Influence of enamel prism orientations on color shifting at the border of resin composite restorations

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INTRODUCTION

Direct resin composite restorations have been widely used as esthetic restorative materials for anterior and posterior teeth. However, the problem of accurate color matching resin composite to the surrounding tooth structure still remains because the color shades of resin composite are limited and tooth color is influenced by various factors such as the type of tooth, site and age. On the other hand, it has been observed clinically that the perceived color difference between tooth and resin composites is less than would be expected from viewing the colors in isolation, even though their color matching is not perfect. This phenomenon, often called the ‘chameleon effect’, is thought to be caused by the color shifting of resin composite and surrounding tooth, resulting from the color reflection from each other. These color shifting effects would be dependent upon reciprocal relationships in the optical properties of resin composite and surrounding enamel. Paravina et al. evaluated the color change of resin composites when placed in a mold made of another color of resin composite which mimicked dental hard tissue. They indicated that the color shifting effect increases with an increase in the translucency parameter, and with a reduction in the size of restoration and the initial color difference between the inner and outer resin composites moreover, it was dependent upon the kind of resin composite and its shade.

Optical properties are intrinsic properties resulting from a combination of various factors, such as specular and diffuse reflection (light scattering) at the surface, specular transmission of light through the tissue, and absorption and scattering of light within the tissue. These properties are in turn affected by the composition and histological structure of the tissue. Enamel is composed of enamel prisms, which are clusters of Hydroxyapatite (HA) nanorods with cross-sectional dimensions of 50×25 nm, up to 1 mm long and approximately 5 µm in diameter. The HA crystals would influence tooth color parameters (hue, chroma, lightness) with variability in the size and degree of carbonization of the crystals. Enamel prisms can act as an optical fiber to collect and distribute light, and enamel prism orientation causes optical anisotropy. The majority of enamel prisms are arranged with their long axes at approximately 90° to the enamel-dentine junction (EDJ), while their orientations are perpendicular towards the enamel surface in the cervical area but gradually lean in the coronal area. Therefore, there would be a difference in these prism orientations between the coronal and cervical sides at the margin of labial surface cavity. These differences of prism orientations might affect the color shifting at the border of resin composite restorations. However, there is little research on how enamel prism orientation affects color shifting at the border of resin composite restorations.

Recently, Aida et al. evaluated the effect of enamel margin configuration on color shifting at the border of resin composite restorations using a digital camera (RC500), whose color gamut was fitted to the CIE XYZ color gamut by the three optical filters. This camera can measure precisely and repetitively the color and evaluate sequentially the color on an arbitrarily selected line in image after acquiring the spectral information about the object. Additionally, this camera incorporates an embedded color calibration device.
system with a spectrophotometer mounted inside the optical system. The authors demonstrated that enamel margin configuration affected color shifting of the resin composite in the cavity and improved color adjustment at the border of resin composite restorations.

Therefore, the purpose of this study was to investigate the influence of the enamel prism orientations on the color adjustment potential of resin composite restorations by evaluating color shifting at the enamel-composite border on the coronal and cervical sides in resin composite restorations in labial surface cavity using a CIE XYZ camera (RC500). The null hypotheses tested were that enamel prism orientation does not affect color (Lightness: L*, Chroma: C* and Hue: h* values) shifting of resin composite restorations.

MATERIALS AND METHODS

Four light-cured resin composites, Estelite Asteria A2B (EA; Tokuyama Dental, Tokyo, Japan), Estelite Pro A2E (EP; Tokuyama Dental), Kalore WE (KA; GC America, Alsip, IL, USA) and Clearfil Majesty ES-2 Premium A2E (MJ; Kuraray Noritake Dental, Tokyo, Japan), were used in this study (Table 1).

Specimen preparation

In this study, forty freshly extracted bovine anterior teeth, which had been stored frozen, were used. Enamel disks (1.0 mm thickness) were sliced from the labial part, parallel to the tooth axis, using a low speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) under water-cooling. Each side of the enamel disks were polished under running water with waterproof abrasive silicon carbide papers up to 2000-grit.

Cylindrical punched cavities with 1.0 and 3.0 mm diameters were prepared in the enamel disks using a diamond bar (#K1ff, ISO 288 010, GC, Tokyo, Japan). A one-step self-etch adhesive (Clearfil SE One, Kuraray Noritake Dental) was applied to the cavities according to the manufacturer's instructions, and then irradiated with a light-curing unit (Optilux 501, Kerr, Orange, CA, USA) for 10 s from both sides 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 celluloid strips on glass plates on both sides, and light cured for 60 s from both sides with the same light intensities to sufficiently polymerize each resin composites. After the composite resins were light cured, the strips and glass plates were removed. After storage at 37 °C in 100% relative humidity for 24 h, the surfaces of the specimens were ground flat under running water with 2000-grit waterproof abrasive silicon carbide paper.

In addition, five resin composite disks (6.0 mm diameter and 1.0 mm thickness) of each material (EA, KA, MJ, EP) were made with celluloid strips on glass plates as well as the enamel disks, and light cured for 60 s from both sides with the same light intensities to sufficiently polymerize each resin composites. After the resin composite disks were light cured, the strips and glass plates were removed. After storage at 37°C in 100% relative humidity for 24 h, the specimens were ground flat under running water using 2000-grit waterproof abrasive silicon carbide paper.

| Material                          | Composition                                                                 | Manufacturer                  | Batch number |
|-----------------------------------|-----------------------------------------------------------------------------|-------------------------------|--------------|
| Estelite Asteria (A2B)            | Filler: 82 wt% Supra-Nano Spherical Filler (200 nm SiO₂-ZrO₂), composite filler (include 200 nm spherical SiO₂-ZrO₂) Base resin: Bis-GMA, Bis-MPEPP, TEGDMA, UDMA | Tokuyama Dental Tokyo, Japan  | W1042        |
| Estelite Pro (A2E)                | Filler: 82 wt% Supra-Nano Spherical Filler (200 nm SiO₂-ZrO₂), composite filler (include 200 nm spherical SiO₂-ZrO₂) Base resin: Bis-GMA, TEGDMA | Tokuyama Dental               | 029041       |
| Kalore (WE)                      | Filler: 82 wt% 30–35 wt% pre-polymerized filler, 20–30 wt% fluoroalumino silicate glass, 20–33 wt% strontium/barium glass, 1–5 wt% silicon dioxide nanofiller Base resin: UDMA, DX-511 | GC America, Alsip, IL, USA    | 1207141       |
| Clearfil Majesty ES-2 Premium (A2E) | Filler: 78 wt% silanated barium glass filler, pre-polymerized organic filler, Micro filler (glass filler); mean 1.5 µm Nano filler; mean 20 µm Base resin: Bisphenol-A-diglycidyl methacrylate (Bis-GMA), hydrophobic aromatic dimethacrylate,dl-Camphorquinone | Kuraray Noritake Dental Tokyo, Japan | 00001A        |
Color measurement of restored tooth and composite disks

The colors of the restored enamel disks with each resin composite (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 a 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.

In this study, XYZ color information captured by the RC500 was converted to $L^*C^*h^*$ values through $L^*a^*b^*$ values, and the $L^*C^*h^*$ values were investigated in a longitudinal direction from coronal to cervical at the centerline of the composite restoration on the restored enamel disks, with an average value in a square of $3\times2$ pixel ($0.099 \times 0.066$ mm).

The results of the $L^*$, $C^*$, and $h^*$ values along a longitudinal direction from coronal to cervical at the centerline of the restoration on the restored enamel disks are graphically represented in Figs. 1–3. Color evaluations of center of the resin composite restorations

![Fig. 1](image1.png)  
**Fig. 1** The $L^*$ values investigated along a longitudinal direction from coronal to cervical at the centreline of the restoration on the restored enamel disks, comparing among the groups according to materials (EA: Estelite Asteria, EP: Estelite Pro, KA: Kalore, MJ: Clearfil Majesty).

![Fig. 2](image2.png)  
**Fig. 2** The $C^*$ values investigated along a longitudinal direction from coronal to cervical at the centreline of the restoration on the restored enamel disks, comparing among the groups according to materials (EA: Estelite Asteria, EP: Estelite Pro, KA: Kalore, MJ: Clearfil Majesty).

![Fig. 3](image3.png)  
**Fig. 3** The $h^*$ values investigated along a longitudinal direction from coronal to cervical at the centreline of the restoration on the restored enamel disks, comparing among the groups according to materials (EA: Estelite Asteria, EP: Estelite Pro, KA: Kalore, MJ: Clearfil Majesty).
and resin composite disks were performed. In addition, the color shifting rate and range in $L^*$, $C^*$ and $h^*$ values were calculated at the coronal and cervical border of resin composite restoration in the graphs of $L^*$, $C^*$ and $h^*$, according to the following relationship.

The color shifting ranges of the enamel or composite sides (Range R or C) were measured as the distance from the enamel border of the resin composite to the point (point E or C) where the value of each color parameter ($L^*$, $C^*$, or $h^*$) was changed in less than 95% of the maximum value change on the enamel sides or 95% of the minimum value change on the composite sides.

The color shifting rate was calculated as the slope between each point (point E and C). (Fig. 4)

Measurement of light transmission characteristics of resin composite

The two-dimensional distribution graphs of transmitted light intensities (incidence angle: 0°, measurement range: −90° to +90°) for five resin composite disks (6.0 mm in diameter, 1.0 mm thickness) of each material (EA, KA, MJ, EP) were measured using a goniophotometer (Model GP-200, Murakami Color Research laboratory, Tokyo, Japan) under regulated conditions (sensitivity: 950; volume: 560) without filter. The light-beams converged onto the pin-hole through the condenser lens, and into parallel beams through the collimator lens. These light-beams reach the specimen plane through the beam iris. The light transmitted from the specimen plane is 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:

\[
\text{Diffusion factor (\%)} = \frac{(B70°+B20°)}{2}/B5° \times 100
\]

(B is brightness at the given angle)

The color shifting rate was calculated as the slope along a longitudinal direction from coronal to cervical at the centerline of the resin composite restorations on the restored labial enamel disks are shown in Figs. 1–3. $L^*$ values of all the materials increased toward the surrounding enamel from the center of restoration and reached a plateau in enamel regardless of the cavity size. For $C^*$ values, there were various behaviors among the materials. In EP and MJ, $C^*$ values increased toward the surrounding enamel from the center of restoration and reached the plateau in enamel regardless of the cavity size. In EA, $C^*$ values increased toward the enamel border from the center of restoration and then decreased toward the surrounding enamel around the border, and reached a plateau in enamel in the 1 mm cavity size group, while $C^*$ values decreased toward surrounding enamel from the center of restoration and reached the plateau in enamel in the 3 mm cavity size group. In KA, $C^*$ values hardly changed on the restored enamel disks regardless of the cavity size. For the $h^*$ values there were different behaviors among the materials. In EA and EP, $h^*$ values increased toward the surrounding enamel from the center of restoration and reached a plateau in enamel regardless of the cavity size. On the other hand, In KA and MJ, $h^*$ values hardly changed on the restored labial enamel disk.

RESULTS

The results of the $L^*$, $C^*$, and $h^*$ values along a longitudinal direction from coronal to cervical at the centerline of the resin composite restorations on the restored labial enamel disks are shown in Figs. 1–3. $L^*$ values of all the materials increased toward the surrounding enamel from the center of restoration and reached a plateau in enamel regardless of the cavity size. For $C^*$ values, there were various behaviors among the materials. In EP and MJ, $C^*$ values increased toward the surrounding enamel from the center of restoration and reached the plateau in enamel regardless of the cavity size. In EA, $C^*$ values increased toward the enamel border from the center of restoration and then decreased toward the surrounding enamel around the border, and reached a plateau in enamel in the 1 mm cavity size group, while $C^*$ values decreased toward surrounding enamel from the center of restoration and reached the plateau in enamel in the 3 mm cavity size group. In KA, $C^*$ values hardly changed on the restored enamel disks regardless of the cavity size. For the $h^*$ values there were different behaviors among the materials. In EA and EP, $h^*$ values increased toward the surrounding enamel from the center of restoration and reached a plateau in enamel regardless of the cavity size. On the other hand, In KA and MJ, $h^*$ values hardly changed on the restored labial enamel disk.
Fig. 5 The $L^*$, $C^*$ and $h^*$ values at the center of resin composite restorations with each material (EA: Estelite Asteria, EP: Estelite Pro, KA: Kalore, MJ: Clearfil Majesty), and composite resin disks as a control. The line (---) indicates significant differences in each material among the cavity size ($p<0.05$) ($N=5$).

Fig. 6 The $L^*$ color shifting rate at the enamel border of resin composite restorations. The line (---) indicated significant differences among the materials (EA: Estelite Asteria, EP: Estelite Pro, KA: Kalore, MJ: Clearfil Majesty) ($p<0.05$) ($N=5$).

Fig. 7 The $C^*$ color shifting rate at the enamel border of resin composite restorations. The line (---) indicate significant differences among the materials (EA: Estelite Asteria, EP: Estelite Pro, KA: Kalore, MJ: Clearfil Majesty) ($p<0.05$) ($N=5$).

Fig. 8 The $h^*$ color shifting rate at the enamel border of resin composite restorations. The line (---) indicate significant differences among the materials (EA: Estelite Asteria, EP: Estelite Pro, KA: Kalore, MJ: Clearfil Majesty) ($p<0.05$) ($N=5$).

enamel disks regardless of the cavity size.

The results of $L^*$, $C^*$ and $h^*$ values at the center of resin composite restorations and those of resin composite disks as a control are shown in Fig. 5. For the $L^*$ values at the center of resin composite restorations, the 1 mm cavity size group was significantly higher than the control resin composite disk, while there was no significant difference between the 3 mm cavity size group and the control resin composite disks ($p<0.05$). On the other hand, for the $C^*$ and $h^*$ values, there were no significant differences at the center of resin composite restorations among the 1 mm, 3 mm cavity size group and the control resin composite disk ($p>0.05$).

The results of the $L^*$, $C^*$ and $h^*$ color shifting rate are shown in Figs. 6–8 and Table 2. Three-way ANOVA revealed that the $L^*$ and $C^*$ color shifting rates were significantly affected by the cavity sizes ($p<0.001$ and $p<0.001$, respectively), materials ($p<0.001$ and $p<0.001$, respectively), and regions in cavity ($p<0.001$ and...
Table 2  

| Color parameter | Cavity sizes (1 mm vs. 3 mm) | Materials | Cavity regions (coronal vs. cervical) |
|-----------------|-----------------------------|------------|-------------------------------------|
| \(L^*\)         | 0.000                       | 0.000      | 0.000                               |
| \(C^*\)         | 0.004                       | 0.000      | 0.000                               |
| \(h^*\)         | 0.421                       | 0.731      | 0.330                               |

\(p=0.044\), respectively). In the \(L^*\) color shifting rates, MJ was the highest following EP, EA and KA in this order, among which, MJ and EP were significantly different from KA \((p<0.05)\). In the \(C^*\) color shifting rates except for KA, MJ was the highest following by EP and EA in this order, among which, MJ was significantly different from EA \((p<0.05)\). Three-way ANOVA revealed that the \(h^*\) color shifting rate was not significantly affected by cavity sizes \((p=0.263)\), materials \((p=0.204)\), regions in cavity \((p=0.596)\).

The results of the \(L^*\), \(C^*\) and \(h^*\) color shifting range are shown in Figs. 9–11 and Table 3. Three-way ANOVA revealed that the \(L^*\) color shifting range in the 1 and 3 mm cavity size groups was significantly affected by enamel vs. composite \((p<0.001\) and \(p<0.001\), respectively) but not affected by materials \((p=0.137\) and \(p=0.053\), respectively) and cavity regions \((p=0.460)\).
The $h^*$ color shifting range at the enamel border of resin composite restorations. The line (●—●) indicate significant differences among the materials (EA: Estelite Asteria, EP: Estelite Pro, KA: Kalore, MJ: Clearfil Majesty) ($p<0.05$) ($N=5$).

Table 3  $p$-Value of the color shifting range

| Color parameter and cavity size | Source of variation | Enamel vs. composite | Materials | Regions in cavity (coronal vs. cervical) |
|--------------------------------|---------------------|----------------------|-----------|---------------------------------------|
| $L^*$ in 1 mm group            | 0.000               | 0.137                | 0.069     |
| $L^*$ in 3 mm group            | 0.000               | 0.079                | 0.004     |
| $C^*$ in 1 mm group            | 0.000               | 0.068                | 0.558     |
| $C^*$ in 3 mm group            | 0.000               | 0.002                | 0.160     |
| $h^*$ in 1 mm group            | 0.000               | 0.657                | 0.158     |
| $h^*$ in 3 mm group            | 0.017               | 0.905                | 0.375     |

Table 4  Light transmission characteristics of resin composite materials used in this study

|   | DF       | G0       | Area               |
|---|----------|----------|--------------------|
| EA| 92.50 (2.16)$^1$ | 18.56 (5.59)$^4$ | 0.55×10^4 (7.52×10^2)$^4$ |
| KA| 56.81 (3.18)$^2$ | 91.79 (4.73)$^h$ | 2.64×10^4 (2.56×10^3)$^h$ |
| EP| 73.89 (5.00)$^3$ | 34.34 (5.81)$^c$ | 1.11×10^4 (5.54×10^3)$^c$ |
| MJ| 70.15 (5.02)$^3$ | 57.30 (3.50)$^q$ | 3.19×10^4 (0.16×10^2)$^q$ |

$p=0.079$, respectively. In addition, it was significantly affected by regions in cavity in the 3 mm cavity size group ($p=0.004$), but not in the 1 mm cavity size group ($p=0.069$). There were significant interactions between enamel vs. composite and regions in cavity in the 1 and 3 mm size groups ($p=0.016$ and $p=0.001$, respectively). For the $L^*$ color shifting range in both cavity size groups, at the enamel side, there was no significant difference between the coronal and cervical borders ($p>0.05$), while at the composite side, the coronal border was higher than the cervical border, in which there were significant differences in EA of the 1 mm cavity size group and in KA, EP and MJ of the 3 mm cavity size groups ($p<0.05$). Three-way ANOVA revealed that the $C^*$ color shifting range except for KA was significantly affected by enamel vs. composite in the 1 and 3 mm cavity size groups ($p<0.001$ and $p<0.001$, respectively), and affected by materials in the 3 mm cavity size group ($p=0.002$) but not in the 1 mm cavity size group ($p=0.068$). On the other hand, it was not significantly affected by regions in cavity in the 1 and 3 mm cavity size groups ($p=0.558$ and $p=0.160$, respectively). There were significant interactions between enamel vs. composite and regions in cavity in the 1 and 3 mm cavity size groups ($p=0.043$ and $p<0.001$, respectively). In the $C^*$ color shifting range in both cavity size groups, at the enamel side, there was no
significant difference between in the coronal and cervical border \((p>0.05)\), while at the composite side, the coronal border was higher than the cervical border except for MJ, in which there were significant differences in EA of the 1 mm cavity size group and EA and EP in the 3 mm cavity size group \((p<0.05)\). Three-way ANOVA revealed that the \(h^*\) color shifting range, except for KA and MJ, in the 1 and 3 mm cavity size groups, was significantly affected by enamel vs. composite \((p<0.001\) and \(p=0.017\), respectively), while not affected by materials \((p=0.657\) and \(p=0.905\), respectively) and regions in cavity \((p=0.158\) and \(p=0.375\), respectively).

The results of the light transmission characteristics of resin composites are shown in Table 4. The DF value (diffusion transmission property) of EA was the highest following by EP, MJ and KA in this order, in which there were significant differences among all the materials \((p<0.05)\) except between EP and MJ. In addition, the G0 value (the straight-line light transmission property) of KA was the highest followed by MJ, EP and EA in this order, in which there were significant differences among all the materials \((p<0.05)\). The area value (whole amount of transmitted light) of MJ was the highest following by KA, EP and EA in this order, in which there were significant differences among all the materials \((p<0.05)\).

**DISCUSSION**

It is well known that translucent materials can reflect a color from the surrounding substrate, leading to shifting of the color. Recently, the color shifting effects at the enamel border of resin composite restorations have been evaluated using human tooth cavities\(^{19,20}\), in which the color shifting effects of resin composite restorations were influenced by the age of the tooth, because a higher light transmission property of aged dentin than young dentin affected light reflection from dentin cavity walls\(^{20}\). The results of \(L^*\), \(C^*\) and \(h^*\) values at the center of the composite restorations in this study would indicate that the surrounding enamel affected \(L^*\) values even in the central part of resin composite restoration, depending upon the cavity size, but not their \(C^*\) and \(h^*\) values.

In the enamel disks filled with resin composite, \(L^*\) values of all the materials gradually increased towards the surrounding enamel from the resin composite and then reached a plateau in both cavity size groups. ANOVA revealed that the \(L^*\) color shifting rate at the cervical border had significantly higher than that at the coronal border \((p<0.001)\). In this study, the enamel prism orientations would be different between coronal and cervical sides of the labial cavity. That is, most of enamel prisms were diagonally cut in the cavity wall at coronal side, whereas at cervical side, they were cut longitudinally. It is well known that enamel prisms affect the optical properties of enamel. Enamel prisms are a most important structure for light scattering within enamel\(^{21}\). Furthermore, enamel prisms can act as optical fibers, and the light is transmitted following the path of the enamel prisms\(^{20}\). Therefore, the light transmitting behavior at the border because of the enamel prism orientations might be a reason why there was a significant difference in the \(L^*\) color shifting rate between the coronal and cervical borders of the resin composite restorations. Additionally, the 1 mm cavity size group exhibited significantly higher values in the \(L^*\) color shifting rate than the 3 mm cavity size group \((p<0.001)\). These would indicate that the \(L^*\) color shifting effects at the enamel border of resin composite restorations would also be influenced by the cavity size with the amount of filled resin composite.

In the \(L^*\) color shifting range at the border, the ANOVA revealed that the enamel side was significantly larger than composite side in the 1 and 3 mm cavity size groups \((p<0.001\) and \(p<0.001\), respectively). This result is in agreement with the previous studies\(^{19}\). Additionally, at the enamel side, the \(L^*\) color shifting range was not significantly different between the coronal and cervical borders \((p>0.05)\), but at the composite side, the coronal border had a higher \(L^*\) color shifting range than the cervical border. These results might indicate that the \(L^*\) color shifting effect of enamel prism orientation developed at the composite side more than enamel side. In the 3 mm cavity size group, the \(L^*\) color shifting range at the coronal border was significantly larger than that at cervical border \((p=0.004)\), although in the 1 mm cavity size group, there was no significant difference among them \((p=0.069)\). The coronal border with a lower color shifting rate and larger color shifting range in \(L^*\) would have an advantage for color adjustment of resin composite restoration compared with the cervical border, because the gentle color shifting and larger color shifting area would obscure the border.

In this study, for the \(C^*\) values in KA and the \(h^*\) values in KA and MJ, the graphs remained flat from enamel to the resin composite because of less color differences in \(C^*\) and \(h^*\) values between enamel and the resin composite materials. Therefore, the color shifting rate and range could not be calculated in KA of \(C^*\) values and KA and MJ of \(h^*\) values. The results of the color shifting rate and range of \(C^*\) and \(h^*\) values in this study indicate that enamel prism orientations might slightly affect the \(C^*\) color shifting at the enamel border of resin composite restorations compared to the \(L^*\) color shifting, but rarely the \(h^*\) color shifting.

In this study, the light transmission characteristics of resin composites used in this study were varied. The order of the DF value (diffusion transmission property), the G0 value (straight-line transmission property) and the area value (whole amount of transmitted light) of the resin composites used in this study was inconsistent with the order of the \(L^*\) and \(C^*\) color shifting rate of those in this study, therefore it was unclear how each of the light transmission characteristics could influence the \(L^*\) and \(C^*\) color shifting rate at the border of resin composite restorations in this study. On the other hand, ANOVA revealed that the materials did not significantly affect the \(L^*\) color shifting range in both cavity size groups \((p=0.137\) and \(0.079\), respectively), and significantly affected the \(C^*\) color shifting range in the 3 mm cavity size group \((p=0.002)\) but not in the 1 mm cavity size.
group ($p=0.068$). Presumably, the color shifting effects of the resin composite restoration at the border might be influenced by each element in the light transmission characteristics of resin composite and also by the cavity size with the amount of filled resin composite. Further experiments are necessary on the effect of the optical properties of resin composite on the color shifting at the enamel border of resin composite restorations.

In this study, the one-step self-etch adhesive (Clearfil SE One) was used as the adhesive system to enamel. It is well known that a one-step self-etching adhesive is less effective for enamel etching than phosphoric acid because of the higher pH values$^{22}$. Additional enamel etching with phosphoric acid before application of a one-step self-etching adhesive has been demonstrated to improve the quality of adhesive interface, therefore some researchers recommend selective enamel etching with phosphoric acid when using one-step self-etch adhesives. The application of phosphoric acid can clearly expose enamel prisms on the enamel surface compared to a one-step self-etching adhesive$^{22,23}$. The different exposure aspects of enamel prisms on the adhesive surface might affect light scattering at the adhesive interface, which would affect the color shifting at the enamel border of resin composite restorations. Further experiments are necessary on the effect of enamel surface conditioning with adhesive procedures on the color shifting at the enamel border of resin composite restorations. In addition, evaluation of color shifting was performed under black back ground in this study, however in most of the clinical situations, back ground of resin composite restoration is dentin. The reflecting light from dentin through resin composite might affect the color shifting at the enamel border of resin composite restorations. Further experiments are necessary on the effect of dentin back ground on the color shifting at the enamel border of resin composite restorations.

**CONCLUSIONS**

Within the limitations of this study, it was concluded that the surrounding enamel with the cavity size affected the $L^*$ color shifting of the resin composite restorations, while it slightly affected the $C^*$ color shifting and rarely the $h^*$ color shifting, which were dependent upon the resin composite materials. Additionally, enamel prism orientations affected color shifting of resin composite restorations at the border, especially for lightness. The gentle and wide-area color shifting at the coronal enamel border would have an advantage for color adjustment of resin composite restorations compared with the cervical border.

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