博 士 論 文

Evaluation of shade matching of a novel supra-nano filled esthetic resin composite employing structural color using simplified simulated clinical cavities

臨床を想定した単純窩洞に構造色を用いた新規スープラナノフィラー含有コンポジットレジンの色差測定評価

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THIS THESIS SUBMITTED IN PARTIAL FULFILLMENT OF REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE DEPARTMENT OF RESTORATIVE DENTISTRY FACULTY OF DENTAL MEDICINE.

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This is to certify that the research work presented in this thesis, entitled ` Evaluation of shade matching of a novel supra-nano filled esthetic resin composite employing structural color using simplified simulated clinical cavities` was conducted by Chen Fei under the supervision of Professor Hidehiko Sano. No part of this thesis has been submitted anywhere else for any other degree. This thesis is to submit to the Department of Restorative Dentistry, Graduate School of Dental Medicine, Hokkaido University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the field of Dental Medicine.

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Abstract

The evolution of adhesive dentistry and patients' esthetic demands have made resin composite the most used restorative material in current dental practice. The use of the recently introduced universal-shade resin composites, which are expected to match nearly all shades, simplifies the restorative procedure, therefore raising interest among clinicians. This study was to evaluate the shade matching ability of a novel supra-nano filled esthetic resin composite employing structural color technology using simplified simulated clinical cavities. Filler morphology and light transmittance characteristics were also evaluated.

One-hundred and twenty frames of resin composite were built in A1, A2, A3, and A4 shades to simulate Class I cavities (diameter = 4 mm, height = 2 mm). For each shaded frame, cavities were filled with three different types of filler containing resin composites (n = 10): supra-nano filled (SN filled) resin composite, micro-hybrid filled (MH filled) resin composite, and clustered-nano filled (CN filled) resin composite. Color parameters were calculated using CIELAB ($\triangle E_{ab}$). Data were analyzed using one-way ANOVA, followed by Duncan's test (α = .05). Five representative discs (diameter = 4 mm, thickness = 1 mm) of each tested filler containing resin composite were prepared for measure the light transmittance characteristics. For each disc, the two-dimensional distribution graph of transmitted light intensity was determined under regulated conditions. Filler morphologies of three tested filler containing resin composites, and ESQ resin composite were observed under SEM. The resin matrix was dissolved with acetone. The specimens were then rinsed with water and air-dried for 5 s. The filler morphologies were examined at × 10,000 and × 20,000 magnifications.

Duncan's post hoc test revealed that $\triangle E_{ab}$ of SN filled group was significantly lower than that of MH and CN filled groups in the cases of A2, A3, and A4 shades ($P < .05$), while $\triangle E_{ab}$ of A1 shade of MH filled group was significantly lower than that of SN and CN filled groups ($P > .05$). The two-dimensional distribution graph of light transmittance characteristics of the tested resin composites revealed that MH filled group had a broader distribution of light transmission intensity than CN and SN filled groups. SN filled resin composite showed regularly distributed, spherical supra-nano filler particles with diameters of approximately 260 nm. The fillers were clustered together in some areas.

From the results of this study, it might be concluded that the SN filled resin composite showed better shade matching with A2, A3, and A4 shades of resin composite frames compared to MH filled resin composite, and CN filled resin composite. Universal-shade resin composites, which were expected to match nearly all shades, simplifies the restorative procedure. Resin composite, which contained spherical supra-nano filler particles, could contribute most to its shade matching by stimulating structural color. Structural color technology may provide additional benefits for shade matching of resin composites.

Background

Esthetic is one of the key current topics of restorative dentistry. [1] Esthetic resin composites can be effectively used to improve smile esthetics through minimally invasive preparations with a much lower cost than equivalent ceramic restorations. [2,3] Artificial reproduction of all the intrinsic properties of the tooth is not always a simple task because the enamel and dentin have different thickness distributions in the dental crown, composition, structure, and especially, optical properties. [4-6] Dentin is characterized by an opaque and rich complex, [7] with varying degrees of saturation and fluorescence, has a well-defined chromatic role. [8] It is covered with a layer of enamel, which is translucent and opalescent, the chromatic and translucent optical properties vary from cervical to incisal. [9]

The Natural Layering Concept (NLC) is a relatively simple and effective approach to the creation of highly aesthetic direct restorations. [10-13] When NLC is applied, an opaque and/or a body-shade can be used to cover up more intense tooth color defects, whereas a more translucent shade can be applied as a last covering layer. [14] The correct application of the layering technique should minimize color discrepancies, such as loss of lightness, and also may promote compensatory changes in the final restoration, which may mask the discolored underlying tooth substrate. [12]

Achieving perfect direct restoration has been, over time, a difficult task to achieve, because of the imperfect optical properties of composite resins and unpredictable clinical procedures. [15] Multichromatic restoration can be complex and time consuming, and if different opacities are not combined correctly, the results can be compromised. [16] Clinical success depends on not only the NLC technology, but the type of composite resins. Universal shade resin composite throws the door to clinical simplification, they claimed that one shade fits all situations, which rise interest to the field of clinical esthetic dentistry. [17]

CIELAB is recommended by the International Commission on Illumination (CIE) for evaluating the color differences ($\triangle E_{ab}$) using corresponding symbols: L* (lightness), a* (green-red coordinate), b* (blue-yellow coordinate). [18-22] In addition to color difference, translucency, diffability, also affect the color matching ability. [23]

This study was to evaluate the shade matching ability of a novel supra-nano filled esthetic resin composite employing structural color technology using simplified simulated clinical cavities. Filler morphology and light transmittance characteristics were also evaluated.

Chapter 1: Introduction

The evolution of adhesive dentistry and patients' esthetic demands have made resin composite the most used restorative material in current dental practice.[24] Resin composites have the ability to reproduce tooth color, but an ideal shade-matching of such restorations to the surrounding tooth structure is still challenging.[4] The layering of different shades allows the conventional resin composites to mimic the natural tooth, a technique named "stratification", also described as the "natural layering concept".[12] Though the stratification technique has been commonly employed in clinical practice, it usually requires excellent restorative skills and an extended chair-side time. To date, this technique has not been standardized for a universal shade guide.[25] On the contrary, the use of the recently introduced universal-shade resin composites, which are expected to match nearly all shades, simplifies the restorative procedure, therefore raising interest among clinicians.[26]

The shades of most current resin composites are primarily determined by pigments and dyes incorporated into the resin matrix, a process known as "chemical coloration."[27,28] Resin composite's "blending effect" (BE) contributes significantly to shade matching. BE is the potential of a resin composite that enables it to take on the color of the surrounding tooth structure via reflections and thus improve the esthetics.[29] In other words, when the same resin composite is viewed in isolation, it appears different from the tooth structure.[30] "Chameleon effect" is another term sometimes used by dental manufacturers and professionals to express BE.[9] When light illuminates through the resin composite, it scatters at the surface of the filler particles and diffuses in multiple directions. Light transmission through resin composite consists of a straight-line transmission and diffusion.[31] Filler particles of resin composite could influence the light transmittance characteristics. Besides, BE of a restoration can be influenced by the scattering and diffusing refraction of light through the resin composite.[9] Therefore, an evaluation of light transmission of resin composite with different filler morphology is important to predict shade matching.[32]

The use of filler morphology for shade matching is a recent technological innovation where shade matching is achieved by the light absorption and emission of a resin composite, a technology named as "structural color".[33] More precisely, structural colors arise from the physical interaction of periodic supra-nano structures of the materials with light through reflection and refraction.[34] The potential benefits of supra-nano filled resin composite shaded mainly via structural color are likely to have less change in the shade over time due to reduced photochemical degradation, and less color distortion, since their filler particles' arrangement corresponds to the wavelengths of the visible light.[33,35,36] Regardless of the technology the manufacturers are employing for shade matching, if these universal products are proven to be effective, it would greatly simplify clinical shade matching and reduce chair-side time.

Many research groups employed simulated tooth preparations instead of real human teeth for the visual and instrumental evaluation of shade matching to achieve predictable esthetic outcomes *in vitro*. [27,29,33] The color of natural human tooth is a result of complex interactions between light and tooth, influenced by various factors such as the type of tooth, site, and age.[37] Therefore, instead of using natural teeth at the beginning, a simplified simulated clinical cavity model could be useful primarily for predicting shade matching of an esthetic resin composite in laboratory settings before embarking on a more relevant yet expensive clinical trial. In a recent study, Trifkovic and his co-researchers measured the color of resin composites after placing them in simulated Class I tooth preparations fabricated from a resin composite to mimic the shades of teeth.[38] Estelite Sigma Quick (ESQ, Tokuyama Dental, Tokyo, Japan) resin composite frames prepared from A1~A4 shades were employed to simulate clinical conditions.

Recently, a novel supra-nano filled resin composite, Omnichroma (Tokuyama Dental, Tokyo, Japan), claiming to rely on structural color technology for shade matching, is gaining attention from the clinicians. The aim of this study was to evaluate its shade matching using simplified simulated clinical cavities. An actual clinical cavity model could add several uncertainties in the experimental design, such as the variety of the depth, the shape of the cavity, and the indeterminacy of the surrounding teeth shade. Thus an in vitro simplified model containing simulated clinical cavities is necessary to have a preliminary idea about the materials' esthetics restorable ability. The null hypotheses tested were the following: (1) the shade matching, (2) light transmittance characteristics of the novel supra-nano filled resin composite would not differ from the other types of filler contained resin composites.

Chapter 2: Materials and methods

2.1 Specimen preparation and the evaluation of shade matching

Three different types of filler containing esthetic resin composites were selected for this study: A3B shade of Filtek Supreme Ultra (3M ESPE, St. Paul, MN, USA) as clustered-nano filled (CN filled) resin composite, universal shade of Essentia (GC Corporation, Tokyo, Japan) as micro-hybrid filled (MH filled) resin composite, and universal shade of Omnichroma (Tokuyama Dental, Tokyo, Japan) as supra-nano filled (SN filled) resin composite. Details about the tested resin composites and ESQ resin composite used to prepare frames in this study are given in Table 1.

A custom-made rubber mold having a round cavity (diameter = 10 mm, height = 5 mm) with a small cylindrical projection (diameter = 4 mm, height = 2 mm) in its center (Figure 1 – A) was prepared from a cured silicone impression material (Correcsil, Yamahachi Dental Mfg., Co., Aichi, Japan). One-hundred and twenty frames of A1, A2, A3, and A4 shades (n = 30) were built by filling the mold cavity with ESQ resin composite (Figure 1 – B). The resin composites were cured with an LED curing light ranging between 660 to 760 mW/cm^2 (PenCure 2000, Morita, Tokyo, Japan). Thirty frames of each shade were prepared with simulated Class I cavities (diameter = 4 mm, height = 2 mm) formed by the small cylindrical projection inside the mold cavity.[27,30] The cavity walls were lined with a thin layer of a chemical-cure adhesive (Bondmer Lightless, Tokuyama Dental, Tokyo, Japan) according to the manufacturer's instructions (Figure 1 – C). Then the simulated Class I cavities were filled with three different filler containing resin composites (n = 10)

(Figure 1 – D): CN filled resin composite, MH filled resin composite, and SN filled resin composite.

The CIEL*a*b* color parameters were determined for each simulated restoration and for the peripheral resin composite frame material using a colorimeter (OFC-300, RC500, PaPaLaB Co., Tokyo, Japan) under D65 illumination that corresponds to "average" daylight.[30] The calibration of the equipment was performed immediately before each series of measurements using a white tile background (L* = 93.2; a* = − 0.3; and b* = 1.6) and a black tile background (L* = 0.5; a* = 0.7; and b* = − 0.6).[24] The illumination geometry for the reflectance measurements was bi-directional 45˚/0˚. The color measurement was repeated three times for both the simulated restorations and the peripheral resin composite frame, with the mean values of the three locations considered as the data points for each restoration and the frame (Figure 1 – F). The color differences between the three simulated restorations and the ESQ resin composite frames with A1, A2, A3, and A4 shades were calculated using the following CIELAB and expressed as Delta E ($\triangle E_{ab}$):[31]

$\triangle E_{ab} = [(\triangle L^*)^2 + (\triangle a^*)^2 + (\triangle b^*)^2]^{1/2}$

where: $\triangle L^* = L^*_{sim} - L^*_{frame}$;

$\triangle a^* = a^*_{sim} - a^*_{frame}$;

$\triangle b^* = b^*_{sim} - b^*_{frame}$

(sim = simulated restoration; frame = resin composite frame).

L\`, C\`, and H\` values of the simulated restorations were also calculated from CIEL*a*b* values:[39]

$L` = L^*_{sim}$;

$C` = (a^*_{sim} + b^*_{sim})^{1/2}$;

$H` = \arctan(b^*_{sim} / a^*_{sim})$.

Table 1 Resin composites, their manufacturers, types of fillers, organic matrices, shades, and batch numbers.

Resin Composites (manufacturers)	Filler Particle Types (codes)	Organic Matrices	Shades	Batch Numbers
Filtek Supreme Ultra (3M ESPE, St. Paul, MN, USA)	Clustered-nano filler (CN filled resin composite)	Bis-GMA, UDMA TEGDMA, Bis-EMA	A3 body	N922261
Essentia (GC, Tokyo, Japan)	Micro-hybrid filler (MH filled resin composite)	Bis-EMA, Bis-GMA Bis-MEPP, UDMA, TEGDMA	Universal	1706302
Omnichroma (Tokuyama Dental, Tokyo, Japan)	Supra-nano filler (SN filled resin composite)	UDMA, TEGDMA	Universal	18B28
Estelite Sigma Quick (Tokuyama Dental, Tokyo, Japan)	Supra-nano filler (SN filled resin composite)	Bis-GMA, TEGDMA	A1, A2, A3, A4	20138P

Abbreviations: Bis-GMA: Bisphnol-A-glycidylmethacrylate; UDMA: Urethane dimethacrylate; TEGDMA: Triethyleneglycol dimethacrylate; BisEMA: Ethoxylated bisphenol-A dimethacrylate; Bis-MEPP: 2,2-Bis (4-methacryloxypolyethoxyphenyl) propane.

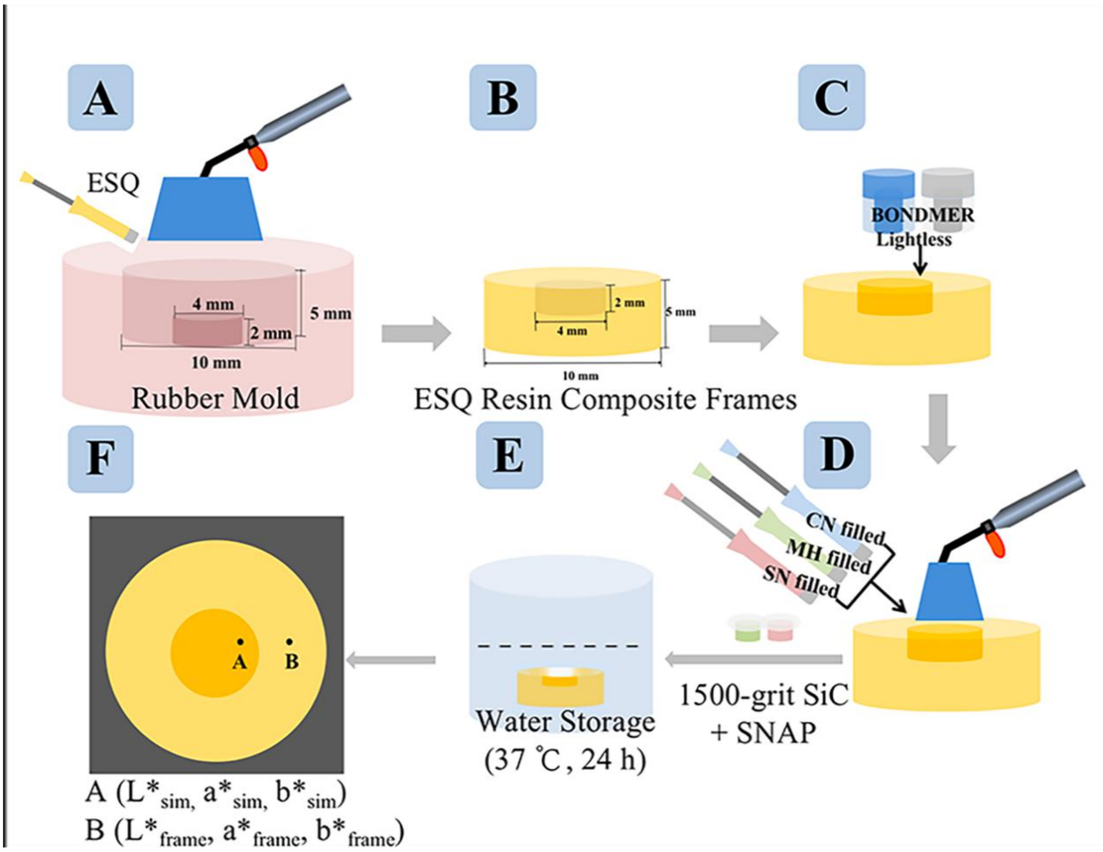

Figure 1 Schematic illustration of the preparation of the specimen's color measurement.

A – ESQ resin composite frames were prepared from a cured silicone impression material. B – ESQ resin composite frames with simulated Class I cavities. C – Applied the Adhesive. D – Cavities were filled with either of the three types of filler contained resin composites: CN filled, MH filled, and SN filled resin composite, and then polymerized. E – Restoration surfaces were polished and then water-storage. F – Color measurement for both the simulated restorations and the peripheral resin composite frame.

2.2 Measurement of light transmittance characteristics

Five representative discs (diameter = 4 mm, thickness = 1 mm) of each tested filler containing resin composite were prepared and stored in distilled water at 37˚C for 24 h before testing. For each disc, the two-dimensional distribution graph of transmitted light intensity (incidence angle 0˚; measurement range − 90˚ to + 90˚) was determined using a goniophotometer (Model GP-200, Murakami Color Research Laboratory, Tokyo, Japan) under regulated conditions (sensitivity: 950; volume: 508).[40]

2.3 Filler morphologies of different types of filler containing resin composites

Filler morphologies of three tested filler containing resin composites, and ESQ resin composite were observed under SEM (S-4000, Hitachi, Tokyo, Japan). The resin matrix was dissolved with acetone (Wako Pure Chemical Industries Co., Ltd., Osaka, Japan). The specimens were then rinsed with water and air-dried for 5 s. After additional air drying, the specimens were mounted on aluminum stubs and sputter-coated with Pt-Pd ion (E-1030, Hitachi, Tokyo, Japan). The discs were then observed using SEM at an accelerating voltage of 10 kV. The filler morphologies were examined at × 10,000 and × 20,000 magnifications. Relative quantitative analysis of the images was done using Image J (Version 1.47 V; National Institutes of Health, Bethesda, MD, USA).

2.4 Color measurement of resin composite filler diameters of 150 nm and 260 nm

Resin composite filler diameters of 150 nm and 260 nm were examined. Resin composite fillers were dispersed in a thin layer on the surface of pure water. The background was black. Color and size matching sticker (Cas Match; Bear Corporation, Japan) was used as a picture correcting color chart aiming to evaluate color efficiency more precisely, Adobe Photoshop 7.0 software (Adobe, San Jose, Calif.) was used for picture management. The filler diameter of 150 nm and 260 nm was evaluated both in dark and light conditions.

2.5 Statistical analysis

The data of color parameters L`, C`, H`, and $\triangle E_{ab}$, were analyzed with parametric statistical methods after ensuring the normality (Shapiro-Wilk test) and homogeneity of variance (Levene test). One-way ANOVA was performed to compare the effects of L`, C`, H`, and $\triangle E_{ab}$ values among the materials, followed by Duncan's post hoc test. The level of significance was set at $\alpha = .05$. The statistical analysis was performed with SPSS 22.0 for Windows (SPSS Inc., Chicago, IL, USA).

Chapter 3: Results

3.1 Specimen preparation and evaluation of shade matching

L`, C`, H`,and △E_{ab} values of the tested filler containing resin composites were summarized in Table 2. Duncan's post hoc test revealed that △E_{ab} of SN filled group was significantly lower than that of MH and CN filled groups in the cases of A2, A3, and A4 shades ($P < .05$), while △E_{ab} of A1 shade of MH filled group was significantly lower than that of SN and CN filled groups ($P > .05$). L` of SN filled group showed significantly lower values than CN filled in all the shades ($P < .05$). However, it was only significantly lower than MH filled group in the case of A3 shade ($P < .05$). C` of SN filled group was significantly higher than that of CN and MH filled groups in the cases of A2, A3, and A4 shades ($P < .05$). H` of SN filled group was significantly higher than that of CN, and MH filled groups in only A4 shade ($P < .05$).

The three-dimensional graphical demonstration of vectorial shifts between the simulated restorations and resin composite frames are shown in Figure 2. With the surrounding A2, A3, and A4 shades, SN filled group showed a shorter vectorial shift than both CN and MH filled groups. For all three tested resin composites, △L* decreased from the simulated restorations to all shades of resin composite frames, while △a* increased, which meant the color shifted more towards green. SN filled group showed narrow △b* values with all the resin composite frame shades compared to CN and MH filled groups, which meant the color shifted less towards blue.

Table 2 L`, C`, H`, and $\triangle E_{ab}$ values of the tested resin composites. $\triangle E_{ab}$ values were determined by comparing with A1, A2, A3, and A4 shades of ESQ resin composites.

ESQ Resin Composite Blocks	Tested Resin Composites	L`	C`	H`	$\triangle E_{ab}$
A1	CN filled	61.2 (0.5)	17.8 (0.8)	69.5 (2.7)	3.3 (0.6)
	MH filled	60.6 (0.5)	17.2 (0.8)	67.2 (1.2)	2.2 (0.5)
	SN filled	60.6 (0.2)	17.9 (0.8)	69.9 (2.2)	3.7 (0.9)
A2	CN filled	65.5 (0.3)	19.8 (0.5)	62.7 (1.1)	3.3 (0.6)
	MH filled	64.1 (0.2)	18.3 (0.8)	60.8 (2.2)	3.8 (0.8)
	SN filled	63.8 (0.4)	21.4 (0.6)	64.1 (0.7)	1.1 (0.4)
A3	CN filled	59.3 (0.3)	18.5 (0.5)	64.7 (1.7)	4.9 (0.7)
	MH filled	59.3 (0.4)	17.9 (0.9)	63.8 (2.8)	4.8 (0.7)
	SN filled	57.7 (0.5)	21.4 (0.7)	65.8 (2.0)	2.1 (0.6)
A4	CN filled	55.9 (0.5)	17.5 (0.9)	58.5 (2.1)	10.7 (0.5)
	MH filled	53.7 (0.4)	16.4 (1.0)	56.8 (1.6)	10.2 (0.9)
	SN filled	53.5 (0.5)	20.7 (0.5)	63.6 (1.2)	5.6 (0.8)

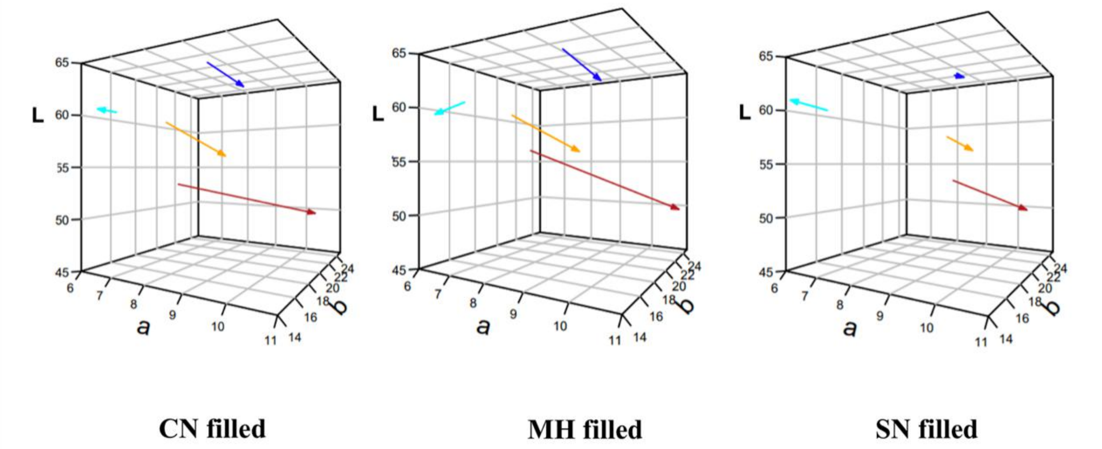

Figure 2 The three-dimensional graphical demonstration of vectorial shifts between the simulated restorations (L^*_{sim}, a^*_{sim}, b^*_{sim}) and resin composite frames (L^*_{frame}, a^*_{frame}, b^*_{frame}). The cyan, blue, orange, and red arrows represent the distances between the simulated restorations and the resin composite frames and indicate the differences for A1, A2, A3, and A4 shades of resin composites, respectively.

3.2 Measurement of light transmittance characteristics

The two-dimensional distribution graph of light transmittance characteristics of the tested resin composites (Figure 3) revealed that MH filled group had a broader distribution of light transmission intensity than CN and SN filled groups, which indicated its enhanced diffusive behavior compared to CN and SN filled resin composites.

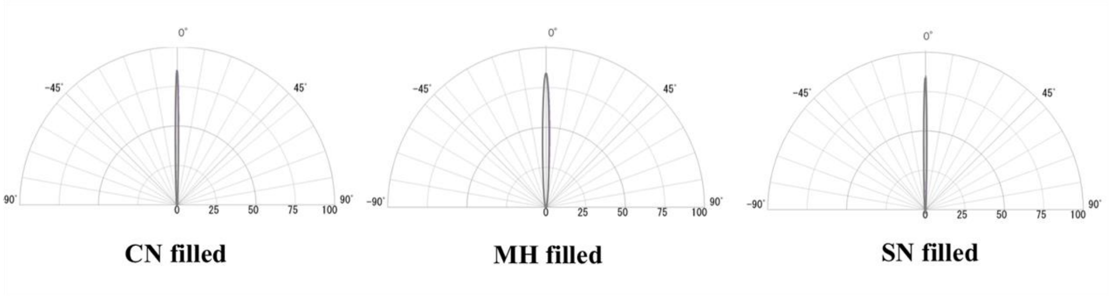

Figure 3 Two-dimensional distribution graph of light transmittance characteristics.

3.3 Filler morphologies of different types of filler containing resin composites

SEM images taken at × 10,000, and × 20,000 magnification showed variations in the shape, size, and distribution of different filler particles resin composites and resin composite frame (Figure 4). CN filled resin composite presented a combination of non-aggregated (diameter = 0.25 μm) and clustered-nano filler particles (diameter 1.2 ~ 2.8 μm; Figure 4 – A, a). On the other hand, MH filled resin composite presented micro-hybrid filler particles ranging from 0.5 to 3.0 μm in diameter (Figure 4 – B, b). SN filled resin composite showed regularly distributed, spherical supra-nano filler particles with diameters of approximately 260 nm (Figure 4 – C, c). The fillers were clustered together in some areas (Figure 4 – C). Resin composite frame ESQ also showed spherical supra-nano filler (SN filler) particles (diameter = 150 nm) with occasional larger and irregular shaped particles (diameter = 220 nm) (Figure 4 – D, d).

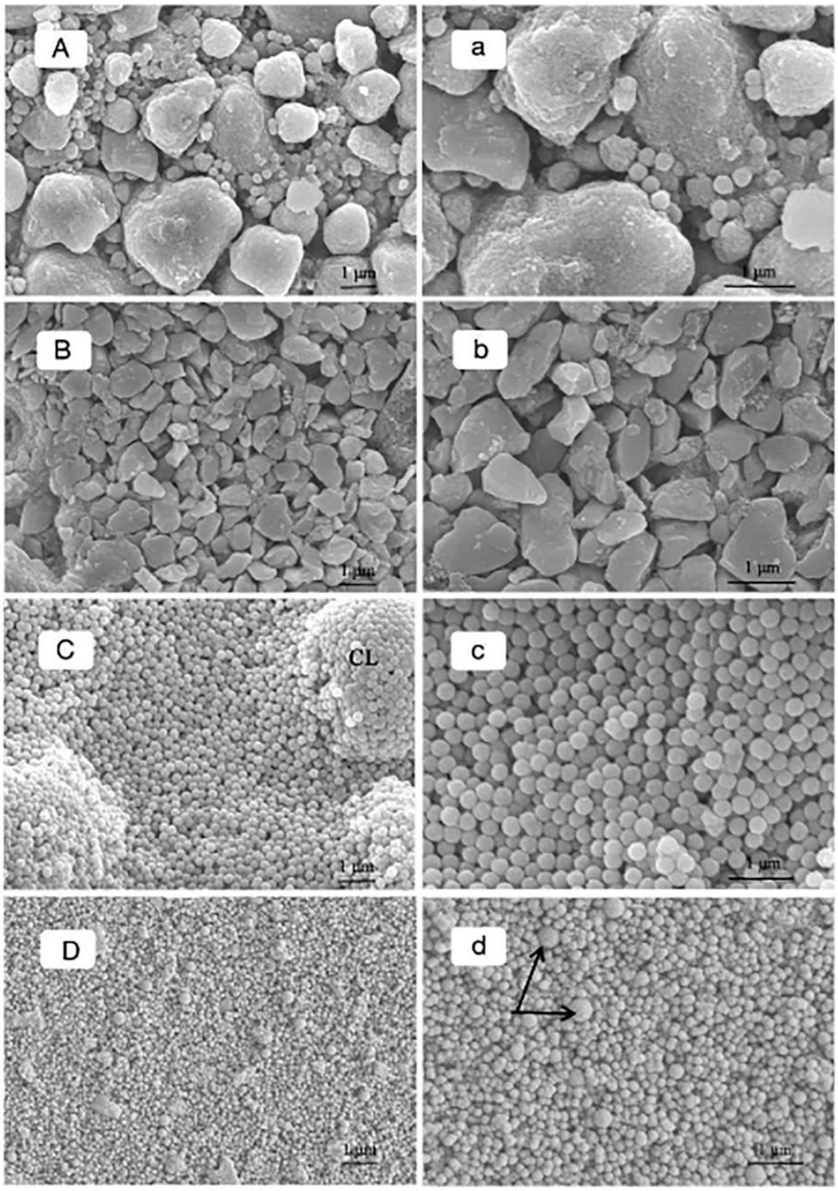

Figure 4 SEM images showing the fillers for the tested resin composites and resin composite frame. The left row is showing images at ×10000 magnification and the right row at ×20000. (A) and (a) CN filled, (B) and (b) MH filled, (C) and (c) SN filled, and (D) and (d) ESQ resin composite frame. CL – clusters; Arrow – large fillers.

3.4 Color measurement of resin composite filler diameters of 150 nm and 260 nm

The color looks similar in the human eye in dark condition, Color difference value was close ($\triangle E_{ab}$ =3.8 ± 1.1) in dark condition digitally. However, while in light condition, filler diameter of 260 nm exhibited larger C` and smaller H` value, which indicates the filler is more reddish and yellowish compared to filler diameter of 150 nm. Also, the color difference was huge ($\triangle E_{ab}$ =18.4 ± 4.7) in light condition (Table 3). The color difference of fillers between different diameter could be explained by structural color.

Table 3 L`, C`, H`, and $\triangle E_{ab}$ of resin composite filler diameter of 150 nm and 260 nm in dark and light conditions.

Color Parameters	Dark Condition		Light Condition	
	150 nm	260 nm	150 nm	260 nm
L`	74.6 ± 1.0	74.3 ± 1.7	57.5 ± 2.8	75.7 ± 2.8
C`	4.2 ± 1.2	6.4 ± 1.0	10.1 ± 0.9	12.0 ± 0.9
H`	92.1 ± 19.4	113.7 ± 8.7	47.1 ± 2.9	53.6 ± 2.2
$\triangle E_{ab}$	3.8 ± 1.1		18.4 ± 4.7	

Chapter 4: Discussions

Mourouzis et al. [41] evaluated the color matching ability of three resin composites at the composite-tooth interface and found no significant statistical differences between them. The differences were also visually indistinguishable. They concluded that the polychromaticity and translucency of the teeth adjacent to the restoration might render the restorations clinically non-differentiable in these situations. To avoid this, in the current study, we opted for using resin-composite blocks made of ESQ. These observations justify the use of resin composite discs/blocks *in vitro* to predict clinical shade matching.[27,33,38]

The perceptibility threshold (PT) and acceptability threshold (AT) are two important factors to evaluate the color matching of materials.[21,42] Several studies aimed at determining the PT and AT of color differences ($\triangle E_{ab}$) in esthetic dentistry.[43,44] According to these reports, the CIELAB 50:50% PT was found to be $\Delta E_{ab} = 1.2$, whereas the 50:50% AT was found to be $\Delta E_{ab} = 2.7$. 50%:50% for perceptibility means that at this value, 50% of the observers were able to perceive the color differences, whereas 50% could not. Similarly, 50%:50% for acceptability indicating that in 50% of the observers, the color differences were visually acceptable, whereas, for the rest, they were unacceptable.[21] These values are considered as the quality assurance tools to guide the selection of esthetic restorative materials in clinical practice.[45,46]

In the current study, in the case of A1 shade, $\triangle E_{ab}$ of MH filled resin composites were significantly lower than CN filled resin composite and SN filled resin composite ($P < .05$). The color differences of both A2 ($\triangle E_{ab} = 1.1 \pm 0.4$) and A3 shades ($\triangle E_{ab} = 2.1 \pm 0.6$) of SN filled resin composite were within their AT, indicating its better shade matching compared to its counterparts (Table 2). These observations are consistent with the visual evaluation using the captured images of the simulated restorations (Figure 5). In case of A4 shade, although color difference of SN filled resin composite ($\triangle E_{ab}$ = 5.6 ± 0.8) was significantly lower (P < .05) than the other tested resin composites, its value was much higher than the reference value.[44] This means all three simulated resin composites failed to produce acceptable shade matching when they were used in A4 shade. Therefore, the first null hypothesis that SN filled resin composite's shade matching does not differ from the other tested resin composites has been rejected.

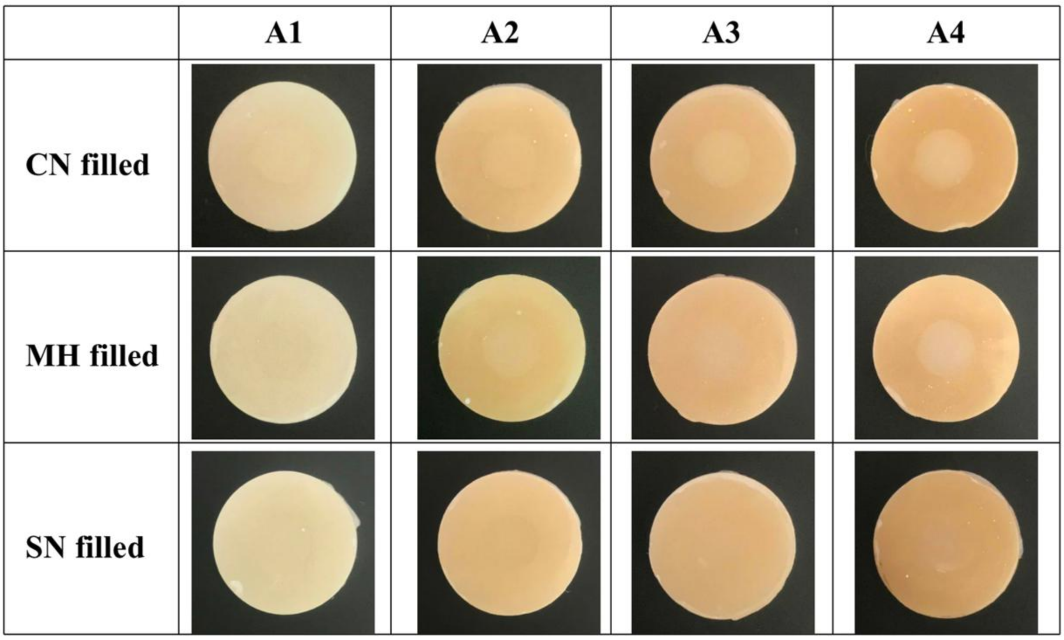

Figure 5 Images of the filled resin composite blocks.

Our results showed that CIE a* and CIE b* contributed more to color change than CIE L* (Figure 2). In the case of CIE a*, $\triangle a^*$ increased from the simulated restorations to resin composite frames in all circumstances, meaning the simulated restorations are more greenish than the resin composite frames. For CIE b*, △b* increased from simulated restorations towards resin composite frames in the case of A2, A3, and A4 shades for CN and MH filled resin composites, indicating that the colors are more bluish. A decrease of △b* of SN filled resin composite has been detected from simulated restorations towards resin composite frames in A1, A2, and A3 shades, which means that the simulated restorations are more yellowish. In general, the shades of human teeth are expressed within a narrow range of red-orange-yellow color. The tooth shades of more than half of the population fall into the orange spectrum.[43] Hence, based on this study's CIE L*a*b* results, SN filled resin composite would match better with the A1, A2, and A3 shades of natural teeth.

The L`, C`, and H` values correlate with how the human eye perceives color,[46] the ideal shade matching for an individual would probably result from a "perfect combination" of these three parameters. However, to the best of the authors' knowledge, the human visual perception correlated to the "perfect combination" threshold has not been defined for L`, C`, and H` parameters. According to this study's results (Table 2), the tested resin composites did not show significant differences in the case of H`, which indicates the same color. However, in both the cases of L` and C`, SN filled resin composite showed significant differences from MH and CN filled resin composites, probably indicating its better shade matching ability. This could be attributed to its reliance on structural color technology for shade matching.

Light transmittance characteristics of MH filled resin composite might have played an important role in shade matching. Clinically, to achieve a successful shade matching of esthetic resin composite with the tooth, it is necessary to make use of the color of the cavity floor as well as the walls.[41] In other words, the balance of diffusion and straight-line transmission properties in resin composite would affect the shade match to the tooth partly.[31] Asami et al. indicated that shade matching of resin composite restoration would be facilitated by the amount of transmitted light and light diffusion property of the material.[47] MH filled resin composite showed straight-line transmission properties, as well as enhanced diffuse transmission characteristics compared to SN and CN filled resin composites, which means MH filler's shade matching attributed not only by the reflection on the floor of the cavity, but also on the walls of the cavity. Further studies are necessary for investigation of the proper balance among light transmission characteristics and color matching ability between different kinds of resin composite. This observation partially rejects the second null hypothesis.

Resin composite which contained spherical supra-nano filler particles could contribute to their shade matching, by stimulating structural color according to the concept mentioned before. It has been reported that uniform SN filler particles in a particular range of sizes can show vivid structural colors, owing to the Bragg diffraction of the white light caused by the face-centered cubic structure of the formed silica photonic crystals.[48,49] The wavelength of visible light (380 nm ~ 780 nm) corresponds to blue, green, yellow, or red, with 380 nm being blue and 780 nm being red.[50,51]

SN filler particles of diameter of 150 nm and 260 nm respectively would result in different wavelength. We tried to verify the fillers' contribution visibly by opting a simple experiment (Figure 5). The SN filler particles of different diameter were evaluated both in dark and light conditions. Our observations revealed that the color difference between 150 nm filler particle and 260 nm filler particle was similar ($\triangle E_{ab}$

= 3.8 ± 1.1) in the dark condition, however, color difference was distinct ($\triangle E_{ab}$ = 18.4 ± 4.7) in the light condition. Also, the filler particles of 260 nm were more reddish and yellowish compared to the filler particles of 150 nm.

The optical properties of resin composites are also determined by the type of monomers in the resin matrix. [52] The dimethacrylates BisGMA and UDMA are commonly used as the primary or base monomers in the formation of the polymeric matrices of dental composites. A previous report suggested that BisGMA-based resin composite exhibits around 10-fold greater color deviation from "ideal white" compared to UDMA-based resin composite. [53,54] Therefore, it is plausible to extrapolate that in this study UDMA-based resin composite OMNI showed better shade-matching than BisGMA-based resin composites SUP and ESS.

Although the advantages of structural color technology have been widely employed in many fields, such as display technologies, cosmetics or textile engineering,[35,36,51-54] the novel supra-nano filled esthetic resin composite tested in this investigation is the first exploration of this technology in esthetic dentistry. Future studies are still necessary for evaluating its shade matching ability when applied in cavities prepared with resin composite from different manufacturers, as well as with natural teeth. Also, it would be worth evaluating the effect of cavity size to the shade matching ability, how chameleon effect works in different size of cavities. Moreover, it is necessary to quantify the contribution of structural color technology as well as pigments in shade matching.

Conclusion

Within the limitations of this experiment, the supra-nano filled resin composite showed a better shade matching ability with all the shades of resin composite frames compared to clustered-nano filled resin composite and micro-hybrid filled resin composite. The supra-nano filled particles might have contributed largely to the superior shade matching ability of the novel esthetic resin composite.

References

[1] Paravina RD, Pereira Sanchez NA, Tango RN. Harmonization of color measurements for dental application. Color Res Appl 2020;45:1094-100. https://doi.org/10.1002/col.22553

[2] Ferracane JL. Resin composite–state of the art. Dent Mater 2011;27(1):29-38. https://doi: 10.1016/j.dental.2010.10.020.

[3] Mackenzie L, Parmar D, Shortall AC, Burke FJ. Direct anterior composites: a practical guide. Dent Update 2013;40(4):297-9. https://doi: 10.12968/denu.2013.40.4.297.

[4] Villarroel M, Fahl N, De Sousa AM, De Oliverira OB. Direct Esthetic Restorations Based on Translucency and Opacity of Composite Resins. J Esthet Restor Dent 2011;23(2):73-87. https://doi: 10.1111/j.1708-8240.2010.00392.x

[5] Pecho OE, Ghinea R, Lonescu AM, Cruz Cardona J, Paravina RD. Color and translucency of zirconia ceramics, human dentine and bovine dentin. J Dent 2012; 40(2): e34-e40. https://doi: 10.1016/j.jdent.2012.08.018.

[6] Yu B, Ahn JS, Lee YK. Measurement of translucency of tooth enamel and dentin. Acta Odontol Scand 2009; 67:57-64.

[7] Ma X, Li R, Sa Y, Liang S, Sun L, Jiang T, Wang Y. Separate contribution of enamel and dentine to overall tooth colour change in tooth bleaching. J Dent 2011;39:739-45. https://doi: 10.1080/00016350802577818.

[8] Kugel G, Petkevis J, Gurgan S, Doherty E. Separate whitening effects on enamel and dentin after fourteen days. J Endod 2007;33:34–7. https://doi: 10.1016/j.joen.2006.07.012.

[9] Chu SJ, Trushkowsky RD, Paravina PD. Dental color matching instruments and systems. Review of clinical and research aspects. J Dent 2010;38s: e2-e16. https://doi: 10.1016/j.jdent.2010.07.001.

[10] De Costa J, Fox P, Ferracane J. Comparison of various resin composite shades and layering technique with a shade guide. J Esthet Restor Dent 2010; 22:114–26. https://doi: 10.1111/j.1708-8240.2010.00322.x.

[11] Vichi A, Fraioli A, Davidson CL, Ferrari M. Influence of thickness on color in multi-layering technique. Dent Mater 2007; 23:1584-9. https://doi: 10.1016/j.dental.2007.06.026.

[12] Miotti LL, Santos IS, Nicoloso GF, Pozzobon RT, Susin AH, Durand LB. The use of resin composite layering technique to mask discolored background: A CIELAB/CIEDE2000 Analysis. Oper Dent 2017;42(2):165-74. https://doi: 10.2341/15-368-L.

[13] Khashayar G, Dozic A, Kleverlaan CJ, Feilzer AJ, Roeters J. The influence of varying layer thicknesses on the color predictability of two different composite layering concepts. Dent Mater 2014;30:493-498. https://doi: 10.1016/j.dental.2014.02.002.

[14] Perez BG, Miotti LL, Susin AH, Durand LB. The Use of Composite Layering Technique to Mask a Discolored Background: Color Analysis of Masking Ability After Aging—Part II. Oper Dent 2019;44(5):488-98. https://doi.org/10.2341/18-016-L

[15] Varvară EB, Mesaroș AȘ, Culic B, Varvară AM. Resin composite layering technique for direct anterior teeth restorations. Palestrica of the third millennium – Civilization and Sport 2018;19(4):234-238. https://doi.org/10.26659/pm3.2018.19.4.234

[16] Romero MF. Esthetic anterior composite resin restorations using a single shade: Step-by-step technique. J Prosthet Dent 2015;114(1):9-12. https:// doi: 10.1016/j.prosdent.2015.02.013

[17] de Abreu JLB, Sampaio CS, Benalcazar Jalkh EB, Hirata R. Analysis of the color matching of universal resin composites in anterior restorations J Esthet Restor Dent 2020;1-8. https://doi.org/10.1111/jerd.12659

[18] Gómez‐Polo C, Montero J, Gomez-Polo M, Casado AM. Comparison of the CIELab and CIEDE 2000 color difference formulas on gingival color space. J Prosthet Dent 2020;29:401-8. https://doi.org/10.1111/jopr.12717

[19] Ikeda T, Murata T, Sano H. Translucency of opaque-shade resin composites. AM J Dent 2004;17(2):127-30.

[20] Sidhu SK, Ikeda T, Omata Y, Fujita M, Sano H. Change of Color and Translucency by Light Curing in Resin Composites. Oper Dent 2016;31(5):598-603.https:// doi: 10.2341/05-109.

[21] Gomez-Polo C, Portillo MM, Luengo MCL, Vicente P, Galindo P, Martin AMC. Comparison of the CIELab and CIEDE2000 color difference formulas. J Prosthet Dent 2016; 115:65–70. https://doi.org/10.1016/j.prosdent.2015.07.001.

[22] Sharma G, Wu W, Dalal EN. The CIEDE2000 Color-Difference Formula: Implementation Notes, Supplementary Test Data, and Mathematical Observations. COLOR RES APPL. 2004; 30(1):21-30. https://doi.org/10.1002/col.20070

[23] Igiel C, Lehmann KM, Ghinea R, Weyhrauch M, Hangx Y, Scheller H, Paravina RD. Reliability of visual and instrumental color matching. J Esthet Restor Dent 2017; 29: 303-8. https:// doi: 10.1111/jerd.12321.

[24] Sidhu SK, Ikeda T, Omata Y, Fujita M, Sano H. Change of Color and Translucency by Light Curing in Resin Composites. Oper Dent 2006; 31:598-603. https://doi.org/10.2341/05-109.

[25] Costa JD, Fox P, Ferracane JL. Comparison of various resin composite shades and layering technique with a shade guide. J Esthet Restor Dent 2010; 22:114-124. https://doi.org/10.1111/j.1708-8240.2010.00322.x.

[26] Abdelraouf RM, Habib NA. Color Matching and Blending Effect of Universal Shade Bulk Fill Resin Composite in Resin Composite-Models and Natural Teeth. Biomed Res Int 2016; 2016:4183432. https://doi.org/10.1155/2016/4183432.

[27] Paravina RD, Westland S, Kimura M, Powers JM, Imai FH. Color interaction of dental materials: blending effect of layered composites. Dent Mater. 2006; 22: 903-908. https://doi.org/10.1016/j.dental.2005.11.018.

[28] De Oliveira DC, De Menezes LR, Gatti A, Correr Sobrinho L, Ferracane JL, Sinhoreti MA. Effect of Nanofiller Loading on Cure Efficiency and Potential Color Change of Model Composites. J Esthet Dent 2016; 28:171-177. https://doi.org/10.1111/jerd.12189.

[29] Paravina RD, Westland S, Imai FH, Kimura M, Power JM. Evaluation of blending effect of composites related to restoration size. Dent Mater 2006; 22:299-307. https://doi.org/10.1016/j.dental.2005.04.022.

[30] Tsubone M, Nakajima M, Hosaka K, Foxton RM, Tagami J. Color shifting at the border of resin composite restorations in human tooth cavity. Dent Mater 2012; 28:811-817. https://doi.org/10.1016/j.dental.2012.04.032.

[31] Arimoto A, Nakajima M, Hosaka K, Nishimura K, Ikeda M, Foxton RM, Tagami J. Translucency, Opalescence and Light Transmission Characteristics of Light-Cured Resin Composites. Dent Mater 2010; 26:1090-1097. https://doi.org/10.1016/j.dental.2010.07.009.

[32] Tanaka A, Nakajima M, Seki N, Foxton RM, Tagami J. The effect of tooth age on color adjustment potential of resin composite restorations. J Dent 2015; 43:253-260. https://doi.org/10.1016/j.jdent.2014.09.007.

[33] Pereira Sanchez N, Powers JM, Paravina RD. Instrumental and visual evaluation of the color adjustment potential of resin composite. J Esthet Restor Dent 2019; 31:465-470. https://doi.org/10.1111/jerd.12488.

[34] Hsiung BK, Justyn NM, Blackledge TA, Shawkey MD. Spiders have rich pigmentary and structural color palettes. J Exp Biol 2017; 220:1975-1983. https://doi.org/10.1242/jeb.156083.

[35] Fu Y, Tippets CA, Donev EU, Lopez R. Structural Colors: From Natural to Artificial Systems. Wiley Interdiscip Rev Nanobiotechnol. 2016; 8:758-775. https://doi.org/10.1002/wnan.1396.

[36] Zhao Y, Xie Z, Gu H, Zhu C, Gu Z. Bio-inspired variable structural color materials. Chem Soc Rev 2012; 41:3297-3317. https://doi.org/-10.1039/C2CS15267C.

[37] Lee YK. Opalescence of human teeth and dental esthetic restorative materials. Dent Mater J 2016; 35:845-854. https://doi.org/10.4012/dmj.2016-091.

[38] Trifkovic B, Powers JM, Paravina RD. Color adjustment potential of resin composites. Clin Oral Investig 2018; 22:1601-1607. https://doi.org/10.1007/s00784-017-2260-6.

[39] Berns RS. Billmeyer and Saltzman's principles of color technology. 4th Edition. Wiley-Blackwell; 2019. https://doi.org/10.1002/9781119367314.

[40] Horie K, Nakajima M, Hosaka K, Kainose K, Tanaka A, Foxton RM, Tagami J. Influences of composite-composite join on light transmission characteristics of layered resin composites. Dent Mater 2012; 28:204-211. https://doi.org/10.1016/j.dental.2011.10.006.

[41] Mourouzis P, Koulaouzidou EA, Palaghias G, Helvatjoglu-Antoniades M. Color match of resin composites to intact tooth structure. J Appl Bio Funct Mater 2015; 13: e259-65. https://doi.org/10.5301/jabfm.5000228.

[42] Paravina RD, Ghinea R, Herrera LJ, Bona AD, Igiel C, Linninger M, Sakai M, Takahashi H, Tashkandi E, Perez Mdel M. Color difference thresholds in dentistry. J Esthet Restor Dent 2015; 27:1-9. https://doi.org/10.1111/jerd.12149.

[43] Khashayar G, Bain PA, Salari S, Dozic A, Kleverlaan CJ, Feilzer AJ. Perceptibility and acceptability thresholds for color differences in dentistry. J Dent 2014; 42:637-644. https://doi.org/10.1016/j.jdent.2013.11.017.

[44] Paravina RD, Pérez MM, Ghinea R. Acceptability and perceptibility thresholds in dentistry: A comprehensive review of clinical and research applications. J Esthet Restor Dent 2019; 31:103-112. https://doi.org/10.1111/jerd.12465.

[45] Xu BT, Zhang B, Kang Y, Wang YN, Li Q. Applicability of CIELAB/CIEDE2000 formula in visual color assessments of metal ceramic restorations. J Dent 2012; 40:3-9. https://doi.org/10.1016/j.jdent.2012.04.011.

[46] Paravina RD, Majkic G, Imai FH, Powers JM. Optimization of tooth color and shade guild design. J Prosthodont 2007; 16:269-276. https://doi.org/10.1111/j.1532-849X.2007.00189.x

[47] Aida A, Nakajima M, Seki N, Kano Y, Foxton RM, Tagami J. Effect of enamel margin configuration on color change of resin composite restora tion. Dent Mater J. 2016; 35:675-83. https:// doi.org/ 10.4012/dmj.2016-2039.

[48] Wang H, Zhang KQ. Photonic crystal structures with tunable structure color as colorimetric sensors. Sensors (Basel) 2013; 13:4192–213. https://doi.org/10.3390/s130404192.

[49] Kim GH, An T, Lim G. Bioinspired Structural Colors Fabricated with ZnO Quasi-Ordered Nanostructures. ACS Appl Mater Interfaces 2017; 9:19057-19062. https://doi.org/10.1021/acsami.6b15892.

[50] Gao W, Rigout M, Owens H. The structural coloration of textile materials using self-assembled silica nanoparticles. J Nanopart Res 2017; 19:303. https://doi.org/10.1007/s11051-017-3991-7.

[51] Gao W, Rigout M. Facile control of silica nanoparticles using a novel solvent varying method for the fabrication of artificial opal photonic crystals. J Nanopart Res 2016; 18:387. https://doi.org/10.1007/s11051-016-3691-8.

[52] Peutzfeldt A. Resin composites in dentistry: the monomer systems. Eur J Oral Sci. 1997;105(2) 97-116. https://doi: 10.1111/j.1600-0722.1997.tb00188.x.

[53] Mourouzis P, Koulaouzidou EA, Palaghias G, Helvatjoglu-Antoniades M. Color match of resin composites to intact tooth structure J Appl Biomater Funct Mater 201513(3) e259-265. https://doi: 10.5301/jabfm.5000228.

[54] Miletic V, Jakovljevic N, Manojlovic D, Marjanovic J, Rosic AA, Dramićanin MD. Refractive indices of unfilled resin mixtures and cured composites related to color and translucency of conventional and low-shrinkage composite Mater Res B Appl Biomater 2017;105(1) 7-13. https:// doi: 10.1002/jbm.b.33523.