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Influences of filler content and size on the color adjustment potential of non-layered resin composites

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The blending effect (BE) plays an important role in esthetics of the composite resin. The objective of this study was to determine the extents to which filler size and content affect the BE. Three types of fillers (0.7, 1.0, and 1.5 µm) were mixed at weight contents of 60, 70, 75, and 80%. This study simulated clinical class 3 or 4 cavities and quantitatively measured the color diffusion of the objects next to the cavities based on the CIELab color space. For each filler size, there was a trend of increasing BE as the filler content was increased. The translucency parameter (TP) exhibited the opposite trend of decreasing ($p<0.05$) with increases in filler content. The filler size did not affect the BE, and the different filler sizes produced statistically non-significant results in this study. Increases in filler content elevated the opacity of the composite resin and significantly influenced the BE.

Keywords: Spectrophotometry, Blending effect, Color adjustment potential, Filler content, Translucency parameter

INTRODUCTION

There are various methods for restoring damaged teeth and treating dental caries. Among the tooth-colored materials in rising demand recently, various types and sizes of the composite resin have been used in the clinic ever since its invention. Composite resin has many advantages over esthetic porcelain crowns: less damage to natural teeth allows more conservative restorations possible, and there is less stimulated pulp, shorter clinic time, and lower price[1)].

A tooth has various hues, values, and chroma, which is why it is often called polychromatic. Therefore, an esthetically successful restoration demands the careful consideration of not only the color of the teeth and the restoration materials but also the translucency, luster, and surface texture[2)]. Of course, the colors of the composite resins used in the clinic do not always match those of the patient's teeth. Furthermore, the colors that manufacturers provide vary slightly based on which manufacturer made them and the characteristics of the resins[3)]. Regardless of this color incompatibility, dentists like to use composite resin for esthetic restoration because they know from clinical experience that unless the size of the restoration is too large, after restoration, people discern the color difference between the applied resin and the tooth to be less than it actually was prior to the restoration. This phenomenon is called the blending effect (BE). According to previous research, the blending effect increases as two similar colors become closer, and the blending effect is affected by the type of composite resin and its tone[4,5)]. The BE increases especially with smaller restoration size, less color difference, and bigger translucency[4)], and the blending effect is highly relevant to the layered effect[5)].

The BE plays an important role in achieving high-quality esthetic restorations with the standardized colors of composite resin[6)]. Many dentists have applied multiple techniques to maximize this effect. However, the cognitive and quantitative research on the BE is currently insufficient[5)]. The BE has been studied not only cognitively but also quantitatively. Quantitative studies use the color adjustment potential (CAP), which seems to be influenced by very complicated color phenomena[7)]. It is not easy to demonstrate the relations between the CAP and the components of the composite resins such as filler size, quantity, and the types of monomer on their manufacturers' labels[7)].

A previous study suggested non-layered composite resins as an area deserving of further study, but no such study has yet been performed[7)]. A previous BE study utilizing a layered composite resin restoration model showed that the more translucent the resin gets, the more BE increases[3)]. Clinically class 3 or 4 cavity restoration, however, the dark background of the oral cavity can be seen through the front of the restoration if the resin is too translucent, which creates an esthetically unnatural look. When a semi-translucent resin is directly used to restore a cavity, the color of the composite resin is affected by the color of the tooth on which the resin is applied. This see-through effect makes it difficult to recognize the difference of colors when a semi-translucent material is adjacent to a colored material.

This study simulated clinical class 3 or 4 cavities

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and quantitatively measured the color diffusion of the object next to a cavity based on the CIELab color space[8]. The quantitative measurements of the change in BE were assessed according to filler contents and filler sizes as suggested in previous research[4]. We also scrutinized whether the translucency parameter (TP) is actually affected by the filler content and filler size and studied the relation between TP and BE.

The primary goal of this study was to identify the condition that maximizes the BE in esthetic restorations. The first step to this goal was to see how much filler sizes and contents affect the BE. This study hypothesized that BE would increase as filler size decreased, and BE would increase as filler content increased. Accordingly, the null hypothesis assumed that filler sizes and filler contents would not affect the BE.

MATERIALS AND METHODS

Preparation of the composite resin

The composite resin used in this study was custom made. The composition of the matrix was as follows: a resin matrix of 39.5% Bisphenol A glycerolate dimethacrylate (Bis-GMA, Sigma-Aldrich, Steinheim, Germany), 59.5% Triethylene glycol dimethacrylate (TEGDMA, Sigma-Aldrich), 0.33% Camphorquinone (CQ, Sigma-Aldrich), and 0.67% 2-(Dimethylamino)ethyl methacrylate (Sigma-Aldrich).

The filler was a silane-processed manufactured product, and its composition (as provided by the manufacturer) is provided below (Table 1). To produce the composite resin for this experiment, fillers of three sizes (0.7, 1.0, and 1.5 µm) were mixed manually at each of the weight contents of 60, 70, 75, and 80%. There were 12 types of resins and each type had five samples.

Table 1 Filler composition of this study

Schott Ultrafine® GM 27884, Index of refraction n_d=1.53(10^{-6}/K)
Size 0.7 µm with 4.2% silane
Size 1.0 µm with 3.2% silane
Size 1.5 µm with 1.6% silane

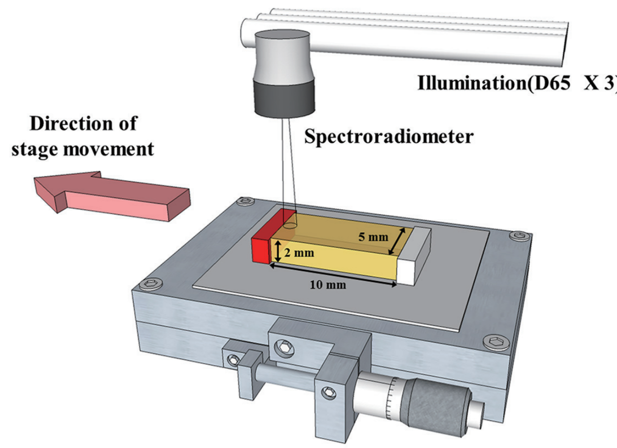

Fig. 1 A sample is fixed to the grey background with the motor installed on.

Sample preparation and color measurement

Three days after mixing the composite resins, the experiment samples were produced. Each sample was a 10×5×2 mm^3 composite resin block with a tightly contacted red tile (Color tile CM-A101R, Konica Minolta Sensing, Osaka, Japan) on one side and a white tile (Color tile CM-A101W, Konica Minolta Sensing) on the other side (Fig. 1). The resin blocks were completely polymerized in custom made acryl molds by Apollo 95E light polymerizer (Apollo 95E, Dental Medical Diagnostics, Woodland Hills, California, USA) for 40 s without a bonding agent. Each resin block was thoroughly light cured to achieve complete polymerization.

The colors of the produced samples were measured by a spectroradiometer (PR-670, SpectraScan, Photo Research, Chatsworth, CA, USA), which was positioned perpendicular to the samples and was 40 cm away from the sample with a 1/4° aperture. The light used in this experiment was D65 (F2DT12/65, Gretagmacbeth, Research Triangle Park, NC, USA), where the D65 light was installed as colored in N7 achromatic grey in the Munsell color coordination system and had a light bulb installed on the top of the booth (Color sense II, Sungjin Hitech, Gyeonggi, Korea) to flash the light at a 45 degree angle to the sample. The measurement mode was specular component excluded (SCE) geometry in order to measure the glossy specimens similar to a visual assessment by a human observer. The aperture of the spectroradiometer was fixed on the area of the sample contacting the red tile. Five samples were produced out of resin consisting of identical filler size and filler content. The motor described below moved the sample 0.25 mm each time and measured the color a total of 32 times per experiment. Therefore, each sample moved 0.25 mm per color measurement for a total of 8 mm until the last measurement. The diameter of the measurement area was calculated as 1.745 mm from the observer, which had a 40 cm of measurement length and an aperture of 1/4°. The XYZ coordinates were measured by the spectroradiometer and converted into a CIELab color space. As an indirect way to compare the light penetration depth of a sample to one another, the translucency parameter was obtained by measuring the color of each resin block under two different conditions, one with white background tile and the other with black background tile.

Results processing

Among the converted CIELab values, the CIEa^* value was selected as the quantitative parameter of measurement. The reasons are as follows. At first, CIEL^* is strongly affected not only by the color of the material near the sample, but also by the lightness; second, in human teeth, the range of CIEa^* values is narrower than that of CIEb^* values[9]; and third, the shade guide also indicated a narrow range of the CIEa^* values compared to that of the CIEb^* values[10].

CIEa^* value was biggest at the area that initially contacted the red block and decreased as the sample was moved. As the distance increased, the a^* value dropped and finally converged to a certain point. The convergence of a^* was the value of the sample resin itself because this value occurred when the measurement was taken too far away from the red block for the BE to influence the color. According for the result of an experiment concluding that unit 1 is the minimum color difference in CIELAB (L^*, a^*, and b^*) that men can recognize[11], the maximum BE effective range was assumed to be the distance getting 'CIEa^* plus 1', *i.e.*, the CIEa^* of the sample itself plus 1, and each value was compared to those from each different measurement point. This experiment focused not on the absolute value of the a^* measurement but on the maximum effective range of the BE, which is shown on the x axis of the graph. The measured a^* value of a sample falls in the form of an exponential function like the graph below. Matlab (MathWorks®) was used to compute the exponential function $y=a^*e^{-bx}+c$ to fit the measurements. The BE distance from the installation position of the spectroradiometer was first calculated. Next, the intrinsic CIEa^* value plus 1 was calculated and multiplied by 0.25 mm to obtain the x value at the intersection point of the graph, and the radius of the measurement area was then added (Fig. 2).

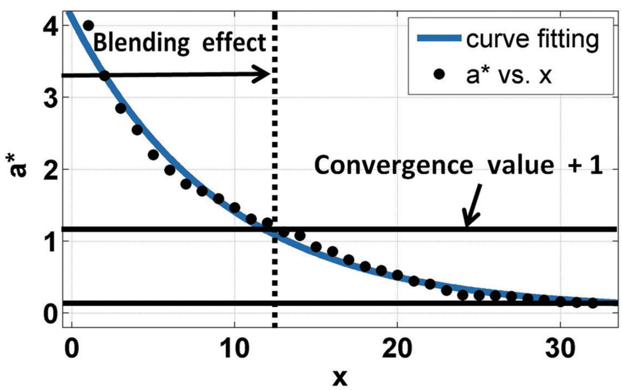

Fig. 2 CIEa^* value was in the form of a reduced functional index (exponential decay) and follows a $y=ae^{-bx}+c$ function.
The variable x refers to the unit movement 0.25 mm.

On the other hand, the translucency parameter (TP) was calculated as $TP=[(L^*_B-L^*_W)^2+(a^*_B-a^*_W)^2+(b^*_B-b^*_W)^2]^{1/2}$, where the subscript B refers to the color coordinates over a black background and the subscript W refers to those over a white background[12]. Samples with greater translucency parameters are more translucent and those with complete opacity have TP value 0. TPs of each sample were calculated and those variation trends were compared to the BE distance variables.

Statistical analysis

The results of each test were analyzed with one-way ANOVA (PASW Statistics 18.0, IBM, USA) followed by Tukey's HSD at a significance level of 0.05. The effects of the filler contents were analyzed according to the filler size conditions. The effects of the filler sizes were separately analyzed according to each filler content condition.

RESULTS

Quantitative calculations of the blending effect distances and TPs of the samples in each experiment are presented in the Tables below (Tables 2 to 4). Briefly, as the filler content increased, there were trends of increases in the BE distances and decreases in the TP values. As the filler content increased from 60 to 80%, the BE distance increased from the minimum measurement of 1.271 mm to the maximum measurement of 4.796 mm, and the TP value decreased from the maximum measurement of 64.593 to the minimum measurement of 51.768. Especially, when the filler content reached 80%, the increases in the BE distances and the decreases in the TP values were remarkable.

At each filler size, a trend of increasing BE distance was observed as the filler content was increased. In the case of the 0.7 μm filler, the mean of BE distance was 1.442, 2.162, 2.068, and 3.355 mm at filler content of 60, 70, 75, and 80%, respectively. In the case of the 1.0 μm

Table 2 BE distance & TP based on filler content in 0.7 μm Filler

0.7 μm Filler	*n*	Mean of BE distance (mm)	Mean of TP
60% content	5	1.442[a] (0.114)	60.567[a] (0.531)
70% content	5	2.162[b] (0.061)	58.179[ab] (1.535)
75% content	5	2.068[b] (0.109)	57.334[b] (1.816)
80% content	5	3.355[c] (0.882)	53.126[c] (1.524)

*Values with the same superscript letters indicate no significant differences (p>0.05).

Table 3 BE distance and TP based on filler content in 1.0 μm Filler

1.0 μm Filler	*n*	Mean of BE distance (mm)	Mean of TP
60% content	5	1.398[a] (0.454)	60.676[a] (0.277)
70% content	5	1.631[a] (0.067)	55.618[b] (1.438)
75% content	5	2.027[b] (0.322)	54.102[b] (1.008)
80% content	5	3.346[c] (0.073)	51.910[c] (0.392)

*Values with the same superscript letters indicate no significant differences (p>0.05).

Table 4 BE distance and TP based on filler content in 1.5 μm Filler

1.5 μm Filler	*n*	Mean of BE distance (mm)	Mean of TP
60% content	5	1.398[a] (0.084)	63.447[a] (1.205)
70% content	5	1.656[ab] (0.090)	60.287[b] (2.135)
75% content	5	2.017[b] (0.377)	57.305[c] (1.918)
80% content	5	3.570[c] (0.496)	53.642[d] (0.827)

*Values with the same superscript letters indicate no significant differences (p>0.05).

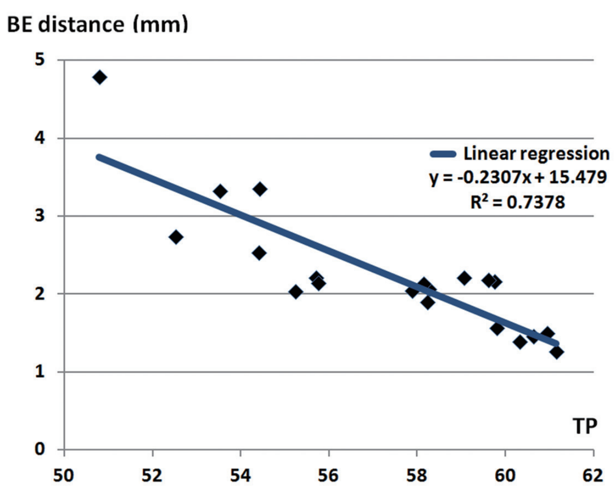

Fig. 3 The correlation between BE distance and TP at 0.7 μm filler model.

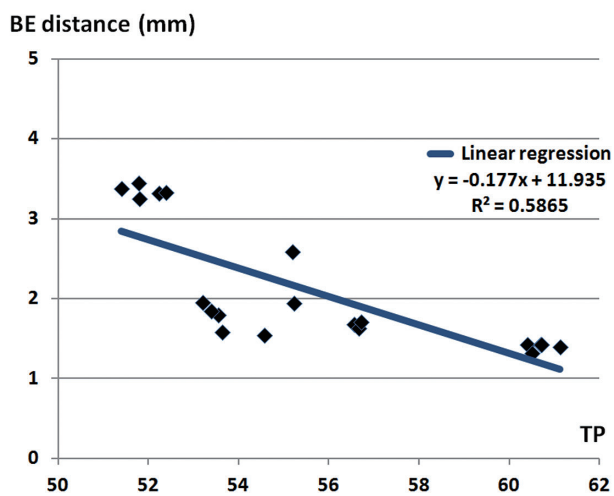

Fig. 4 The correlation between BE distance and TP at 1.0 μm filler model.

filler, the mean of BE distance was 1.398, 1.631, 2.027, and 3.346 mm at filler content of 60, 70, 75, and 80%, respectively. In the case of the 1.5 μm filler, the mean of BE distance was 1.398, 1.656, 2.017, and 3.570 mm at filler content of 60, 70, 75, and 80%, respectively.

At each filler size, a trend of decreasing TP value was observed as the filler content was increased. In the case of the 0.7 μm filler, the mean of TP was 60.567, 58.179, 57.334, and 53.126 at filler content of 60, 70, 75, and 80%, respectively. In the case of the 1.0 μm filler, the mean of TP was 60.676, 55.618, 54.102, and 51.910 at filler content of 60, 70, 75, and 80%, respectively. In the case of the 1.5 μm filler, the mean of TP was 63.447, 60.287, 57.305, and 53.642 at filler content of 60, 70, 75, and 80%, respectively.

Especially at the 80% filler content, the increases in BE distance were statistically significant for every filler size (p<0.05) compared to the other filler contents, but the TPs exhibited the opposite decreasing trend (p<0.05).

The filler sizes of 0.7, 1.0, and 1.5 μm, however, did not affect the BE distance or TP value. They were not

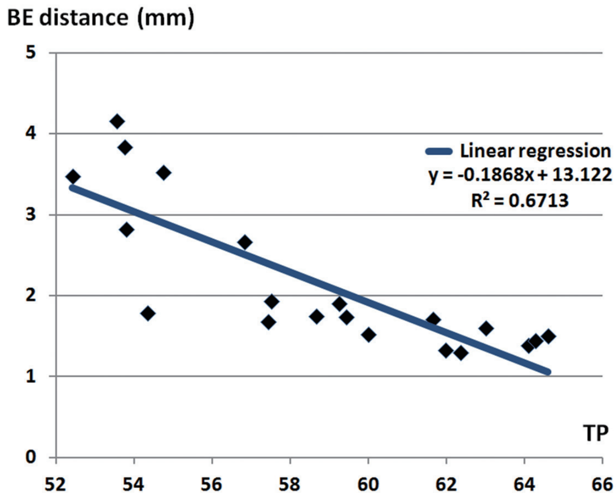

Fig. 5 The correlation between BE distance and TP at 1.5 μm filler model.

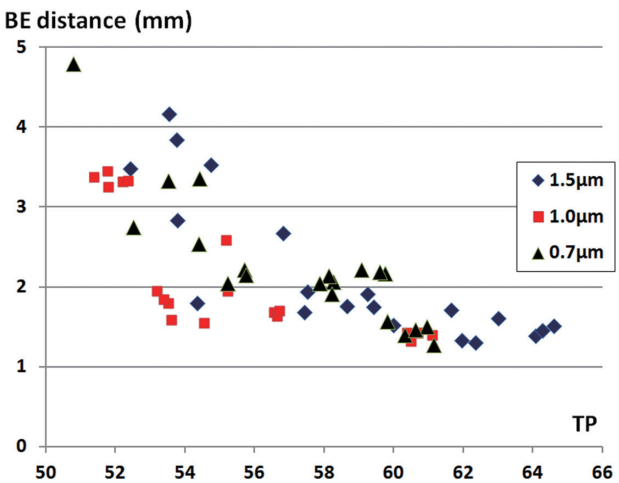

Fig. 6 The correlation between BE distance and TP at various filler sizes.

statistically significant.

The BE distance and the TP value exhibited a negative correlation on the graph and as the TP decreased, which means the opacity increased, the BE distance increased (Figs. 3 to 6). Counting only the effect of filler, increasing filler content in a composite resin made TP decrease and BE increase.

DISCUSSION

The resin used in this experiment was made by mixing the pre-made matrix and filler, and no opacifier (oxide titanium or oxide aluminium) was added. In this experiment, opacifier itself was absolutely excluded to control the experimental conditions and to focus on the changes in BE based on filler sizes and contents, because the opacifier, which is so little (0.001–0.007%)[13] of the weight content, is expected to influence the result much more than the filler.

This study developed previous studies of BE and created a reliable model to measure the BE of non-layered restorations. This model focused on the influences of the filler content and filler size on the BE as has been suggested as an area for future research in previous studies, such as that by Paravina *et al.*[4].

This study did not show a statistical trend of BE value based on particle size difference, but found that filler content was statistically significant to the BE. That is, this study found that increase in filler content elevated the opacity of the sample resin and the BE. Therefore, the previously described null hypothesis was partially rejected. It is thought that the filler size difference was quite small in this study, consequently the effect of filler size was not clear.

The result that the TP value decreased as the opacity of the resin samples increased does not agree with the findings of a previous study[5]. The previous study concluded that greater translucencies of layered composite resins cause increases of the BE[5]. Because this study excluded the opacifier to focus only on the influence of the filler, the basic TP value was higher than that of the regular resin and it was speculated as a reason for the higher BE with translucency decreasing.

Although this study concluded that there is no effect of filler size on BE, this issue is subject to further speculation because the variation in the sizes of the fillers was not that extensive. Because resins that utilize nano-sized particle clusters have been developed as fillers to take advantage of their greater mechanical strength, it is necessary to compare BE variations between resins with particle cluster fillers and resins with uniform fillers. An in-depth study also needs to be conducted to determine the extent to which BE is affected by the opacifier because the TP values of the samples used in this study, which included no opacifier, were significantly greater than those of regular resins[14,15].

In addition, the quantitative evaluation of BE as proposed in this study is expected to be applied to measure BE differences between regular resins in the clinic in the future. Clinicians may be able to use this result as a guide for esthetic restorations.

It is thought that BE studies will flourish in the esthetic restoration field of dentistry. If it is possible to maximize the BEs of composite resins, the composite resins can be esthetically improved and the number of shade guides in clinics will be significantly reduced. Further study needs to be continuously conducted to understand and utilize the BE in dentistry.

CONCLUSION

Within the limitations of this study, the filler contents affected the BEs of composite resins more strongly than the filler sizes, and this correlation was positive. The TPs of resins for restorations were also related to the BEs.

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