Acta Odontologica Scandinavica, 2013; 71: 120–129

informa healthcare

ORIGINAL ARTICLE

The influence of a continuous increase in thickness of opaque-shade composite resin on masking ability and translucency

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Abstract

Objectives. This study was conducted to determine the minimum thickness of opaque-shade composite resin required to mask discolored tooth structures or darkness of the oral cavity and to determine the effect of the brand and shade of composite resins on masking ability and translucency. ***Materials and methods.*** Discs and beveled specimens were manufactured using six opaque-shade light-curing composite resins (Charisma, Heraeus Kulzer; Estelite Sigma Quick, Tokuyama; Gradia Direct Anterior, GC). The discolored tooth structures and darkness of the oral cavity were reproduced using background tiles. The disc specimen colors were measured using a spectroradiometer by increasing the thickness of the beveled specimens on the backing by 0.05 mm in series, and color difference (ΔE^*_{ab}) and translucency parameter (TP) were calculated. ***Results.*** The thicknesses of opaque-shade composite resins that masked the C4 shade and black backings were 0.80–1.45 and 1.85–2.00 mm, respectively. Overall, the ΔE^*_{ab} and TP values decreased as the thickness of the opaque-shade composite resins increased. When the shades of the composite resins were identical, the TP decreased in the order of Charisma, Estelite Sigma Quick and Gradia Direct Anterior. When the brand was fixed, the TP was higher in the OA3 shade than in the OA2 shade. A significant correlation was seen between ΔE^*_{ab} and TP ($p < 0.05$). ***Conclusions.*** The brands and shades of the composite resins were shown to have a clear effect on TP, but an inconsistent tendency for ΔE^*_{ab}.

Key Words: *composite, esthetics, masking ability, opacity, translucency*

Introduction

The demand for esthetic restorations has rapidly increased due to growing awareness and emphasis on the importance of naturally colored restorations, making shade matching a major challenge for dental practitioners. Therefore, the necessity for aesthetic restoration which enables harmonization with the adjacent teeth structure by restoring the natural color and shape of the defective tooth area has also increased [1]. Composite resin has been used as an aesthetic restorative material for almost all types and sizes of restorations. Using composite resin, restoration is accomplished with minimal loss of tooth structure, little or no discomfort, relatively short operating time and modest expense to the patient when compared with aesthetic porcelain crowns [2].

It is not easy to choose the restoration color for composite resins. Color harmonization with the adjacent teeth and the remaining dentin should be considered. In the cases of severely discolored tooth structures, however, or in a ‘through and through’ class III or IV cavity, it is difficult to select the color since there is almost no tooth structure surrounding the restorations, resulting in a reflecting or transmitting color base [3]. Compared to previous techniques, the minimal-intervention concept introduced in the restorative area enables greater preservation of tooth structure, but results in more discolored parts remaining, which produce greater discoloration [4,5]. In addition, the black background color in the oral cavity may affect the lightness and chroma of the restorative materials [6]. In such circumstances, composite resin restorations are affected by the discolored tooth structures or by the darkness of the oral cavity. This results

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(Received 20 July 2011; revised 21 October 2011; accepted 14 December 2011)

ISSN 0001-6357 print/ISSN 1502-3850 online © 2013 Informa Healthcare
DOI: 10.3109/00016357.2011.654250

in a grey color tone, different from the color of the adjacent teeth, which fails to achieve a satisfactory color match [7].

To minimize the background color effect, a layering technique is applied by generally using opaque-shade composite resin as a backing material. In this case, material translucency and color are considered as important factors [3,7–12]. Composite resin thickness is one of the factors affecting translucency [10]. Therefore, in order to achieve natural harmonization with the adjacent-teeth structure by selecting an appropriate color for the restorations, the effect of opaque-shade composite resins on masking ability and translucency should be understood. Translucency can be described as partial opacity or a state between complete transparency and complete opacity and is defined as the relative degree to which materials prevent or permit any underlying color from affecting the appearance of a colorant layer [1].

The color properties of opaque-shade composite resins, especially masking ability, are essential for aesthetic restorations, but there is insufficient study available on these topics. Masking ability or the ability to mask the background effect through the complex interaction between absorption and scattering can be achieved by adding opacifiers, such as titanium oxide or aluminum oxide added to composite resin, which make the composite resin appear lighter by increasing the light reflected toward an observer [11,13].

The function of the metal oxides is to mask highly reflective under layers by scattering incident and reflected light [14].

Ikeda et al. [7] reported that translucency is lower in opaque-shade composite resins than in dentin or enamel-shade composite resins and that 2-mm-thick opaque-shade composite resins are better than 1-mm-thick opaque-shade composite resins for shade matching when considering the effect of a dark background color. Kim et al. [1] reported that opaque-shade composite resins with a thickness of 0.5–1.0 mm were required to mask the C4 shade background color, and that opaque-shade composite resins with a thickness of 1.0–2.0 mm were needed to mask the black background color. Such results were obtained by changing the specimen thickness of the composite resin at 0.5 mm intervals. Thus, an accurate masking thickness was not identified and comparisons of the masking thickness by brand and shade were difficult. Meanwhile, in the present study, a more accurate masking thickness was determined by measuring the specimen color of the composite resin at 0.05 mm thickness intervals. Additionally, in order to investigate the effect of the brand and shade on the masking ability, composite resins with OA2 and OA3 shades were used to prepare specimens for each composite resin brand.

Furthermore, contact measurement devices such as a spectrophotometer and a colorimeter were used in the previous studies, whereas a spectroradiometer was used in this study [1,7,15]. Contact measurement devices may cause the edge-loss effect, which can affect the validity of the measured color by significantly decreasing the lightness of an object [16–18]. As a non-contact color measurement device, the spectroradiometer successfully avoids the edge-loss effect, since no shadows are cast due to absence of an aperture between the external light source, instrument and object [19,20]. Therefore, spectroradiometer-based color measurements are expected to provide a more accurate assessment of an object's true color.

This study was conducted to determine the minimum thickness of the opaque-shade composite resin required to mask discolored tooth structures or the darkness of the oral cavity, to measure the translucency of composite resins of various thickness by changing the thickness of the opaque-shade composite resins in series, and to determine the effect of the brand and shade of composite resins on masking ability and translucency.

We hypothesized (1) that the brand and shade of opaque-shade composite resins may affect the translucency and masking ability and (2) that a correlation between translucency and masking ability of the resins may exist.

Materials and methods

Preparation of the composite resin specimens

The following six opaque-shade light-curing composite resins packaged as syringes were used to manufacture the disc specimens (Table I, Figure 1): Charisma OA2 and OA3 (CA2 and CA3; Heraeus Kulzer, Hanau, Germany), Estelite Sigma Quick OA2 and OA3 (ES2 and ES3; Tokuyama, Tokyo, Japan), and Gradia Direct Anterior AO2 and AO3 (GD2 and GD3; GC, Kasugai, Japan), Letter 'O' in the shade name refers to 'opaque' (Charisma and Gradia Direct Anterior) or 'opalescent' (Estelite Sigma Quick) resin shade. The filling was done in four increments with an approximate thickness of 1 mm per increment.

After putting an acrylic mold with an 8 mm inner diameter and 4 mm thickness onto the glass cover, each material was light cured via incremental filling, according to the manufacturer's instructions. The uppermost part was slightly overfilled and covered with a cover glass to ensure a flat and smooth surface through compression and then light cured. While measuring the specimen thickness using a Vernier caliper (530–101, Mitutoyo, Tokyo, Japan), the surface was polished with 1500-grit wet sandpaper (Buehler Ltd., Lake Bluff, IL) until a thickness of 4 mm was obtained. The thickness of specimen was limited to 4 mm based on a report that an enamel shade of 4 mm thickness is sufficient to keep out the

Table I. Shades and manufacturers of the opaque-resin-based materials that were used in this study.

Material (Abbreviation)	Shade	Lot No./Manufacturer
Charisma (CA2)	OA2	010309/Heraeus Kulzer GmbH, Hanau, Germany
Charisma (CA3)	OA3	010305/Heraeus Kulzer GmbH, Hanau, Germany
Estelite Sigma Quick (ES2)	OA2	004E40/Tokuyama Dental Corp., Tokyo, Japan
Estelite Sigma Quick (ES3)	OA3	007E40/Tokuyama Dental Corp., Tokyo, Japan
Gradia Direct Anteriors (GD2)	AO2	1002161/GC Dental Products Corp., Kasugai, Japan
Gradia Direct Anteriors (GD3)	AO3	0911131/GC Dental Products Corp., Kasugai, Japan

influence of background color and the colors of 4 mm thick specimens can be considered the inherent colors of composite resins not affected by background color [1]. Since Lee et al. [21] reported that the surface roughness of composite resin that had been polished using 600-, 1000- and 1500-grit sandpapers (in that order) was similar to when a clinical polishing system was used; the specimen surface was expected to be very similar to that under clinical conditions.

After cuboidal-shaped resin blocks were manufactured with each of the six composite resins using a metal mold, they were ground into a beveled form using a grinding machine (HRG-150, AM Technology, Chungcheongnam-Do, South Korea) (Figure 1). During the preparation of the specimens, the output of the light-curing unit (Spectrum 800, Dentsply Caulk, Milford, DE) was set at 400 mW/cm^2 and was periodically verified using a radiometer (Demetron, SDS Kerr, Orange, CA). The measurements were derived from the beveled specimen. Values for the two end parts of each specimen were excluded since the color of these regions could be influenced by light refraction and light absorption.

Preparation of backing

The following three backings were prepared in order to calculate the translucency parameter (TP) and to reproduce the discolored or stained tooth structures and darkness of the oral cavity: white tile (CM-A101W, Konica Minolta Sensing, Inc., Osaka, Japan), black tile (L^* = 10.38, a^* = 5.87, b^* = 0.90, CM-A101B, Konica Minolta Sensing, Inc.) and C4 shade body porcelain plate (L^* = 66.12, a^* = 3.47, b^* = 21.70, Duceram Kiss Dentine Porcelain C4, DENTSPLY Ceramco, York, PA).

The TP was calculated by obtaining the color difference (ΔE^*_{ab}) of the beveled specimens on white and black backings. In addition, a C4 shade body porcelain plate was manufactured for use as a discolored or stained tooth structure color. A black tile was used to mimic the dark background color of the oral cavity.

Color measurement

Inside the light booth (Color Sense II, Sungjin Hi-Tech, Gyeonggi-Do, South Korea), the walls and floor were in the Neutral Munsell N7 grey color and the manual XY stage (MXY-A 40L, MID, Gyeonggi-Do, South Korea), which can move at 0.01 mm intervals towards the X and Y axes, respectively, was installed. For the light source, D_{65} simulating tubes (F2DT12/65, Gretagmacbeth, Research Triangle Park, NC) were used. The tubes were set to 45° irradiation angle and 30 cm away from the specimen (Figure 2). A spectroradiometer (PR-670, SpectraScan, Photo Research, Chatsworth, CA) equipped with a Macro Spectar MS-75 lens (Photo Research) was fixed at a point 355 mm away from the specimen. The measurement area was oval-shaped, with a longer diameter of 1.35 mm and a shorter diameter of

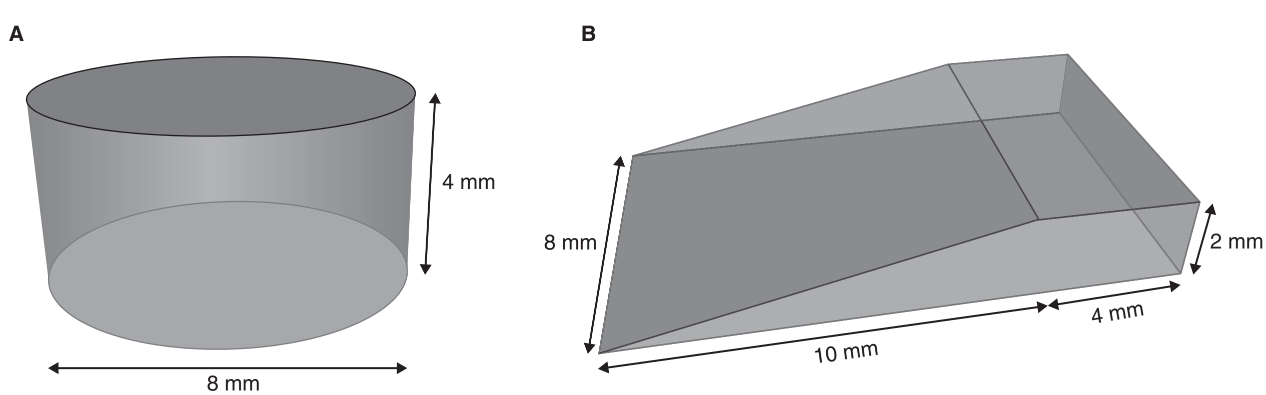

Figure 1. Schematic representation of the opaque-shade composite resin specimen: (A) disc specimen and (B) beveled specimen.

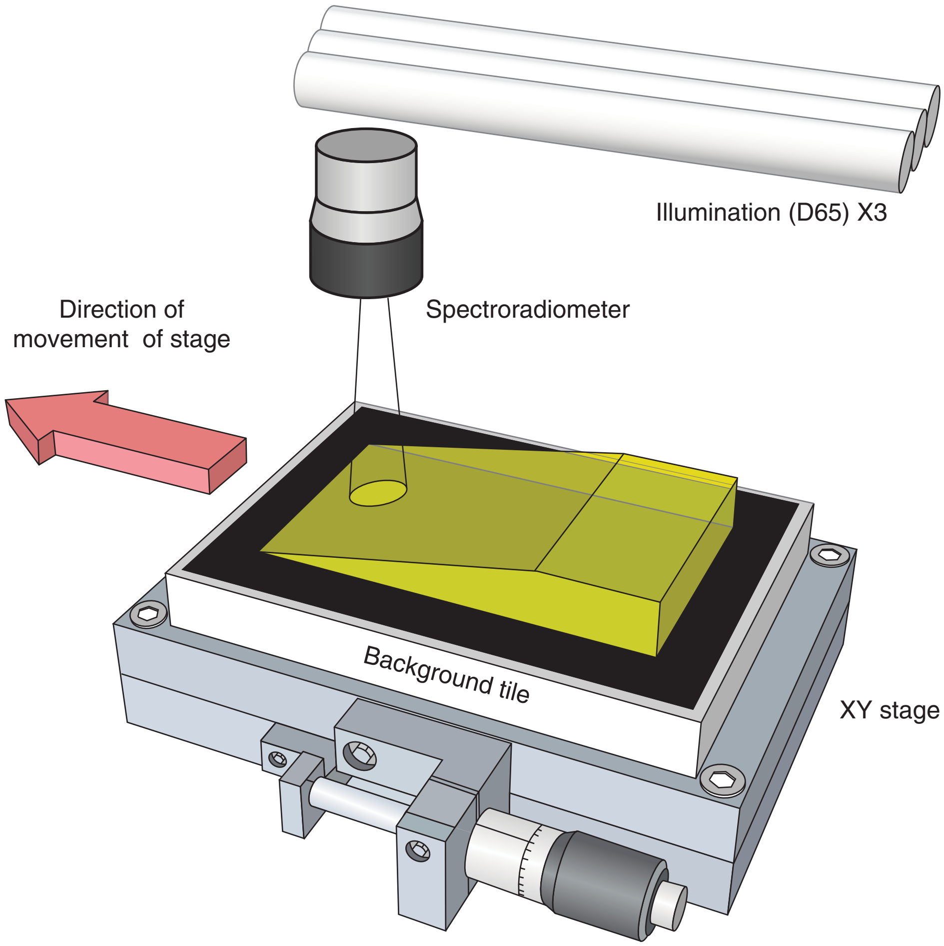

Figure 2. Schematic representation of specimen measurement using a spectroradiometer.

1.32 mm. In addition, the corresponding optical configuration allowed for a 2° standard observer according to CIE standard specification and the location was adjusted so that the measurement area would pass through the specimen center.

On the neutral-grey backing (Kodak, Rochester, NY) with a reflectance of 18%, the intrinsic color of the opaque-shade composite resin was measured using three 4-mm-thick disc specimens (Table II). In addition, after the backing was fixed on the XY stage on which the beveled specimens were then positioned, the color was measured while moving the stage at 0.25 mm intervals from the right to the left (the thickness increased at each 0.05 mm interval). Similar to previous studies [1,8,10], this study used an optical fluid (Cargille Immersion Oil Type B, Cargille Laboratories, NJ) with a refractive index of 1.515 to establish optical contact between the backing and the beveled specimens. The color was measured five times for each specimen with the three backings (white tile, black tile and C4 shade body porcelain plate).

Table II. CIELAB values of the 4-mm-thick disc specimens of the opaque-resin-based materials that were used in this study.

		CIELAB value		
Material	Shade	L^*	a^*	b^*
CA2	OA2	73.58	4.40	16.80
CA3	OA3	71.53	4.63	18.08
ES2	OA2	71.19	2.63	16.42
ES3	OA3	72.14	6.39	23.43
GD2	AO2	79.61	4.81	21.11
GD3	AO3	75.79	5.45	21.89

During the color measurement, the outer light was masked by covering the booth with a cloth to block light. In addition, the white tile was always used to calibrate the spectroradiometer before measurement. The measurement values obtained from the thicker ends of the beveled specimens were excluded because the thicker-end color was significantly affected by the reflection and absorption of light.

After measurement within the wavelength range of 380–780 nm, the spectral reflectance was obtained at 2 nm intervals (Spectrawin 2.0, Photo Research) and the result was converted into the L^*, a^* and b^* parameters of *Commission Internationale de l'Eclairage* (CIE). L^* represents lightness (where 0 represents complete black and 100 represents complete white), a^* is the chroma co-ordinate system from red (positive value) to green (negative value) and b^* is the chroma co-ordinate system from yellow (positive value) to blue (negative value) [22].

Composite resin on the C4 shade backing and the corresponding intrinsic color of the composite resin (disc specimen color of the composite resin) were compared and composite resin on the black tile and the corresponding intrinsic color of the composite resin were compared in order to calculate ΔE^*_{ab}. The following equation was used to calculate ΔE^*_{ab} [22]:

$$\Delta E^*_{ab} = \{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\}^{1/2}.$$

In addition, the following equation was used to calculate the translucency parameter of the materials with various thicknesses [3,7-12]:

$$TP = \{(L^*_W - L^*_B)^2 + (a^*_W - a^*_B)^2 + (b^*_W - b^*_B)^2\}^{1/2},$$

where the subscripts W and B are the CIELAB values of the materials on the white and black tiles, respectively.

When the color difference is lower, the specimen is not affected by either the C4 shade or the dark background color, which is indicative of superior masking ability. By setting the permissible color difference range ($\Delta E^*_{ab} \leq 3.3$) [23] the minimum thickness of the opaque-shade composite resin required to mask the background effect was obtained and was defined as the critical thickness.

Analysis of covariance (ANCOVA; SAS 9.2, SAS Institute Inc., Cary, NC) was performed to confirm the effect of composite resin thickness change on ΔE^*_{ab} and TP.

Results

The critical thicknesses of the opaque-shade composite resins where $\Delta E^*_{ab} < 3.3$ for the C4 shade and black backings are presented in Table III. The critical thicknesses of the six opaque-shade composite resins on the C4 shade backing ranged from 0.80–1.45 mm. On the other hand, the critical thicknesses of the six opaque-shade composite resins on the black backing were 1.85–2.00 mm; thicker than the values from the C4 shade backing with a narrow distribution.

The ΔE^*_{ab} change based on the opaque-shade composite resin thickness is presented in Figures 3 and 4. Overall, ΔE^*_{ab} decreased as the opaque-shade composite resin thickness increased under both background conditions. In some composite resins on the C4 shade backing, however, the color difference in the end part ranging from 1.70–2.00 mm increased slightly. The translucency parameters consistently decreased in accordance with the increased thickness (Figure 5).

Table III. Minimum thicknesses of the opaque-shade composite resins with ΔE^*_{ab} values lower than 3.3 and their color differences.

Material	Critical thickness (mm)	ΔE^*_{ab} (SD)
(a) On the black backing		
CA2	1.90	2.73 (0.61)
CA3	1.85	3.05 (0.23)
ES2	1.95	3.05 (0.27)
ES3	2.00	2.98 (0.23)
GD2	1.85	2.88 (0.12)
GD3	1.95	3.16 (0.13)
(b) On the C4-shade backing		
CA2	1.25	3.14 (0.14)
CA3	0.80	3.07 (0.19)
ES2	0.85	2.95 (0.37)
ES3	1.15	3.00 (0.23)
GD2	1.45	2.91 (0.36)
GD3	1.20	3.10 (0.08)

When the effect of the six kinds of opaque-shade composite resins and their thicknesses on ΔE^*_{ab} were analyzed using ANCOVA, a significant interaction was found between the opaque-shade composite resin type and thickness ($p < 0.05$). When the effect of the opaque-shade composite resin type on ΔE^*_{ab} was analyzed using the least square mean, a statistically significant difference was shown among all the opaque-shade composite resins on the C4 shade backing ($p < 0.05$). No statistically significant difference was found among CA2, CA3 and GD2 on the black backing ($p > 0.05$). When the effect of the composite resin type and thickness on TP was analyzed, a significant interaction was also found between the opaque-shade composite resin type and thickness ($p < 0.05$), but there was no statistically significant difference between CA2 and ES3 ($p > 0.05$).

In the case of the same shade, the three brands were always in the following order based on the magnitude of TP value (Figure 5): Charisma > Estelite Sigma Quick > Gradia Direct Anterior. For ΔE^*_{ab}, however, the aforementioned consistent tendency was found for neither the C4 shade nor the black backings (Figures 3 and 4). In the case of the same brand, the TP was always higher in the OA3 shade than in the OA2 shade (Figure 5), but ΔE^*_{ab} did not show such consistent results (Figures 3 and 4).

There was a significant correlation of ΔE^*_{ab} with TP. The correlation coefficient of TP and ΔE^*_{ab} was 0.711 ($p < 0.0001$) between the C4 shade backing and intrinsic color and 0.938 ($p < 0.0001$) between the black backing and intrinsic color.

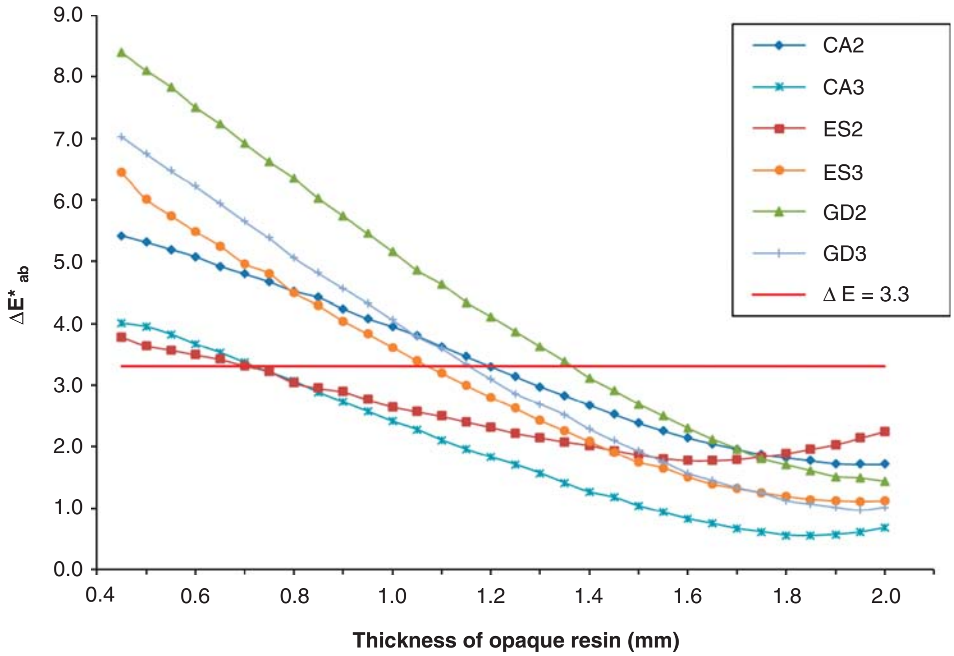

Figure 3. ΔE^{*}_{ab} values of the specimens between the colors in the C4 shade backing condition and their intrinsic states. Horizontal line is the perceptibility threshold by Ruyter et al. [23].

Discussion

Color characterization and reproduction is a great challenge in aesthetic dentistry [24]. Geometric properties such as surface roughness, gloss and translucency may significantly affect the appearance of the restoration [25]. Although the human eyes have an excellent color difference recognition capability, they have difficulty in matching color [26]. As a result, shade matching is technically very difficult. In particular, in cases of discolored tooth structures or 'through and through' class III or IV cavity restorations, it is more difficult to harmonize the natural-teeth color with the restoration color due to background color transmission [1]. Furthermore, in many cases, since enamel-shade composite resin layering on the upper part of the opaque-shade composite resin is required, the thickness that can be used in the backing is limited. Therefore, for aesthetic restorations with composite resin, it is important to know the minimum opaque-shade composite resin thickness that is required to mask the background color.

The background condition and change in the composite resin thickness may affect the final restoration color [27]. Therefore, in this study, a C4 shade body porcelain plate and black tile were set as the background conditions and beveled composite resin specimens were manufactured. The study was then

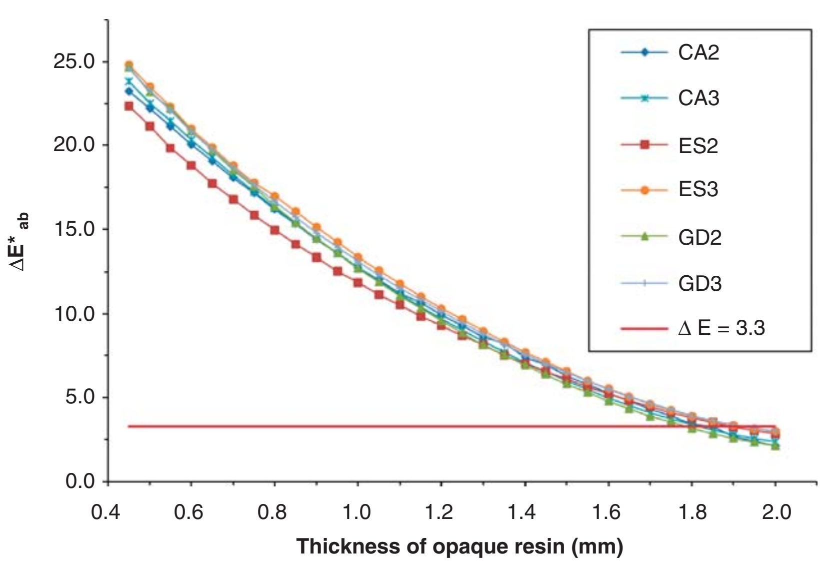

Figure 4. ΔE^{*}_{ab} values of the specimens between the colors in the black backing condition and their intrinsic states.

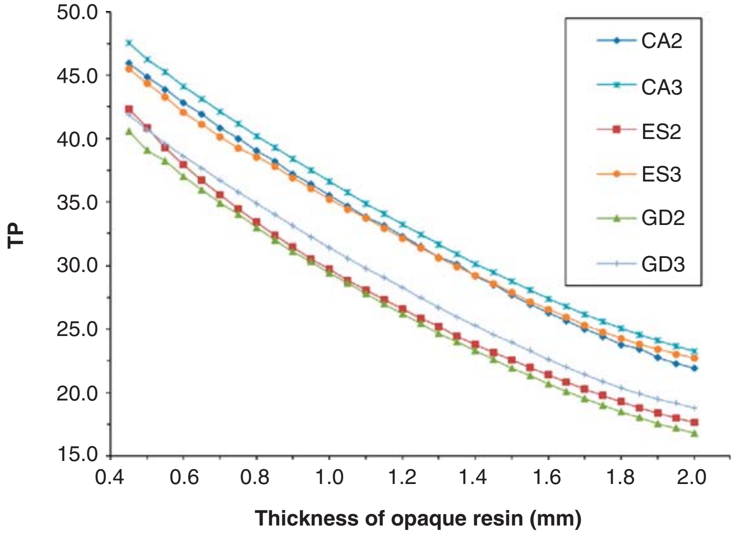

Figure 5. Translucency parameter change in the opaque-shade composite resins at various thicknesses.

conducted by changing the thickness in series (0.45–2.00 mm). As seen in previous studies, the C4 shade body porcelain was used to imitate discolored tooth shade [1], not only because the C4 shade has the darkest and lowest L^* value in the Vitapan Classic Shade Guide, but also because an emphasis on matching lightness is consistent with the physiology of the eye [28-30].

Kamishima et al. [10] reported that 4-mm-thick enamel-shade composite resin was sufficient to mask the background color. Accordingly, 4-mm-thick disc specimens (Figure 1) were manufactured in this study and their colors were used as the intrinsic color of the composite resin (Table II). The thickness of the beveled specimens that were used to investigate the effect of the backing thickness on the masking ability and translucency (Figure 1) was restricted to 2 mm, since opaque-shade composite resins greater than 2 mm in thickness are rarely created in clinical practice.

Color difference (ΔE^*_{ab}) has been conventionally used to assess color matching. The perceptible or clinically acceptable color difference threshold varies depending on the references used. In one study that analyzed the metal ceramic-crown color difference using a colorimeter, the acceptable color difference threshold was reported to be 1.7 ΔE^*_{ab} units [26]. In another study on composite resin, this time using a spectrophotometer, the acceptable color difference threshold was reported to be 3.3 ΔE^*_{ab} units [23]. As the aforementioned values were obtained under *in-vitro* conditions, it may not be appropriate to directly apply them to clinical situations. In a study that compared composite resin veneer restorations and their corresponding teeth using a colorimeter, it was reported that the clinically perceptible threshold was 3.7 ΔE^*_{ab} [31]. In a recent study where artificial teeth were analyzed using a spectroradiometer, it was reported that the predicted color difference that 50% of dentists could perceive was 2.6 ΔE^*_{ab} units and the value at which 50% of dentists would remake the restoration due to color mismatch was 5.5 ΔE^*_{ab} units [32].

The results of a study conducted by Ruyter et al. [23] which utilized study materials and conditions similar to those in the present study indicated that a ΔE^*_{ab} of 3.3 was an appropriate color difference threshold. This value has been widely used as a color difference threshold standard. In accordance with this, a ΔE^*_{ab} of 3.3 was set as the acceptable threshold in the present study; however, a spectroradiometer was used to measure the color. Compared to the spectrophotometer type devices, spectroradiometers have a tendency to yield slightly higher CIE L^*, a^* and b^* value measurements [20], resulting in a slightly increased ΔE^*_{ab} value. In addition, since the upper enamel-shade composite resin may additionally reduce the background color transmission, the ΔE^*_{ab} of 3.3 that was used in this study could be somewhat strict.

Ikeda et al. [7] reported that 2-mm-thick opaque-shade composite resin is better than 1-mm-thick opaque-shade composite resin for shade matching when considering the dark-background effects in the range of $\Delta E^*_{ab} \leq 2.0$, which is consistent with the result of this study. In addition, in a previous study using a colorimeter, Kim et al. [1] reported that opaque-shade composite resin with a thickness of 0.5–1.0 mm was required to mask the C4 shade background color and that opaque-shade composite resin with a thickness of 1.0–2.0 mm was required to mask the black background color. In this study, the minimum thickness of the opaque-shade composite resins required for masking the background color on the C4 shade backing ranged from 0.80–1.45 mm and the minimum thickness of the opaque-shade composite resin required to mask the background color on the black backing ranged from 1.85–2.00 mm. Although the aforementioned results of this study appear to differ slightly from those of the previous study, the two sets of results are significantly similar when taking into account the fact that different types of composite resins were used and a somewhat strict standard was applied in this study.

There was a significant difference in the masking ability of the opaque-shade composite resin between the C4 shade background color (Figure 3) and the black background color (Figure 4). For the C4 shade backing, a statistically significant difference in masking ability was found among all the composite resins and the critical-thickness range had a wide distribution. Meanwhile, for the black backing, no statistically significant difference in masking ability was found among CA2, CA3 and GD2 and the critical-thickness range had a narrow distribution (Table III). The opacifiers that were added to the composite resins increased composite resin lightness by increasing the light reflected toward an observer [13]. For the black tile, the L^* value increase caused by the opacifiers in each composite resin was similar among the products due to the absence of color. On the other hand, for the C4 shade body porcelain, the color-masking ability caused by the unique color pigments of the composite resin brands and the lightness increase caused by the opacifiers were likely to have had a complex interaction with each other.

ΔE^*_{ab} and TP decreased as the thickness increased in all six types of composite resin. However, due to the interaction between the composite resin type and thickness, it cannot be concluded that the masking ability of a specific composite resin is always superior to that of other composite resins at various thicknesses. The masking ability of composite resin is expected to be affected by opacifiers, pigments, fillers and various additives. As commercial resins were used in this study, however, it was difficult to determine the factor that most critically affects the masking ability. Therefore, further studies on composite resins with different compositions are required.

No statistically significant difference in TP was found between CA2 and ES3, whereas a statistically significant difference in masking ability was found between them. In general, the OA3 shade is expected to have a higher masking ability since it has lower lightness and higher chroma than the OA2 shade [33]. Translucency of aesthetic restorative materials has usually been determined with the translucency parameter (TP). TP is the color difference of a uniform thickness of a specimen over a white and a black background and corresponds directly to common visual assessment of translucency [34].

TP, however, which represents the translucency of a composite resin, was higher in the OA3 shade than in the OA2 shade. Meanwhile, decrease in ΔE^*_{ab} represents an increase in actual masking ability and was higher in the OA2 shade than in the OA3 shade, with the latter having an overall higher masking ability. This result supports the findings from the previous study in which the masking ability was not determined by TP alone [1]. Johnston and Reisbick [3] reported that the translucency and color of aesthetic restorative materials are affected by pigments or other chemicals that are added as well as macro phenomena, such as the ratio of the matrix and the filler or the filler amount. Therefore, the masking ability of opaque-shade composite resin should be assessed using a method that directly analyzes the color difference between the intrinsic color and the color in a specific thickness rather than TP.

In contrast to the black backing, the light reflected from the C4 shade backing contains significant color. On the other hand, the amount of external light coming from the side increased as the thicknesses of the beveled specimens within the measurement area increased. As a result, more reflected light from the backing was absorbed by the specimens. The slight increase of color difference in the end portion of the specimen ranging from 1.70–2.00 mm in some composite resins on the C4 shade backing is likely attributable to the aforementioned phenomenon.

This study was limited with respect to the measurement methods that were used. Measurements were taken in the beveled area of the composite resin, and the measurement area was oval-shaped. Since the measurement area was not flat, the composite resin thickness at the measurement point was inconsistent, which may have resulted in measurements that were not representative of an actual clinical situation. In addition, although the spectroradiometer was fixed onto a tripod, the specimens moved along the axis of the XY stage during color measurement. Thus, there was a slight change in the distance between the spectroradiometer and the measurement area. This slight difference (within 2 mm) was confirmed to rarely affect the result based on the precedent study [35]. Thus, the difference is likely to be negligible, although this condition must be kept in mind when applying the results of this study to clinical practice.

The results of this study in relation to the C4 shade backing suggest that a minimum thickness is required to mask the discolored or stained tooth structure with a lightness comparable to or higher than that of the C4 shade. On the other hand, the application of the study results in relation to the black backing will be useful for masking the dark background color of the oral cavity in the restoration of a 'through and through' class III or IV cavity.

Considering the results of this study, the first hypothesis, i.e. that the brand and shade of opaque-shade composite resins may affect the translucency and masking ability, was accepted because the brands and shades of the composite resins were shown to have a clear effect on ΔE^*_{ab} and TP. The second hypothesis, i.e. that a correlation between translucency and masking ability of the resins may exist, was also accepted because a significant correlation was seen between the two ($p < 0.05$).

Further studies comparing the CIELAB values of contact measurement devices and those of non-contact measurement devices, determining a clinically acceptable color difference threshold based on various color measuring devices, evaluating composite resins with various additive compositions, and investigating the effect of the surface conditions of composite resins (e.g. polishing) are all required.

Conclusions

(1) (1) The minimum thickness of the opaque-shade composite resin that was required to mask the background color was lower in the C4 shade backing condition than in the black-backing condition.

(2) (2) A statistically significant difference in ΔE^{*}_{ab} was found among all six opaque-shade composite resins in the C4 shade backing condition, whereas there was no statistically significant difference in ΔE^{*}_{ab} among Charisma OA2, Charisma OA3 and Gradia Direct Anterior AO2 in the black-backing condition.

(3) (3) A statistically significant difference in TP was found in all six opaque-shade composite resins, except for Charisma OA2 and Estelite Sigma Quick OA3.

(4) (4) The brands and shades of the composite resins had a clear pattern with respect to TP, but had an inconsistent tendency for ΔE^{*}_{ab}.

Acknowledgement

This study was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2011-0005559).

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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