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Color interaction of dental materials: Blending effect of layered composites☆

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ABSTRACT

Objectives. To evaluate the in vitro blending effect (BE) of layered resin composites related to material, shade, and differences in color and translucency between compared materials.
Methods. Specimens made of two composites (2CS, $n = 5$) consisted of the outer composite with an outer diameter of 10 mm, 4 mm thick and an inner diameter of 4 mm, 2 mm thick for the inner composite. Thus, the inner composite was encircled by a 3 mm outer composite around its circumference and backed by a 2 mm thick outer composite, to simulate a dental restoration surrounded by hard dental tissues. The outer composite was Palfique Estelite (PE, C2 shade, standard shade), while the inner composites were PE A2, B2 and C2 shades and corresponding shades of Point 4 (P4), Tetric Ceram (TC) and Filtek A110 (FA) composites (batch shades). Single-composite, disk-shaped specimens (1CS) of all five shades ($D = 10$ mm, 2 mm thick, $n = 5$) were made as well. Visual color assessments were done by six observers using a lightbooth and 1 (mismatch) to 5 (perfect match) scale. The BE was calculated as a difference in scores between corresponding 2CS and 1CS. Z-scores and corresponding BE values (BE_Z) were calculated. 1CS were also evaluated using a spectrophotometer.
Results. Blending effect ranged from −0.4 to 2.2, while BE_Z ranged from −0.6 to 3.0. Mean visual scores for 1CS and 2CS were 1.8 (1.2) and 2.2 (1.3), respectively. BE increased with a decrease in color difference ($r = 0.41$) and increase of translucency parameter (TP, $r = 0.77$). High agreement was recorded among pairs of observers for both 1CS, $r = 0.95$ (0.03) and 2CS, $r = 0.96$ (0.02).
Significance. Blending effect is composite and shade dependent. Quantifying of blending potential of dental materials might provide useful clinical information for dental professionals.

1. Introduction

Blending effect (BE) of esthetic dental materials refers to interrelation of these materials or materials and hard dental tissues, manifested by smaller color difference if they were observed together than if viewed in isolation [1–3]. It can be easily seen in dental office by comparing a color difference between a tooth and resin composite: when a piece of poly-

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merized composite is placed next to the tooth to be restored, color difference can be bigger than if the same material were polymerized in the cavity. This phenomenon is sometimes named a "chameleon effect," the term not being the most appropriate. Dentin that forms the pulpal surface of the cavity (referring to either pulpal floor or wall) and deep layers of a translucent dental material influence the final color of the restoration as well [4]. This phenomenon is known as double-layer effect (DLE), although mentioned interactions can be observed for multiple layers as well [5–12]. As the BE, DLE is related to optical interaction of hard dental tissues, these tissues and esthetic materials, or interaction of dental materials. BE and DLE seem to be interrelated and influenced by translucency and thickness of tissues/materials involved.

There are two methods of color measurement: visual and instrumental. Color measurements are made in order to define color appearance (describing color within an environment, observing a single specimen), to judge color equality (color comparison, batch – the shades which are compared versus standard – the shade against which the comparison is made), or to determine color composition, the former two being achievable visually [13]. Since color measurement devices have been developed based on the response of so-called standard observer, the expectation of agreement between visual and instrumental findings appears to be quite reasonable. Instrumental methods became very popular in dental research due to development of new technologies that are user friendly and offer objective information on color specification as well as magnitude and direction of color differences. However, it should not be forgotten that patient's visual judgment on color match or mismatch is usually the final and decisive one.

There is only one published report on blending effect of dental materials [1]. Reports on double-layer effect are available, but these studies mostly employed instrumental color measurement techniques [5–12]. The model used in this study represented an example of combined BE and DLE. The purpose of this study was to evaluate blending effect of layered resin composites as related to material, shade, and differences in color and translucency between compared materials.

2. Materials and methods

Fifteen shades of five commercial resin composites were studied (Table 1). Specimens were made of two composites (2CS, $n=5$) and of a single-composite (disk-shaped specimens, 1CS, $n=5$).

The 2CS consisted of an outer and inner composite. The outer composite had an outer diameter (OD) of 10 mm, 4 mm thick and an inner diameter (ID) of 4 mm, 2 mm thick for the inner composite. Specimens were made using custom-designed, stainless-steel molds and tools mounted on the metal platform (Fig. 1), similar to ones reported in the previous study [1], except for the fact that the difference in height between outer and inner composite was 2 mm (4 mm versus 2 mm). Due to this difference in height, resin composites were incrementally applied up to the top of cylindrical extension (2 mm) of the inner mold component and polymerized holding the tip of a polymerization lamp (Demetron 501, Demetron/Kerr, Danbury, CT, USA) centered over the specimen. Polymerization times were in accordance with manufacturers' recommendations (Table 1). The second layer of composite was then applied and polymerized with the same duration as the first layer. The outer composite was Palfique Estelite C2 shade (standard) and it was removed from the mold before the inner composite was applied [1]. Thus, the inner composite was encircled by a 3 mm outer composite around its circumference and backed by a 2 mm thick outer composite, to simulate a dental restoration surrounded by hard dental tissues. Single-composite disk-shaped specimens of all 15 shades ($D=10$ mm, 2 mm thick, $n=5$) were made as well.

Table 1 – Product, manufacturer, composite type (CT), average particle size, filler content by weight and volume, code, shade, lot, and polymerization time (PT, s) of resin composites tested

Product	Manufacturer	CT	Particle size	Filler content		Code	Shade	Lot	PT
				wt.%	vol%				
Palfique Estelite	Tokuyama Dental (Tokyo, Japan)	Microhybrid	0.2 μm	82	71	PE	A2 B2 C2	E6162 W66832 W3301	30
Esthet-X	Dentsply/Caulk (Milford, DE)	Microhybrid	0.6–0.8 μm	77	60	EX	A2 B2 C2	021004 020628 0205202	20
Point 4	SDS Kerr Orange, CA)	Microhybrid	0.4 μm	77	59	P4	A2 B2 C2	208371 205212 110677	40
Tetric Ceram	Ivoclar Vivadent (Amherst, NY)	Microhybrid	0.7 μm	80	60	TC	A2 B2 C2	D62694 D54572 C31889	40
Filtek A110	3M ESPE (St. Paul, MN)	Microfill	0.04 μm	56	40	FA	A2D B3D C2D	2AT 2BJ 2BB	40

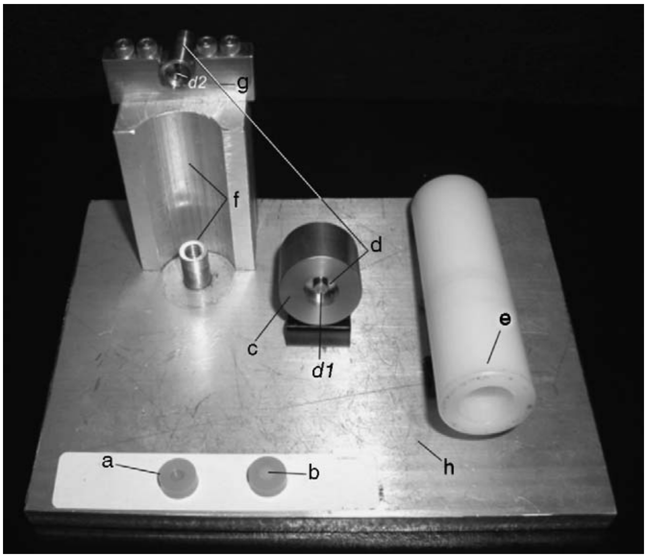

Fig. 1 – Custom-made molds and tools and specimens made of two composites: (a) 2CS, outer composite before placement of inner composite; (b) 2CS, after placement of inner composite; (c) stainless steel mold: outer component; (d) stainless steel mold: inner component ((*d1*) *cylindrical extension*; (*d2*) *screw*); (e) plunger; (f) plunger guide; (g) inner component holder; (h) platform.

Further specimen manipulation and experiment procedures were exactly the same as described in the previous paper [1]. The same techniques were followed for specimen fabrication, visual color assessment conditions and method, observers, instrumental measurement and calculation of color and translucency parameter, statistical analysis and calculation of the Z-scores and inter- and intra-observer agreement.

Specimens were finished wet for 30 s using 600-grit silicon carbide disks in a dual-platen 20 cm table-top grinder-polisher (Ecomet 6, Buehler, Lake Bluff, IL, USA). Afterwards, specimens were dry-polished for 40 s by the same operator using a polishing system (PoGo, lot # 021112, Dentsply/Caulk, Milford, DE, USA). Specimens were randomly marked at the back and stored at 37 °C and 100% relative humidity for one week.

A lightbooth (Judge II, GretagMacbeth, New Windsor, NY, USA) was used for visual color assessments, made by six observers: four dentists and two scientists. A 45°/normal illuminant/viewing geometry was provided, with the observing distance of 25 cm and illuminance that ranged from 960 to 1020 lx. Results were expressed using the 1–5 scale in the following manner: 1, mismatch/totally unacceptable; 2, poor match/hardly acceptable; 3, good match/acceptable; 4, close match/small difference; and 5, exact match/no difference in color. All observers were educated and trained in shade matching [11].

Color and translucency parameter (TP) of 1CS were also evaluated using a spectrophotometer (Color-Eye 7000, GretagMacbeth LLC, New Windsor, NY, USA). Spectral reflectance values were recorded in increments of 10 nm and converted to CIELAB values (D55, 10 °). The total color difference (ΔE^*) was calculated as follows [13]:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \tag{1}$$

TP was calculated as a color difference between CIELAB values obtained for the same specimen against black and white backings.

Means, standard deviations and correlation coefficients (*r*-values) were calculated. BE was calculated as a difference in visual score between corresponding 2CS and 1CS pair, while differences in Z-scores were used to calculate BE_Z.

Since the Mean-Category Method implicitly assumes that the perceptual differences between each two scores are identical, visual scores were also processed using the Categorical-Judgment Method. The inverse of the equation for the standard normal cumulative distribution was used to calculate and convert the proportional cumulative frequency scores to Z-scores. Influence of DLE on BE was evaluated by comparison of BE values from this study and previous paper (4 mm inner diameter of 2CS, same shades) [1]. For the DLE evaluation, BE observed in this study was considered as a complex blending effect (BE_C) because it involved DLE, while corresponding values from the previous study [1] were considered to represent a simple blending effect (BE_S). DLE was calculated as the difference between BE_C and BE_S.

The mean value of the highest percentage of observers that graded specimens of each shade combination represented the inter-observer agreement. The intra-observer was represented by the mean value of the highest percentage of identical scores for each group of five specimens of the same shade and observer.

3. Results

Visual scores and Z-scores for single-composite specimens and specimens made of two composites (both compared to PE/C2) and BE values are listed in Table 2. The mean score by observer ranged from 1.4 to 2.1 for 1CS and was 1.8 (s.d. 1.2) for all observers together. Corresponding score for 2CS ranged from 1.8 to 2.4 and was 2.2 (s.d. 1.3) for all observers together. Correlation among visual scores and Z-scores was almost linear, $r > 0.99$.

Differences in L^*, a^*, and b^* values as well as total color difference (ΔE^*_{ab}) among each of four batch shades and PE/C2 are listed in Table 3, together with TP for the batch shades. When all BE values were compared to all ΔE^*_{ab} values for 1CS (14 batch shades versus standard, all except double PE/C2 combination), BE increased with a decrease in initial color difference ($r = 0.41$). When scores for 1CS and 2CS were compared with ΔE^*_{ab} values, *r*-values were 0.77 and 0.83, respectively. BE increased with the increase of TP ($r = 0.77$). When scores for 1CS and 2CS were compared with TP values, recorded *r*-values were 0.13 and 0.51, respectively.

DLE for PE/A2, PE/B2, EX/A2 AND EX/B2 was 0.5, 0.4, 0.3, and 0.2, respectively. DLE decreased with the decrease of BE. BE_C and BE_S [1] were highly correlated ($r = 1.00$) and their relationship for the specified composite thicknesses was given

Table 2 – Mean (s.d.) visual scores (VS) and mean categorical-judgment scores (Z)[a] of single-composite specimens (1CS), specimens made of two composites (2CS), and corresponding blending effect (BE and BE_Z, 2CS minus 1CS)

Code/shade	1CS		2CS		BE	BE_Z
	VS	Z	VS	Z		
PE/A2	2.1 (0.8)	0.2	4.3 (0.5)	3.2	2.2	3.0
PE/B2	1.1 (0.3)	−0.8	2.7 (0.6)	1.2	1.6	2.0
PE/C2/	4.8 (0.5)	3.4	5.0 (0.0)	4.0	0.2	0.6
EX/A2	1.1 (0.3)	−0.8	1.4 (0.5)	−0.5	0.3	0.2
EX/B2	1.2 (0.4)	−0.7	1.3 (0.5)	−0.6	0.1	0.1
EX/C2	1.2 (0.4)	−0.7	1.3 (0.5)	−0.6	0.1	0.1
P4/A2	1.3 (0.5)	−0.4	2.1 (0.8)	0.2	0.7	0.6
P4/B2	1.1 (0.3)	−0.8	1.3 (0.5)	−0.6	0.2	0.2
P4/C2	3.7 (0.7)	2.1	3.5 (0.6)	1.9	−0.2	−0.2
TC/A2	1.3 (0.5)	−0.4	1.9 (0.6)	0.1	0.6	0.5
TC/B2	1.6 (0.5)	−0.4	2.4 (0.8)	0.6	0.8	1.1
TC/C2	2.1 (0.7)	0.3	1.8 (0.6)	0.0	−0.3	−0.3
FA/A2D	1.1 (0.3)	−0.8	1.0 (0.0)	−1.1	−0.1	−0.3
FA/B3D	1.4 (0.6)	−0.3	1.1 (0.3)	−0.8	−0.4	−0.6
FA/C2D	1.7 (0.6)	−0.1	1.5 (0.6)	−0.3	−0.2	−0.1

[a] The 95% confidence interval for the Z-scores was ±0.25.

through the following regression equation:

$$BE_C = 1.14BE_S + 0.25 \quad (2)$$

The correlation between BE_C and DLE was sub-maximal ($r = 0.97$), with the regression equation as follows:

$$DLE = 0.12BE_C + 0.22 \quad (3)$$

The correlation coefficient for agreement among pairs of observers for 1CS and 2CS was 0.95 (s.d. 0.03) and 0.96 (s.d. 0.02), respectively. When scores of all six observers were compared, means (s.d.) for the inter-observer agreement were 75% (s.d. 17%) for 1CS and 72% (s.d. 20%) for 2CS, while the intra-observer agreement was even higher: 81% (s.d. 15%) for 1CS and 82% (s.d. 5%) for 2CS. Inter-observer agreement by shade ranged from 0.3 to 0.8 for 1CS and from 0.0 to 0.8 for (s.d. values in Table 2). The standard deviation for intra-observer agreement for 1CS and 2CS ranged from 0.2 to 0.5 and from 0.1 to 0.4, respectively.

Table 3 – ΔL^*, Δa^*, Δb^*, and ΔE^*_{ab} values (s.d.) as compared to PE/C2 (all recorded against white backing) and translucency parameter (TP) of the shades listed in the first column[a]

Code/shade	ΔL[a]	Δa[a]	Δb[a]	ΔE^*_{ab}	TP
EX/C2	8.2 (0.6)	−1.5 (0.1)	−4.7 (0.5)	9.6 (0.3)	6.0 (0.8)
P4/A2	6.4 (0.3)	0.3 (0.1)	−4.3 (0.9)	7.8 (0.4)	8.1 (0.6)
P4/B2	8.6 (0.5)	−1.5 (0.1)	−3.0 (0.6)	9.3 (0.5)	7.0 (0.5)
P4/C2	3.0 (0.6)	0.1 (0.1)	−2.1 (0.6)	3.8 (0.3)	5.8 (0.6)
TC/A2	5.6 (0.6)	−0.1 (0.1)	−0.1 (0.4)	5.6 (0.6)	8.6 (0.3)
TC/B2	5.8 (0.6)	−0.8 (0.1)	−1.6 (0.4)	6.0 (0.4)	9.1 (0.4)
TC/C2	5.0 (0.7)	−0.8 (0.1)	−2.4 (0.5)	5.6 (0.5)	6.6 (0.6)
FA/A2D	9.5 (0.5)	−2.8 (0.1)	−8.0 (0.4)	12.8 (0.4)	5.2 (0.2)
FA/B2D	10.2 (0.4)	−1.5 (0.1)	−3.2 (0.7)	10.9 (0.4)	5.3 (0.7)
FA/C2D	5.1 (0.5)	−2.2 (0.1)	−6.5 (0.5)	8.6 (0.4)	4.9 (0.4)

[a] Corresponding values (1CS) for PE/A2, PE/B2, EX/A2 and EX/B2 are published in previous paper [1].

4. Discussion

Blending effect was highly varied by composite and shade. It was the most pronounced for A2 shades, followed by B2 and C2 shades. Within the A2 shades, it decreased as follows: PE > P4 > TC > EX > FA. Corresponding order for B2 and C2 shades was PE > TC > P4 > EX > FA and PE = P4 > EX > FA > TC, respectively. When BE was compared to ΔE^*_{ab} values (batch versus standard, only 1CS), there was an inverse correlation, but ΔE^*_{ab} values did not appear to be the most decisive factor for BE. However, strong correlation was recorded between 1CS scores and ΔE^*_{ab} as well as between 2CS scores and ΔE^*_{ab}, which is related to quality of visual color assessments rather than to BE. As compared to PE/C2, all evaluated shades were lighter (lower L^* values), all except P4/A2 and P4/C2 were greener (lower Δa^* values), and all shades except PE/B2 were bluer and less chromatic (lower Δb^* values).

A strong correlation between BE and TP indicated that in the given set of shades BE was more related to translucency than to ΔE^*_{ab} values. The 1CS scores were not correlated to the TP values, while a strong correlation between the 2CS scores and TP was observed.

As far as the possible influence of chemical/physical properties of resin composites on BE is concerned, it should be mentioned that the data on composite type, average particle size and filler content (Table 1) were provided by manufacturers. According to these data and recorded BE values, it seems that composite type and particle size did not determine BE, while the filler content might be more influencing. However, this topic, especially relationship between particle size and BE, requires further research.

Color of the tooth is influenced by the double-layer effect. The color of the dentin and the thickness, scattering and translucency of the enamel, where the enamel properties were found to be a function of wavelength of incident light and moisture content, were important factors [10–12]. A combination of dental materials (e.g. dentin and enamel ceramics) with stratiformed layers are also called turbid media [4]. A color difference coefficient was proposed as color change resulting from a 1 mm thick layer of body porcelain on a opaque porcelain [7]. Since both scattering and absorption are involved in dentin/enamel and dental material combinations, it presents a complex-subtractive mixing [13]. This type of color mixing is commonly described by simplified Kubelka–Munk equations, which primarily considered translucent colorant layer placed atop of opaque backing. Simplification relates to the following assumptions: (1) light travels only up or down perpendicular to the plane sample surface; (2) the light within colorant layer is completely diffuse; and (3) there is no change in refractive index at the sample's boundaries [13]. Both single-constant Kubelka–Munk theory and two-constant Kubelka–Munk theory have been used in dental research. Although Kubelka–Munk theory neglects fluorescence [14], observed in both dental tissues and dental materials, very good results of its application were reported in literature. Theoretical diffuse reflectance spectra of dentin and enamel were found to be in good agreement with the observed diffuse reflectance [15]. Another study reported high correlation ($r \geq 0.96$) between observed and predicted reflectance values of veneer porcelain on various backings [8]. When opaque/dentin and opaque/dentin/enamel ceramic layered specimens were observed, a $\Delta E^*_{ab} \approx 1.0$ was recorded between computer color matched specimens and target specimens [9]. A recently proposed fluorescent extension to the Kubelka–Munk model [14] and similar research might enable even better results of color prediction in dentistry.

Blending effect observed in this study was higher than corresponding values (for 4 mm diameter inner composite) reported in the previous paper [1]. That occurred for all four shades that were evaluated in both studies: PE/A2 (2.2 in this study versus 1.7 in the previous one), PE/B2 (1.6 versus 1.2), EX/A2 (0.3 versus 0.0), and EX/B2 (0.1 versus −0.1). It is important to mention that 1CS scores in both studies were almost the same. These differences might have occurred due to the double-layer effect of 2CS in this study. Hence, the difference in BE appears to be an exact visual measure of the influence of double-layer effect on BE of evaluated composites.

Evaluation of blending effect of translucent dental materials as performed in the previous study and this study is very specific due to several reasons. Opposite to majority of studies in other areas that evaluated color assimilation of surfaces [16–20], BE in dentistry is a three-dimensional phenomenon.

Specimen design and size of observed specimens were factor as well. Color equality can be measured by comparing batch and simple standard (as in 1CS comparisons) or by comparing batch and multiple standards (natural tooth and shade guide tabs, typical for shade matching in dentistry) [13]. The batch-standard comparison using only one specimen (2CS) is not a common practice in color science and it was chosen because it mimics reality in dentistry. Observation distance and size of the specimen determine visual angle of subtense. Although larger sizes increase visual precision, a 10 mm diameter was chosen because is approximates the tooth size. In accordance with the rule that viewing distance should enable visual angle not less than 2°, this distance was set to 25 cm. Fulfilling of CIE recommendation [21] for the angle of subtense of at least 4° with so small specimens would decrease a viewing distance to approximately 14 cm thus impacting some other principles of vision, starting form the visual acuity up to observer's vergence (eye movements that enable pointing the fovea of both eyes on a near object) [22,23].

Both inter- and intra-observer agreement were very high, with almost maximal r-values among pairs of observers for each shade/combination of shades. There are several possible explanations for this result and they are predominantly associated with observers' background and working conditions. It has been reported that years in practice, specialty, and gender did not influence color matching quality [24–26]. Conversely, color education and training as well as differences in shade matching conditions and method did influence color matching quality and consistency [24,27]. The basics of a color training program, mastered by all six observers, are described in literature [4]. Stable and controlled color measuring conditions play an important role in intra- and inter-observer agreement. That is why the use of a lightbooth with standardized illuminants and interior painting is highly recommended in visual color assessments.

Another method of determining the observer accuracy was reported in the study of color emotion and color preference. It was calculated as follows [28]:

$$\text{accuracy} = \sum_i \frac{1 - w_i}{N} \tag{3}$$

where w_i is the proportion of wrong decisions within the observer group concerned with the specimen i and N the number of specimens. A wrong decision was defined as the number of observers whose score was different from the majority of the group. This method is mainly used for the binomial distribution such as pair comparison.[1] The mean observer accuracy obtained in that study was 0.73 (0 stands for the poorest accuracy and 1 for the best).

One concern might be difference in thickness between 1CS and 2CS. This difference was not considered to be critical since no visual assessments with direct comparison of 1CS and 2CS were employed and since experiment design already involved different thicknesses of inner and outer composites in 2CS. In addition to that, both the nature of illuminant and illuminance level were quite different as compared to the high-power penetrative xenon-flash lamps used in some color measuring instruments.

Blending effect of dental materials is multi-causal. This research provided information on combined effect of BE and double-layer effect as well on some factors that might influence BE. However, additional research is required in order to understand blending effect in dentistry more completely.

5. Conclusions

Within the limitations of this study, it was found that blending effect was composite and shade dependent. It increased with the decrease of initial color difference and the increase of translucency parameter.

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