_{pre} - L^*_{post}$, $\Delta a^* = a^*_{pre} - a^*_{post}$, and $\Delta b^* = b^*_{pre} - b^*_{post}$. The differences measure the tendency for:

1. darkening or lightening of the sample in the black-white gray scale given by a positive or negative change in the ΔL^*, respectively;

2. a shift toward less reddish or green chromaticity given by a positive value of Δa^* or toward a more reddish color by a negative value of Δa^*; and
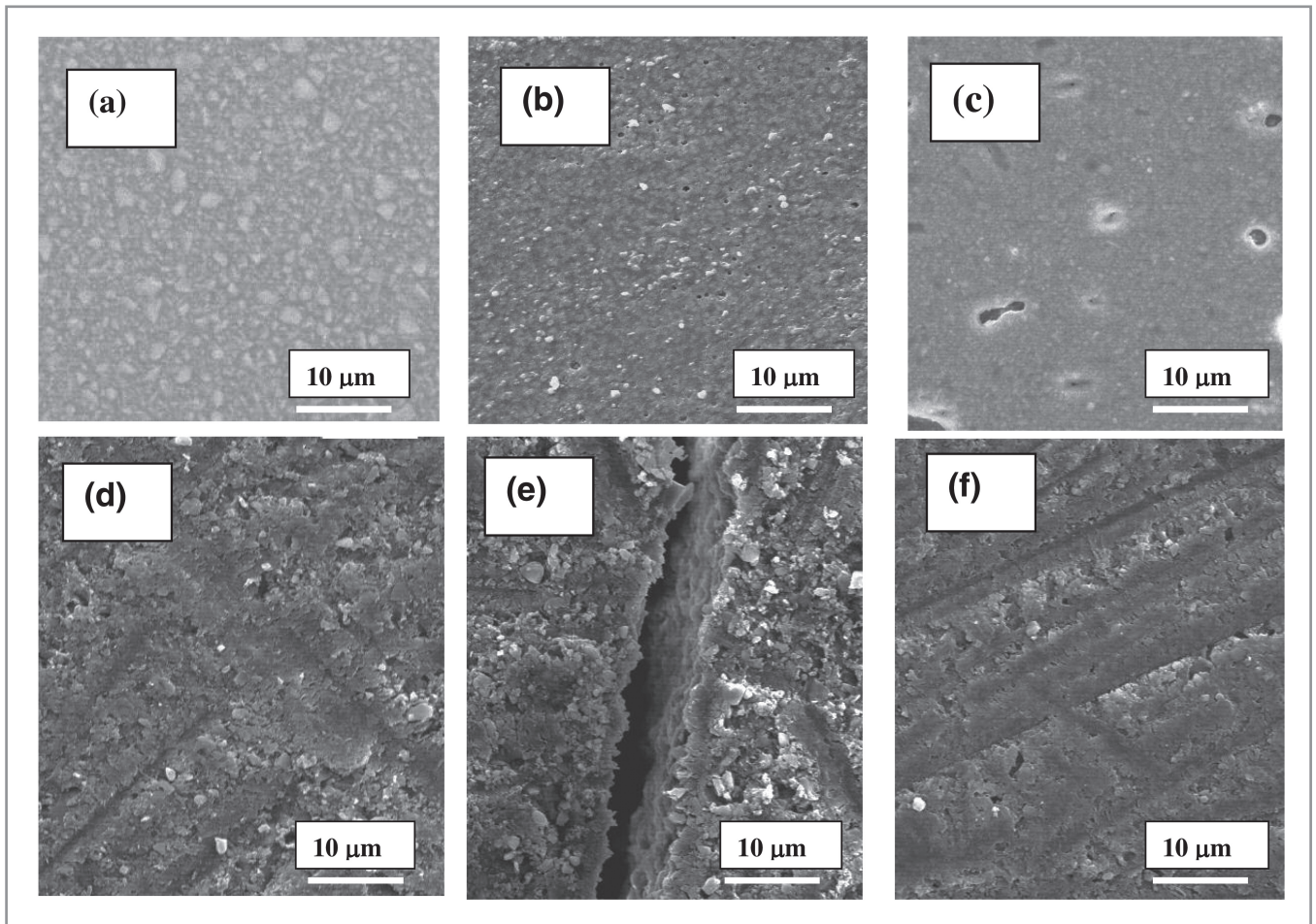
Figure 3. Scanning electron microscopy images of representative samples: (a) composite (unpolished); (b) resin-modified glass ionomer cement (RMGIC; unpolished); (c) compomer (unpolished); (d) composite (polished); (e) RMGIC (polished); and (f) compomer (polished). Note the surface roughness in all the polished samples relative to the unpolished samples and the pronounced microcracks on the RMGIC-polished surface. Magnifications indicated by line markers.

3. a shift to a less yellowish chroma given by a positive value of Δb^* or a change to a more yellowish color given by a negative Δb^* value, with all changes being within the yellow region of the b^* color coordinate.

An analysis of these shifts in specific significant trends is briefly described next.

As seen in Figure 3a, a high negative shift of L^* value ($\Delta L^* > -7.5$) for the C2 shade of the compomer in the unpolished condition was observed. This was considered statistically significant under the ±3 SD criterion. Clinically, it also represented a visual lightening of the gray level. This, however, was not observed in its polished state. Neither A2 nor B2 shades of compomer were found to have statistically significant or visually detectable changes in the L^* value. For the RMGIC, L^* changes in shade C2 also exceeded the ±3 SD criterion for significant change with treatment. In this case, however, there was a significant increase in L^* value post treatment ($\Delta L^* > +7.5$) and a detectable darkening of the material, both for the polished and unpolished surfaces. There were, however,

no significant changes in ΔL^* for RMGIC shades A2 or B2. Finally, the changes in the composite were similar to RMGIC, although the changes in shade C2 with treatment were smaller ($\Delta L^* < +5$) than those seen for RMGIC. Thus, changes in gray level with cola exposure vary interactively by material, shade, and polish.

In all cases, neither the A2 nor B2 shades showed significant changes in L^* dimensions in any material, polished or not. For the C2 shade, however, a complicated interaction among material and polish indicated lightening of polished compomer, and darkening of both RMGIC and the composite.

The compomer and RMGIC in shade A2 shifted toward the green side (positive Δa^*) in the red-green axis in the unpolished samples after cola immersion, as seen Figure 3b. In contrast, the RMGIC sample shades B2 and C2, for both the polished and unpolished samples, shifted slightly to more reddish chroma, with this change being statistically significant under the ±3 SD criterion. The composite samples in shade

C2 showed similar trends and became more reddish. All other samples showed little to no change in a* after cola immersion. Overall, however, the change in a* values, although statistically significant in many cases under the ±3 SD criterion, were not clinically visible changes.

The changes in b* paralleled the changes seen in L*. These changes are shown in Figure 3c. All changes in b*, indicated as follows, were considered statistically significant or nonsignificant using the ±3 SD criterion to separate the means Thus, the compomer C2 shade polished samples became less yellowish and the C2 shade samples of both the RMGIC and the composite became more yellowish. The RMGIC samples all became significantly more yellow for all samples, regardless of shade or polish. In the case of b*, the composite and the compomer showed little or no change in lighter A/B shades, regardless of polish condition. From a clinical perspective, the changes in b* in the C2 shade of composite and compomer and in all shades of RMGIC were visually detectable changes.

In the final analysis, all color changes should be related to changes in visual perception, and the restoration should appear clinically acceptable both to the clinicians and patients or their parents. The color changes observed in this study were complex. They were, however, visually perceptible changes in the gray scale (L* values) and yellow-blue chromaticity values (b* values) and are, therefore, considered clinically significant.
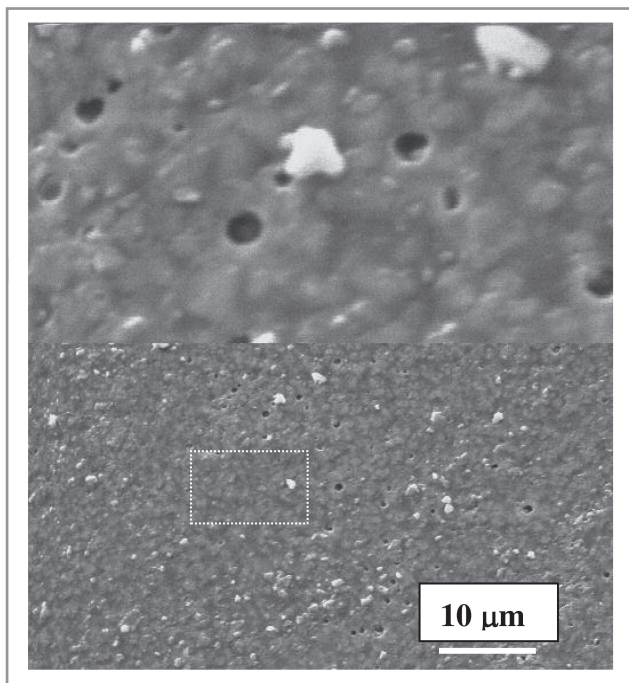

Figure 4. A split sanning electron microscopy image of resin-modified glass ionomer cement (unpolished surface). The magnification at the top half of the image is 5 times that of the bottom half. Note the distribution of pores on the material surface. The magnification of the bottom image half is given by the line marker.

SEM analysis of the samples before cola immersion showed that the surfaces of polished samples were relatively rough compared to unpolished samples in all materials (Fig. 3). This is because polishing using abrasives introduces scratches in the resin matrix phase of restorative materials. The RMGIC samples displayed porosity on the surface of unpolished samples (Figure 4) and perceptible surface microcracks (Figure 3e) in polished samples. Cola exposure showed no significant changes in morphological features in both unpolished and polished samples.

Discussion

This in vitro study of color stability of restorative materials presents data based on exposure to cola, the beverage choice of many American children. In today's society, both adults and children are conscious of appearances, particularly smiles. Many parents opt for their children to have esthetic restorations placed in the anterior segment. The expectation is for the dental restoration to be ideal and undetectable to others upon visual inspection. The choice of the right restorative material may provide more pleasing, long-lasting results for the patient and the practitioner.

The RMGIC samples showed more significant staining after continuous immersion in the cola for 72 hours compared to the composite and the compomer. Some researchers have suggested that hydrophobic materials such as resin composite were more stain resistant than hydrophilic materials, such as RMGICs.[10] This is consistent with this study's results. Abu-Bakr et al also found similar results regarding both compomers and RMGICs immersed in cola for 60 days.[9] The authors concluded that the resin composite was less susceptible to stain than the other 2 materials. Fay et al also found that compomer stained when exposed to cola for 48 hours.[7]

The SEM photographs show that polishing causes significant abrasion in all samples, resulting in distinct morphological changes at the surface. Such morphological changes are known to adversely affect color perception due to the fact the surface texture can significantly modify light scattering effects.[31] This explains the significant differences observed between polished and unpolished sample groups in all materials. In addition, unpolished samples of RMGIC revealed surface porosity (Figure 4). Since the RMGIC materials are formulated for onsite mixing, the porosity may be the result of air entrapment during manual mixing. Moreover, pronounced microcracks were also noticed (Figure 3e) in the polished RMGIC samples. During polishing, the pores in the unpolished samples may be extended to cracks by abrading particles. Such perceptible cracking of the RMGIC material was also noted by Iazetti et al.[10] In addition to the light-scattering effects due to the rough morphology, the microcracks in the samples may cause far more stain penetration and discoloration of the sample.[32] Since RMGIC releases the most fluoride of the three materials tested, the presence of more hydrophilic particles in this material than in composite resin and compomer may ahave adversely

affected its color stability. Thus, both compositional and morphological factors might have influenced the significant color changes in RMGIC samples.

The compomer showed color change in shade C2 that would not be acceptable. Fay et al[7] and Abu Bakr et al[9] also found that compomer was susceptible to stain by cola beverages. Fay et al found discoloration in compomer A2 shade. Shade A2 in the compomer samples in our study became redder, but overall did not show visually significant changes after 72 hours of continuous immersion in cola beverage.

The polished and unpolished TPH shade C2 samples displayed the most pronounced color change of all the materials examined. The other shades of this material did not change significantly. Although the material is hydrophobic, it seems that the cola's caramel color penetrated the material and reacted with the orange-brown pigment used to produce the C2 shade of the composite.

This investigation was an in vitro study, and some limitations of the results vis-à-vis clinical observations must be noted. For example, the experiments were designed to study the color changes of the restorative materials, with no consideration of the marginal discoloration of restorations observed in the clinical situation. Clinically, the margins tend to show more discoloration due to deeper stain penetration under capillary action. It is to be expected, however, that the increased staining of the material may also cause increased stain at the margins.

This study did not simulate the role of saliva and oral clearance on slowing down the long-term buildup of stains in the oral environment. Saliva dilutes the concentration of the ingested beverage. Often, saliva can also function as a buffer for the beverage's pH. Moreover, this study did not address the issue of expected differences among individuals in vivo. In addition, besides color, there are other factors that favor choice of restorative materials for restorations in the pediatric patients. For example, the RMGIC is often used in precooperative or uncooperative young children with early childhood caries, where fluoride release is more important. Many of these restorations are placed to prevent further progression of caries until the patient is more cooperative and will allow for a more esthetic restoration. While the compomer fared better in this study, its efficacy in fluoride release that is often claimed by the manufacturers has not been corroborated by past in vitro fluoride release studies.[1,2]

Conclusions

Based on this study's results, the following conclusions can be made:

1. Exposure to cola causes significant differences of in vitro discoloration of restorative materials both in polished and unpolished conditions.
2. The observed discoloration varies with selected shades. The composite and compomer materials were noticeably stained in the darkest C-2 shade. The resin-modified glass ionomer cements were stained significantly in all shades.
3. From an esthetic point of view, compomers and composites in the darker shades and the RMGIC in any shade should preferably be avoided in anterior restorative applications for children.

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