Effect of enamel margin configuration on color change of resin composite restoration

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INTRODUCTION

As esthetic restorative materials, direct resin composites are now widely used in both anterior and posterior teeth because of their superior adhesion to tooth substrates, excellent aesthetics, acceptable longevity, and relatively low cost. On the other hand, it is difficult to match the color of restorative materials to the surrounding tooth structure accurately within the limited color shades, because tooth color is influenced by various factors such as the type of tooth, site and age1-3. Additionally, the perception of tooth color is a complex phenomenon influenced by the different optical properties of enamel and dentine, and is the result of diffuse reflectance from the inner dentine through the outer translucent enamel layer2-5. Therefore, matching the color of the resin composite to the surrounding tooth is still challenging.

The color appearance of resin composite is influenced and perceived by various factors; their color (Lightness, Chroma and Hue) and optical properties (translucency, opalescence, straight-line and diffusion light transmission characteristics)6-9. Additionally, resin composite restorations can reflect a color from the surrounding tooth substrate due to its translucency property, leading the color shifting10,11. It is well known that the perceived color difference between resin composite and surrounding tooth is less than that would be expected from viewing the colors in isolation, even though their color matching is not perfect6,11. Paravina et al. demonstrated the color shifting of resin composites when placed in a mold made of another color of resin composite which mimicked dental hard tissue12,13, and recently, it was revealed that the color shifting at the border of resin composite restorations, when placed in human tooth cavities, was caused on the tooth side as well as on the resin composite side14,15. Discovering the mechanisms of the color shifting of resin composites and/or the surrounding tooth would improve the esthetics of resin composite restorations and simplify shade matching with a reduction in the number of the shades. And it should be noted that these color shifting effects of resin composite and the surrounding tooth might be influenced by enamel margin configuration.

Beveling the enamel margins of cavities has been introduced recently to improve color adjustment of resin composite restoration, whereby a 45-degree bevel is recommended as an esthetic finish line, allowing smooth gradual shade change from composite to enamel16. However, there is little research on the effect of enamel bevel on color adjustment of resin composite restoration in teeth16. Additionally, it is still debated how free enamel should be treated in esthetic resin composite restorations.

Therefore, the purpose of this study was to investigate the effect of the enamel margin configuration on color adjustment of resin composite restoration. The color measurements of resin composite restorations in punched enamel cavities with three enamel margin configurations (non-bevel, 45-degree bevel and 45-degree reverse-bevel), prepared in bovine enamel disks, were performed using a digital camera (RC500), color gamut of which is fitted to CIE XYZ color gamut17,18. The null
hypotheses tested were that enamel margin configuration does not affect color (Lightness: \(L^*\), Chroma: \(C^*\) and Hue: \(h^*\) values) shifting of resin composite restorations, and that the bevel preparation does not affect color change of resin composite restorations.

**MATERIALS AND METHODS**

Four commercially available resin composites, Estelite Asteria A2B (EA; Tokuyama Dental, Tokyo, Japan), Estelite Pro A2E (EP; Tokuyama Dental), Kalore WE (KA; GC America, Alsip, USA) and Clearfil Majesty ES-2 Premium A2E (MJ; Kuraray Noritake Dental, Tokyo, Japan), were used in this study, which are selected as final over-filled resin composites when A2 shade resin composite restorations are produced (Table 1).

**Specimen preparation**

Sixty freshly extracted bovine anterior teeth, which had been stored frozen, were used in this study. The enamel disks (1.0 mm-thick, 6.0×8.0 mm-wide) were sliced from the coronal labial part, parallel to the tooth axis, using a low speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) under water-cooling. Both sides of the enamel disks were polished using a waterproof abrasive silicon carbide paper up to 2000-grit under running water.

Cylindrical punched cavities with a diameter of 1.0 mm were prepared in the enamel disks by using a cylindrical diamond bar (#K1ff, ISO 288 010, GC, Tokyo, Japan) with a high speed handpiece, and then divided equally into three groups:

- **Group 1 (non-beveled cavity):** cavities remained with a cavo-surface angle of 90°,
- **Group 2 (beveled cavity):** cavities were prepared with bevel to create a cavo-surface angle of 135°,
- **Group 3 (reverse-beveled cavity):** cavities were prepared with reverse-bevel to create a cavo-surface angle of 45° (Fig. 1).

After a one-step self-etch adhesive (Clearfil Tri-S Bond Plus, Kuraray Noritake Dental) was applied to the cavities according to the manufacturer's instructions, and irradiated with a light-curing unit (Optilux 501, Kerr, Orange, GA, USA) with an intensity of 850 mW/cm², one of the four composite resins (EA, KA, MJ, EP) was placed in each of the cavities and covered with transparent strips on glass plates by both sides. After light curing for 60 s from the top and bottom sides with the same light intensities as for the bonding procedures, the strips and glass plates were removed. After storage at 37°C in 100% relative humidity for 24 h, the specimens were ground flat using a waterproof abrasive silicon carbide paper of 2000-grit under running water.
to remove the excess of resin composites.

Five resin composite disks (6.0 mm in diameter) in each material (EA, KA, MJ, EP) were made with 1.0 mm thick spacers and covered with transparent strips on glass plates. After the disks were light-cured with a light-curing unit (Optilux 501, Kerr) with an intensity of 850 mW/cm² for 60 s from the top and bottom sides, the strips and glass plates were removed. After storage at 37°C in 100% relative humidity for 24 h, the specimens were ground flat using a waterproof abrasive silicon carbide paper of 2000-grit under running water.

Color measurement of restored tooth

The colors of restored enamel disks with the resin composites (EA, KA, MJ, EP) and the resin composite disks were measured in 100% relative humidity over a black background (EVER-BLACK, No.0005, Evers, Osaka, Japan) using a CIE XYZ camera (RC500, PaPaLaB, Shizuoka, Japan), from a distance of 20 cm, a duration time of 0.2 s with specifications of shutter speed of 1/1000 to 1/15 s, spotted with D65 standard illuminant from 45/0-degrees geometry on both sides in a black box.

This camera (RC500) is equipped with three filters (S₁, S₂, and S₃) with spectral transmittance derived from the CIE color matching functions in XYZ color system. In the computer, a set of S₁, S₂, and S₃ digitized signal captured by CCD (active pixel of 4008H by 2672V) at 43.3 mm diagonal (3:2 ratio) are treated as an image and converted to XYZ color information by a 3×3 color conversion matrix, which is derived from a set XYZ measured values of the reference color samples and their equivalent imager outputs with regard to the filter of the camera by multiple regression analysis. Additionally, the camera incorporates an embedded color calibration system with a spectrophotometer mounted inside the optical system. Therefore, the outputs of the camera are linearly transformed into device-independent XYZ tristimulus values.

In this study, XYZ color information captured by RC500 was converted to L* a* b* values through L*a*b* values with the calculation using the following equations (1) (2).

\[ C_{ab} = \sqrt{(a*)^2 + (b*)^2} \]  
\[ h_{ab} = \tan^{-1}(a*/b*) \]

And the L*C*h* values were investigated along a mesiodistal direction at the centerline of the restoration on the restored enamel disks, with an average value in a square of 1×2 pixel (0.033 mm (w)×0.066 mm (h)).

Then, the color evaluations were performed at 5 regions (region 1: the center of resin composite restoration; region 2a: the upper-side border of non-beveled cavities; region 2b: the upper-side border of the beveled cavities; region 2c: the lower-side border of the reverse-beveled cavities; region 3: the plateau area in enamel) (Fig. 1). Additionally, in non-beveled cavity specimens, the distance between the enamel-composite border and the change point to the plateau in enamel was calculated.

Measurements of light transmission characteristics of resin composite

Additional five resin composite disks (6.0 mm in diameter, 1.0 mm thickness) were prepared in each material (EA, KA, MJ, EP) as described above.

The two-dimensional distribution graph of transmitted light intensity (incidence angle: 0°, measurement range: -90° to +90°) of each resin composite was obtained using a goniophotometer (Model GP-200, Murakami Color Research laboratory, Tokyo, Japan) under regulated conditions (sensitivity: 950; volume: 560) without filter. The lights were converged onto the pin hole through the condenser lens, into parallel beams through the collimator lens. These lights reach the specimen plane through the beam iris. The lights transmitted from the specimen plane are fed to receptor via a telescope lens and receiving iris. The light transmission and diffusion properties of specimen can be obtained by measuring the light intensity. Using the distribution graph, the straight-line light transmission property was calculated from the peak gain at 0° angle (G₀), and the transmitted light diffusion property was calculated as the diffusion factor (DF) using the following calculation formula:

\[ \text{Diffusion factor} = \left(\frac{G_0 + G_{20}}{2}\right) \times 100 \]

Total area of the graph was calculated as whole amount of transmitted light (Area) with ImageJ software (ImageJ 1.47 for Windows).

Statistical analysis

The color data at the center of resin composite restorations and those of the resin composite disks as a control were analyzed by two-way ANOVA (materials and margin configurations) with Dunnett’ T3 and t-test for post hoc. The distance data between the enamel-composite border in non-beveled cavity and the change point to the plateau in enamel were analyzed by one-way ANOVA (materials) with Dunnett’s T3 for post-hoc multiple comparisons test. The color data of the enamel-composite borders and the plateau areas in enamel were analyzed by three-way ANOVA (regions on the restored enamel, materials and enamel margin configurations), with Dunnett’ T3 and t-test being used for post hoc analysis. The data of light transmission characteristics were analyzed by one-way ANOVA with Dunnett’s T3 for post-hoc multiple comparisons test (materials). All statistical procedures were performed at the confidence level of 95% using the Statistical Package for the Medical Science (SPSS Ver.11 for Windows).

RESULTS

The results of the L*, C*, and h* values along a mesiodistal direction at the centerline of the restoration on the restored enamel disks are shown in Figs. 2–4. Regardless of the materials, L* values of all the materials increased toward the surrounding enamel from the
Fig. 2 The $L^*$ values investigated along a mesiodistal direction at the centerline of the restoration on the restored enamel disks, comparing among the groups according to margin configurations (Non-bevel: non-beveled cavity, Bevel: beveled cavity, R-bevel: reverse-beveled cavity) in each material (EA: Estelite Asteria, EP: Estelite Pro, KA: Kalore, MJ: Clearfil Majesty).

Fig. 3 The $C^*$ values investigated along a mesiodistal direction at the centerline of the restoration on the restored enamel disks, comparing among the groups according to margin configurations (Non-bevel: non-beveled cavity, Bevel: beveled cavity, R-bevel: reverse-beveled cavity) in each material (EA: Estelite Asteria, EP: Estelite Pro, KA: Kalore, MJ: Clearfil Majesty).

center of restoration and then reached the plateau. For the non-beveled cavity, the $L^*$ values increased over the enamel-composite border and then reached the plateau in enamel. For the beveled cavity, $L^*$ values increased with gentle inclination toward the upper-side enamel-composite border and then reached the plateau level at the border. On the other hand, for the reverse-beveled cavity, $L^*$ values increased with sharp inclination toward the bottom-side enamel-composite border, and then reached the plateau level at the border.

For the $C^*$ value, there were different behaviors among the materials. In EA, $C^*$ values decreased toward the surrounding enamel from the center of restoration and then reached the plateau, in which there were different curves in the bevel area between the bevel-preparation cavities. In EP, $C^*$ values increased toward
the surrounding enamel from the center of restoration and then reached the plateau, in which there were different curves in the bevel area among the bevel-preparation cavities. In MJ, $C^{*}$ values increased toward the surrounding enamel from the center of restoration and then reached the plateau, but their changing curves were different among the groups with margin configurations. In KA, $C^{*}$ values hardly changed on the restored enamel disks, in which no difference was observed among the groups with margin configurations.

For the $h^{*}$ values, there were different behaviors on surfaces of the restored enamel disks. In the case of EA and EP, $h^{*}$ values increased toward the surrounding enamel from the center of restoration and then reached the plateau, in which there was little difference between the non-beveled cavity and the bevel-preparation cavities. In MJ, the non-beveled cavity hardly changed $h^{*}$ values on the restored enamel disks, while there was different change at the center of restoration and the bevel area among the bevel-preparation cavities. In KA, $h^{*}$ values hardly changed on the restored enamel disks, in which no difference was observed among the groups with margin configurations.

The results of distance between the enamel-composite border in the non-beveled cavity and the change point to the plateau in enamel. The line (●—●) indicate a significant difference between the connected materials (EA: Estelite Asteria, EP: Estelite Pro, KA: Kalore, MJ: Clearfil Majesty) ($p<0.05$) ($n=5$). “NA”: not available data.

The results of $L^{*}$, $C^{*}$ and $h^{*}$ values at the center of resin composite restorations and those of resin composites as a control are shown in Figs. 6–8. Two-way ANOVA revealed that $L^{*}$, $C^{*}$ and $h^{*}$ of resin composites were significantly affected by margin configurations ($L^{*}$, $p<0.0001$: $C^{*}$, $p<0.0001$: $h^{*}$, $p<0.0001$), by materials ($L^{*}$, $p<0.0001$: $C^{*}$, $p<0.0001$: $h^{*}$, $p<0.0001$). There were significant interactions in $L^{*}$, $C^{*}$ and $h^{*}$ between materials and margin configurations. In the non-beveled value at the enamel-composite border. On the other hand, $h^{*}$ value of all the materials reached the plateau at the border, and color shift of $h^{*}$ value in surrounding enamel was not observed.
cavity, all of the resin composites were significantly higher $L^*$ values at the center of restoration than the control disks of resin composites. Additionally, $C^*$ of EA and MJ and $h^*$ of EP were significantly influenced by restoration into the non-beveled cavity. The beveled cavity had significantly lower $L^*$ values of MJ and KA than the non-beveled cavity, and the reverse-beveled cavity reduced $L^*$ values in all of the resin composites than the beveled cavity. For $C^*$ and $h^*$ values, MJ was significantly influenced by margin configuration, while in EA, EP and KA, there were no significant differences in $C^*$ and $h^*$ between the groups with margin configurations.

The results of $L^*$, $C^*$ and $h^*$ at the border of resin composite restorations and the plateau area in enamel are shown in Figs. 9–11. Three-way ANOVA revealed
that $L^*$, $C^*$ and $h^*$ values were significantly affected by regions on restored enamel ($L^*$, $p<0.0001$: $C^*$, $p=0.001$: $h^*$, $p<0.001$), by materials ($L^*$, $p<0.0001$: $C^*$, $p=0.0001$: $h^*$, $p=0.003$), and by enamel margin configurations ($L^*$, $p<0.0001$: $C^*$, $p=0.0001$: $h^*$, $p=0.013$). For $L^*$, $C^*$ and $h^*$, there were significant interactions between materials and enamel margin configurations ($L^*$, $p<0.0001$: $C^*$, $p=0.0001$: $h^*$, $p=0.003$), between materials and regions on restored enamel ($L^*$, $p<0.0001$: $C^*$, $p=0.0001$: $h^*$, $p=0.001$), and between enamel margin configurations and regions on restored enamel ($L^*$, $p<0.0001$: $C^*$, $p=0.0001$: $h^*$, $p=0.048$). The interaction among these three factors was also significant ($L^*$, $p<0.0001$: $C^*$, $p=0.0001$: $h^*$, $p<0.0001$). Regardless of enamel margin configuration and materials, there were no significant differences in $L^*$, $C^*$ and $h^*$ values at the plateau area in enamel. In $L^*$ values, all the materials in the non-beveled cavity were significantly different between at the enamel-composite border and the plateau in enamel, while in the beveled cavity there were no significant differences between at the upper-side border and the plateau in enamel. However, the reverse-beveled cavity significantly lowered the $L^*$ values at the upper-side border compared with those in non-beveled cavity. In the case of the $C^*$ values at the border, EA and KA were not influenced by margin configuration, while in EP and MJ, the reverse-beveled cavity significantly lowered the $C^*$ values at the upper-side border compared with those in the non-beveled cavity and beveled cavity. In $h^*$ values at the border, KA and MJ were not influenced by margin configuration, while in EA and EP, the reverse-beveled cavity significantly lowered the $h^*$ values at the upper-side border compared with those in the non-beveled cavity.
The results of DF (diffusion transmission property), G0 (straight-line transmission property), and Area (amount of transmitted light) of resin composites are shown in Table 2. In the results obtained with the goniophotometer, the area values (whole amount of transmitted light) of MJ and KA were larger than those of EA and EP, in which there was no significant difference between MJ and KA. The G0 value (the straight-line light transmission property) of KA was significantly higher than those of EA, EP and MJ, while the DF value (light diffusion property) of KA was significantly lower than those of EA, EP and MJ.

DISCUSSION

In this study, color measurements on the composite-restored enamel disks were performed using a CIE XYZ camera. This camera (RC500) is equipped with three optical filters that are mathematically equivalent to linear combinations of the CIE color matching function, which allows for representation of the pixel values by CIE XYZ tristimulus values per pixel[17,18]. Additionally, the camera incorporates an embedded color calibration system with spectrophotometer, which allows for precise and repetitive measurement of the colors[17,18]. After acquiring the spectral information about an object, accurate colors can be sequentially evaluated on an arbitrarily selected line in the image[17,18].

In this study, all of the resin composite restorations in the non-beveled cavity significantly increased \( L^* \) values compared with the control composite disks. Additionally, \( C^* \) of EA and MJ and \( h^* \) of EP were significantly influenced by filling in non-beveled bovine enamel cavity. These results would indicate that resin composites in the non-beveled cavity caused color shifting due to the presence of surrounding enamel. And the beveled cavity had significantly lower \( L^* \) values of MJ and KA than the non-beveled cavity, and the reverse-beveled cavity reduced \( L^* \) values in all of the resin composites than the beveled cavity. For \( C^* \) and \( h^* \) values, MJ was significantly influenced by margin configuration, while in EA, EP and KA, there were no significant differences in \( C^* \) and \( h^* \) between the groups with margin configurations. These results indicate that the effect of enamel margin configuration on color shifting of resin composite restoration was dependent upon the materials used, in which the color perception of MJ would be subjected by enamel margin configuration. Therefore, the results of this study would require partial rejection of the null hypothesis that enamel margin configuration does not affect color (\( L^*, C^* \) and \( h^* \) values) shifting of resin composite restorations at enamel margin.

Paravina et al., demonstrated using a mold made of another color of resin composite which mimicked dental hard tissue and placing a restoration in the mold, that the color shifting effect increased with an increase in the translucency parameters, and with a reduction in the size of restoration[12,13]. The resin composites used in this study had various light transmission characteristics; in the results obtained with the goniophotometer, the area values (whole amount of transmitted light) of MJ and KA were larger than those of EA and EP, in which there was no significant difference between MJ and KA. Additionally, the G0 value (the straight-line light transmission property) of MJ was lower than that of KA, while the DF value (light diffusion property) of MJ was higher than that of KA. These results might indicate that color shifting effect on resin composite restoration would be facilitated by amount of transmitted light and light diffusion property of the material.

On the other hand, color shifting at the border of resin composite restoration was caused on the tooth side as well as the resin composite side, in which the color shifting effect of the tooth side was larger than that of resin composite side[14,15]. In this study, with non-beveled cavity, \( L^* \) values of all the materials gradually increased over the enamel-composite border and then reached the plateau in enamel, in which there were significant differences in \( L^* \) values between at the border and the plateau. Additionally, EA and MJ increased \( C^* \) value over the enamel-composite border although EP and KA obtained the plateau level in \( C^* \) value at the border. On the other hand, \( h^* \) value of all the materials reached the plateau at the margin. These results would indicate that resin composites affected the perception of the color, especially lightness of surrounding enamel. The distance between the enamel-composite border in the non-beveled cavity and the change point to the plateau in \( L^* \) value was dependent upon the materials, in which MJ was significantly longer than the other materials.

The color shifting effect of the surrounding enamel, observed in MJ, might be due to amount of transmitted light and light diffusion property of a resin composite. On the other hand, EA, which had the highest light diffusion property and the lowest amount of transmitted light, could shift \( C^* \) value in surrounding enamel, but had the lowest shifting ability of \( L^* \) value in surrounding enamel, which might be due to a reason that only EA is higher \( C^* \) value than enamel.

In this study, the beveled cavity had no significant differences in \( L^*, C^* \) and \( h^* \) values between at the border and the plateau of enamel in all the materials, except for \( C^* \) value of EA. Additionally, in the beveled cavity, change of \( L^* \) value on restored enamel disk was more gentle than that of the non-beveled cavity. These results indicate that bevel preparation in the cavity could improve the color adjustment at the border of the resin composite restoration. Especially, MJ would have a bigger effectiveness of bevel preparation on color adjustment of the restoration, because \( C^* \) value as well as \( L^* \) value at the border significantly increased compared with the non-beveled cavity. On the other hand, KA would have a smaller effectiveness of bevel preparation on color adjustment of the restoration, because bevel preparation did not significantly affect \( C^* \) and \( h^* \) values compared with the non-beveled cavity; therefore KA might not require bevel preparation in the cavity.

On the other hand, the reverse-bevel preparation significantly lowered \( L^* \) values at the upper side enamel-composite border in all the materials compared with the
non-beveled cavity. Additionally, C* values of EP and MJ and h* values of EA and EP at the border significantly lowered in the reverse-bevel preparation compared with the non-beveled cavity. These results would indicate that the reverse-bevel preparation was not effective in altering the color adjustment of the restoration although color gradually changed toward the bottom side enamel-composite border form the upper side border on the restored enamel disk. When removing carious dentin under the MI concept, free enamel often remains in the prepared cavity. It is reported that free enamel should be removed from the cavity for resin composite restoration because free enamel might fail due to the contraction stress of resin composite19). The results of this study would also recommend removing free enamel from the cavity for esthetic resin composite restorations and which would help to resolve color adjustment issue.

In this study, color measurement was performed on restored enamel disks in the punched cavity on a black background. Presumably, color adjustment potentials of resin composite restoration would be influenced by color and/or optical properties of background substrate. It was demonstrated that light transmission characteristics of dentine in restored teeth affected color shifting effects at the border of the resin composite restorations19). Further experiments are necessary on the factors influencing the color adjustment potential of resin composite restorations.

Within the limitation of this study using the bovine enamel, enamel margin configuration affected color shifting of the resin composite in the cavity and color adjustment at the border of resin composite restoration, the degree of which was dependent upon the materials. The bevel preparation in the cavity could improve the color adjustment at the border of the resin composite restoration. Presumably, in enamel colored resin composites, a larger amount of transmitted light with increased of light diffusion could improve the color shifting effect of the restoration, being influenced by enamel margin configuration.

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