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COLOR, TRANSLUCENCY AND MASKING ABILITY OF A RECENTLY DEVELOPED BULK-FILL RESIN COMPOSITE

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ABSTRACT

Objectives: To evaluate the color, translucency and masking ability of a newly developed bulk-fill resin composite with enhanced opacity.

Materials and Methods: A3 shade composite discs (n=20/material) (Filtek bulk-fill; FB and Filtek bulk-fill One; FBOne) were prepared at 2 and 4 mm thickness (n=10/thickness). Three different backgrounds (white tile, black tile, and C4 shade porcelain) and the intrinsic color for each material were used to determine the translucency parameter (between white and black backgrounds), and to simulate oral cavity darkness (between the black background and the intrinsic color of resin composite), and the discolored tooth structure (between C4 shade porcelain and the intrinsic color of resin composite). Additionally, the chroma coordinates were measured for 2 mm thickness on the different backgrounds. Data were analyzed by Mann-Whitney U test, and Wilcoxon test as a post hoc for multiple comparisons ($p < .05$).

Results: A clinically perceptible color difference ($\Delta E^* > 1.74$) was recorded between FB and FBOne. FBOne showed significantly higher TP values ($p < .001$) than FB. None of the two materials could mask the oral cavity darkness in a clinically acceptable threshold ($\Delta E^* > 2.7$). FBOne showed a clinically acceptable (2 mm, $\Delta E^* < 2.7$) and un-perceptible threshold (4 mm, $\Delta E^* < 1.74$) for masking the discolored tooth substrate.

Conclusions: FBOne is a promising bulk-fill resin composite showing an appropriate masking ability of the discolored tooth structure without interfering with its translucency.

Key Words: Bulk-fill; Color; Masking ability; Translucency

INTRODUCTION

Resin composites have achieved a popularity as restorative materials due to their aesthetic properties, low cost, and excellent longevity.[1] However, clinicians might encounter difficulties in matching their colors to that of the surrounding dentitions due to the difference in optical properties between the tooth structure and resin composites.[1,2]

Bulk-fill resin composites have been developed to shorten the restoration process by allowing 4 mm thick increment to be light polymerized. In order to allow a deeper penetration of light, the majority

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of bulk-fill composites have higher translucency.[3,4] Nevertheless, this beneficial property could compromise the aesthetics especially in through-and-through class III and IV restoration or in the presence of discolored tooth structures by transmission of the background color.[5,6]

The translucency could be measured in terms of translucency parameter (TP) or contrast ratio (CR). TP is the color difference between a uniform thickness of the material over a white and a black background[7-9] and is an indicator for the masking ability.[5,10] The contrast ratio is the percentage of spectral reflectance of a specimen over a black to that of a white backing. Therefore, a material with a high contrast ratio would be a relatively opaque and have a lower translucency.[11,12]

The translucency of resin composites is largely associated with the mismatch between the refractive indices (RI) of fillers and monomers. The less the mismatch, the higher the translucency of the cured material. This property is essential for the specimens beyond the typical 2 mm thick increments suggested for dental composite placement.[13]

A new bulk-fill resin composite has been recently launched without any investigations. The manufacturer claimed that **"**Because of a scientifically designed refractive index mismatch between the filler and resin matrix, the contrast ratio is increased. Consequently, the cured material exhibited a greater final opacity for the improved aesthetics of the restoration.**"**[14] Therefore, this study aimed to evaluate the color and translucency of the newly developed bulk-fill resin composite with enhanced opacity. In addition, its ability to mask two different clinical situations (oral cavity darkness and discolored tooth structure) was assessed. The null hypotheses tested were that, there were no significant differences between the tested bulk-fill resin composites in (1) color (2) translucency and (3) masking ability.

MATERIALS AND METHODS

Materials

Two bulk-fill composites shade A3; Filtek bulk-fill posterior (FB) (3M ESPE, St.Paul, USA) and Filtek bulk-fill One (FBOne) (3M ESPE, St.Paul, USA) were the materials used in this study (table 1).

TABLE (1) Materials used in the study

Materials/Codes	Manufacturer	Shade	Contents		Lot. No
			Organic matrix	Fillers	
Filtek Bulk- Fill posterior (FB)	3M ESPE, St.Paul, USA	A3	AFM, AUDMA, UDMA, and DDDMA	Silica, zirconia, and aggregated zirconia/silica cluster fillers (76.5 Wt %)	N703817
Filtek Bulk- Fill One* (FBOne)	3M ESPE, St. Paul, USA	A3	AFM, AUDMA, UDMA, and DDDMA	Silica, zirconia, and aggregated zirconia/silica cluster fillers (76.5 Wt %)	N885576

AFM: addition fragmentation monomers; AUDMA: a high-molecular-weight aromatic urethane dimethacrylate; UDMA: urthane dimethacrylate; DDDMA: 1, 12-Dodecanediol dimethacrylate.

****The manufacturer claimed, "Because of a scientifically designed refractive index mismatch between the filler and resin matrix, the cured material exhibited a greater final opacity for the improved aesthetics of the restoration***

Methods

Specimen Preparation

Forty cylinderical resin composite discs (n=20/material) were prepared using split teflon molds 10 mm in diameter and either 2 or 4 mm thick (n= 10/thickness). The composites were inserted into the molds on a Mylar matrix. After that, the specimen's surfaces were sheltered by another Mylar matrix and a glass plate. Half kg customized metallic tool was applied as a standardized constant pressure to get a uniform thickness. A LED curing light (Elipar FreeLight 2, 3M ESPE; St Paul, MN USA, light output: 1226 mW/cm^2) were used to photo-polymerize the specimens according to the manufacturer's instructions. A radiometer (Demetron/Kerr, CT-100, Danbury, USA) was utilized to check the light curing output. Then, the specimens were kept dry at 37 °C in an oven for 24h after removal of the Mylar matrix.

Backgrounds Preparation

Three backgrounds were used in this study; a white tile (CIE L* = 98.35, a* = - 0.2, and b* =1.16), a black tile (CIE L* = 2.88, a* = - 0.12, and b* = - 1.09) and C4 shade porcelain backing (CIE L*= 65.56, a* = 1.23, b* =13.50). C4 shade porcelain backing was constructed at 2 mm thick specimen (Vita VMK68, Vita Zahnfabrik, Bad Säckingen, Germany). [15]

Color Measurements

The color was measured using a spectrophotometer (Cary 5000 UV-Vis-NIR, Agilent Technologies, USA) in the reflectance mode relative to the standard illuminants D65 excluding the ultraviolet light. The aperture size was 3 mm, and the illuminating and viewing configurations were CIE diffuse/8° geometry. Considering the optical contact between the specimen and the backings, saturated sucrose solution was used to reduce the edge-loss effect. According to the manufacturer's instructions, calibration was performed before each color measurement. An average of three measurements was performed for each specimen.

Evaluation of Intrinsic Color Differences

The intrinsic CIELAB values were measured at 4 mm thickness for each resin composite on a neutral-grey backing (CIE L* = 76, a* = - 0.4, and b* = 0.00).[15] The intrinsic color difference (ΔE*) between FB and FBOne was calculated as the difference in CIE *L** , *a** , *b** using the following formula [16,17]:

$$(\Delta E^*)= \left[(L^*_{FB} - L^*_{FBOne})^2 + (a^*_{FB} - a^*_{FBOne})^2 + (b^*_{FB} - b^*_{FBOne})^2\right]^{1/2}$$

where the subscripts FB and FBOne refer to 4 mm thickness from the material itself.

Translucency measurement

Translucency was measured in terms of translucency parameter (TP). The CIELAB coordinates (L*, a*, b*) of the specimens were measured at 2 and 4 mm thickness. L* denotes to the lightness which ranged from zero (black) to 100 (white). The a* and b* are the chromaticity coordinates in the red- green axis (–a* = green and +a* = red) and the yellow-blue axis (–b*= blue and +b* = yellow) respectively.[17] The differences in CIELAB color coordinates between the white and black backgrounds were claculated to obtain the translucency parameter (TP) according to the following formula[17]:

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

Where the subscripts W and B refer to color coordinates over the white and black background respectively.

Additionally, the contrast ratio (CR) and chroma coordinates were determined at 2 mm thickness.[9,12,18] The CR was calculated according to the following formula: $CR=Y_B, / Y_W$ where the subscripts Y_B and Y_W refers to the spectral reflectance over black and white background respectively. Chroma was

calculated from CIELAB coordinates (a*, b*) on the different backbrounds as $C^*_{ab} = [a^{*2} + b^{*2}]^{1/2}$

Masking Ability Measurement

CIELAB color differences (ΔE*) were also calculated for each thickness on the backgrounds simulating two different clinical situations; the discolored tooth structure (between the black background and the intrinsic color of resin composite) and oral cavity darkness (between C4 shade porcelain and the intrinsic color of resin composite)[5,9,15] according to the following formula:

$$(\Delta E^*)=[(L^*_{4-mm} - L^*_{thickness})^2 + (a^*_{4-mm} - a^*_{thickness})^2 + (b^*_{4-mm} - b^*_{thickness})^2]^{1/2}$$

Where the subscripts 4-mm and thickness refers to CIELAB values of the intrinsic color of each material at 4 mm thickness and CIELAB values of each specimen thickness on either black or porcelain backing respectively.

Statistical analysis

SPSS software version 22 (SPSS Inc., Chicago, IL, USA) was used to analyze the data. Shapiro–Wilk test and Levene test were used for checking the normal distribution and the homogeneity of the data respectively. The data were not normally distributed in some groups as shown by Shapiro–Wilk test ($p<.05$). As Levene test showed non-homogeneity of the variances ($p<.05$), the Mann-Whitney U test was used to compare the results between the two materials in each thickness. Wilcoxon test was used as a post hoc to compare the two thicknesses for each material. All statistical tests were set at 5% level of significance. The clinical relevance for CIELAB color difference (ΔE*) was evaluated in this study in terms of 50:50% perceptibility (ΔE*= 1.74) [19] and 50:50% acceptability (ΔE* = 2.7) [20,21].

RESULTS

Descriptive statistics were expressed as the means ± standard deviations. Regarding the color difference between FB and FBOne (shade A3), FBOne recorded a clinically perceptible color difference (ΔE*= 2.52) (table 2). CIE L*, a*, b* of bulk-fill resin composites (2 and 4 mm thickness) on the three different backgrounds are presented in table 3. Translucency parameters (TP) and masking ability of the oral cavity darkness and the discolored tooth substrate of FB and FBOne are shown in tables 4 and 5.

TABLE. (2) The intrinsic color (CIE L*, a*, b*) values (means and standard deviations) of bulk-fill resin composites at 4 mm thickness

Material codes	CIELAB values			Color difference (ΔE*)			
	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*
FB	65.61 ^{B} (±0.13)	0.44 ^{B} (±0.06)	12.74 ^{B} (±0.23)	2.07 (±0.24)	1.25 (±0.08)	0.72 (±0.15)	2.52 (±0.21)
FBOne	67.68 ^{A} (±0.18)	1.69 ^{A} (±0.14)	13.46 ^{A} (±0.38)				

Mean values represented with different superscrit uppercase letters in each column are significantly different *(P<.05)*

TABLE (3) CIE L*, a*, and b* values (means and standard deviations) of bulk-fill resin composites at 2 and 4 mm thickness on the different backgrounds .

Material codes	Backing	2 mm thickness			4 mm thickness		
		CIELAB values			CIELAB values		
		L*	a*	b*	L*	a*	b*
FB	White	69.13 (±1.28)	1.45 (±0.14)	15.56 (±0.04)	64.31 (±1.64)	0.88 (±0.04)	14.74 (±0.49)
	Black	61.94 (±1.50)	- 0.51 (±0.06)	9.86 (±0.36)	62.16 (±1.54)	- 0.24 (±0.04)	10.69 (±0.41)
	C4 shade porcelain	62.89 (±0.43)	0.32 (±0.08)	12.76 (±0.47)	63.13 (±0.25)	0.50 (±0.14)	13.04 (±0.31)
FBOne	White	72.64 (±0.81)	3.08 (±0.25)	17.71 (±0.62)	68.80 (±0.96)	2.68 (±0.08)	16.75 (±1.17)
	Black	64.72 (±0.69)	0.70 (±0.15)	11.20 (±0.39)	64.05 (±0.93)	1.15 (±0.09)	12.54 (±0.97)
	C4 shade porcelain	66.19 (±0.24)	2.39 (±0.06)	14.52 (±0.39)	67.29 (±0.39)	2.29 (±0.15)	14.51 (±0.32)

TABLE (4) ΔL*, Δa*, Δb*, and ΔE* values (means and standard deviations) of bulk-fill resin composites at 2 and 4 mm thickness on the different backgrounds

Material	2 mm thickness				4 mm thickness			
codes	ΔL*	Δa*	Δb*	ΔE*	ΔL*	Δa*	Δb*	ΔE*
Color differences (ΔE*) between white and black backgrounds (TP measurements)								
FB	7.19 ^{B} (±0.19)	1.96 ^{B} (±0.08)	5.69 ^{B} (±0.33)	9.39 ^{B} (±0.19)	2.15 ^{B} (±0.10)	1.12 ^{B} (±0.05)	4.05 ^{A} (±0.15)	4.72 ^{B} (±0.19)
FBOne	7.93 ^{A} (±0.19)	2.38 ^{A} (±0.089)	6.44 ^{A} (±0.15)	10.49 ^{A} (±0.25)	4.75 ^{A} (±0.07)	1.53 ^{A} (±0.03)	4.21 ^{A} (±0.21)	6.53 ^{A} (±0.18)
Color differences (ΔE*) between black background and material itself (masking the oral cavity darkness)								
FB	3.67 ^{A} (±1.27)	0.95 ^{A} (±0.05)	2.88 ^{A} (±0.31)	4.83 ^{A} (±0.99)	3.45 ^{A} (±1.29)	0.68 ^{A} (±0.04)	2.05 ^{A} (±0.34)	4.17 ^{A} (±0.99)
FBOne	2.96 ^{A} (±0.58)	0.99 ^{A} (±0.13)	2.26 ^{B} (±0.29)	3.78 ^{B} (±0.73)	3.63 ^{A} (±0.78)	0.54 ^{B} (±0.07)	0.92 ^{B} (±0.82)	3.91 ^{A} (±0.44)
Color differences (ΔE*) between material itself and C4 shade porcelain (masking the discolored teeth)								
FB	2.72 ^{A} (±0.37)	0.12 ^{B} (±0.07)	0.37 ^{B} (±0.12)	2.74 ^{A} (±0.36)	2.48 ^{A} (±0.21)	0.08 ^{B} (±0.10)	0.34 ^{B} (±0.21)	2.51 ^{A} (±0.20)
FBOne	1.49 ^{B} (±0.21)	0.69 ^{A} (±0.05)	1.06 ^{A} (±0.33)	1.99 ^{B} (±0.10)	0.43 ^{B} (±0.27)	0.61 ^{B} (±0.13)	1.05 ^{A} (±0.27)	1.36 ^{B} (±0.22)

Mean values represented with different superscrit uppercase letters in each column are significantly different *(P< .05)*

TABLE (5) Comparisons between ΔE* values (means and standard deviations) at 2 and 4 mm thickness for each material

Material codes	ΔE* values		z value	*P* value
	2 mm	4 mm		
Color differences (ΔE*) between white and black backgrounds (TP measurements)				
FB	9.39 (±0.19)	4.72(±0.19)	3.45	*P* =0.001
FBOne	10.49(±0.25)	6.53(±0.18)	3.50	*P* =0.001
Color differences (ΔE*) between black background and material itself (masking the oral cavity darkness)				
FB	4.83 (±0.99)	4.17 (±0.99)	0.29	*P* =0.77
FBOne	3.78 (±0.73)	3.91 (±0.44)	0.36	*P* =0.77
Color differences (ΔE) between material itself and C4 shade porcelain (masking the discolored teeth)				
FB	2.74 (±0.36)	2.51 (±0.20)	1.15	*P* =0.25
FBOne	1.99 (±0.10)	1.36 (±0.22)	3.45	*P* =0.001

FBOne showed significantly higher TP values (z value= 4.7, p< .001) than FB at 2 and 4 mm thickness. Wilcoxon test showed statistically significant differences between 2 and 4 mm thickness in FB (z value= 3.45, p< .001) and in FBOne (z value= 3.50, p< .001) (table 5). As for the contrast ratio (CR), there was no significant difference (z value= 1.6, p=0.12) between FB (CR=0.77±0.008) and FBOne (CR=0.75±0.004). FBOne statistically recorded significant higher chroma coordinates than FB in the three different backgrounds (p< .001) (fig. 1).

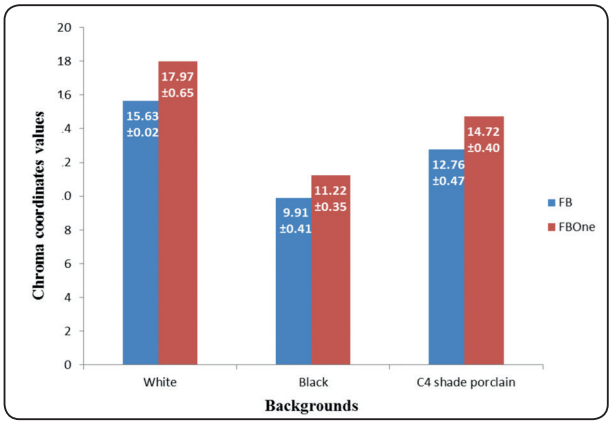

Fig. (1) Chroma coordinates values of bulk-fill resin composite on the different backgrounds

Regarding the ΔE* values for the masking ability of the oral cavity darkness, although FBOne showed a statistically significant better masking ability than FB at 2 mm thickness (z value= 2.63, *p* = 0.009), no significant difference was detected between FB and FBOne at 4 mm thickness (z value=1.6, *p*=0.12). Overall, none of them recorded the clinically acceptable threshold (ΔE* = 2.7). No significant difference (z value=0.29, *p* = 0.77) was detected between 2 and 4 mm thickness in FB and in FBOne on masking the oral cavity darkness.

Regarding the ΔE* values for the masking ability of the discolored substrate, FBOne showed better masking ability within the clinically acceptable threshold (ΔE* = 1.99) at 2 mm thickness (z value=4.73, *p*< .001) and the clinical perceptible threshold (ΔE* = 1.36) at 4 mm thickness (z value=4.79, *p*< .001). FB showed a clinically acceptable threshold at 4mm thickness (ΔE* = 2.65). By comparing 2 and 4 mm thickness; no significant difference was detected in FB (z value=1.15, *p*=0.25), however, a significant difference was recorded in FBOne (z value=3.45, *p=0.001*).

DISCUSSION

Color, chroma, and translucency (TP, CR, and masking ability) are among the factors that could influence the aesthetic appearance of restorative materials.[22-25] Although the human eye could detect the change in color difference, shade matching is a technical challenge especially in cases where little or no tooth structure surround the restoration, or in discolored tooth structure.[5, 26]

Up to the knowledge of authors, although there is scarce of data regarding the evaluation of the translucency of bulk-fill resin composites [1,27-30], no available data for assessment of their masking ability. Accordingly, the aims of this study were to evaluate the color, translucency and masking ability of a newly developed bulk-fill resin composite.

It has been stated that a 4 mm thick composite disc was appropriate to mask the background color. [5,9,15] Consequently, the color of a 4-mm-thick specimen was used as a reference for the intrinsic color measurements. The intrinsic color was measured on a neutral gray backing as it produces a little visual interference and provides more accurate color profiles.[15]

The final color differences could be altered by changing the backgrounds.[31] Thus, black and porcelain backgrounds were used in the current study. Porcelain background simulates a discolored tooth shade since it has the darkest L* value in the classical shade guide.[32-34] A black backing simulates the oral cavity darkness especially in 'through and through' class III and IV cavities.[5,15]

Color matching was evaluated by measurements of the color differences (ΔE*). The perceptible or clinically acceptable color difference thresholds vary depending on the references used. The threshold for clinically accepted color difference has been reported as $\Delta E^* \leq 2$ [35], $\Delta E^* \leq 2.7$ [20,21], $\Delta E^* \leq 3.3$ [36], $\Delta E^* \leq 3.48$ [19], and $\Delta E^* \leq 3.7$ [37]. The current study followed Paravina *et al* [20] ($\Delta E^* \leq 2.7$) and Ragain *et al* [21] ($\Delta E^* \leq 2.7$) as this color difference is midway between those values reported by Ruyter *et al* [36] ($\Delta E^* \leq 3.3$) and O'Brien *et al* [35] ($\Delta E^* \leq 2$). Regarding the perceptible threshold, the present study followed Cengiz *et al* [19] ($\Delta E^* \leq 1.74$).

The results showed a clinically perceptible color difference ($\Delta E^* > 1.74$) between FB and FBOne. Regarding translucency, FBOne showed significantly higher TP values ($p < .001$) than FB. In addition, none of the two materials could mask the dark oral cavity darkness in a clinically acceptable threshold ($\Delta E^* > 2.7$). Conversely, FBOne recorded a clinically acceptable and un-perceptible threshold (2 mm: $\Delta E^* < 2.7$ and 4 mm: $\Delta E^* < 1.74$) respectively for masking the discolored tooth substrate. So, the first and the second null hypotheses were rejected. Meanwhile, the third null hypothesis was partially accepted.

The color differences between FB and FBOne were in the perceptible range ($\Delta E^* > 1.74$). By comparing their color coordinates, L*, a*, and b* were statistically larger in FBOne. Although the reason for this difference was not clear since there is no difference in composition, the manufacturer claimed, **"**Because of a scientifically designed refractive index mismatch between the filler and resin matrix, the contrast ratio is increased. Consequently, the cured material exhibited a greater final opacity for the improved aesthetics of the restoration.**"**[14] The results of the present study showed no significant difference (p=0.12) between the contrast ratios of the tested material. From our point of view, a possible explanation is the more light reflecting from the surface or inside the FBOne might cause the brighter and yellowish aspect due to their statistically larger color coordinates compared to FB.

Translucency is a state between the transparency and the opacity, which prevents or permits the appearance of the underlying background.[25] In our study, TP values of FBOne was statistically larger than FB at 2 and 4 mm. This could be attributed to the higher Δ L* values in FBOne, which reflect more light from the surface of the material. These findings are in agreement with other studies [5,6,10,16] which stated that the higher the light difference between white and black background, the higher the TP value for this material.

The TP was higher in FBOne than FB. Meanwhile, a decrease in ΔE* indicates a better masking ability. Regarding the 2 mm thickness, ΔE* was lower in FBOne than FB in the both two simulating clinical situations. These results confirm the finding from previous studies [5,15,22,23,38] in which the TP is not the only determining factor for the masking ability, especially when the TP is in a similar range. Chroma

coordinates are one of the factors which could affect the color of the restorative material.[9,22,23] FBOne showed higher chroma values than FB on all different backgrounds (fig.1). Consequently, and limited to our point of view, this could be a possible explanation for the color difference and the better masking ability of FBOne rather than the CR as claimed by the manufacturer. A point to be mentioned, the manufacturer claimed that the higher CR of FBOne compared to FB is the average of all shades.[14] Thus, more studies are required to be conducted on the different shades of FBOne. Shade A3 was used in the study hence it is the universal shade of resin composite.

Regarding the masking ability of 4 mm thickness, FBOne showed better masking ability than FB on the C4 shade porcelain backing. In addition, no difference was detected between FB and FBOne for the black backing. These findings are in agreement with Kim *et al* [5] and An *et al* [15] studies .These studies stated that, although ΔE* decreased as the thickness increased, it cannot be concluded that the better masking ability is attributed to that of resin composite at various thicknesses. This is due to the interaction between the resin composite and thickness. In addition, from the results of these studies [5,15], no significant differences were detected in some resin composites between (2, 2.5, 3, 4) thicknesses.

CONCLUSIONS

Within the limitations of this study, the followings could be concluded:

- FBOne showed a clinically perceptible color difference than FB.
- FBOne showed higher translucency than FB.
- FBOne showed better masking ability of the discolored tooth substrate than FB at 2 and 4 mm thickness within the acceptable and perceptible threshold respectively.
- FB showed acceptable masking ability of the discolored tooth substrate within the acceptable threshold at 4 mm thickness.
- FB and FBOne could not mask the background simulating oral cavity darkness within the clinical acceptable and perceptible thresholds.

REFERENCES

1. Ae Son S, Park JK, Seo DG, KO CC, Kwon YH. How light attenuation and filler content affect the microhardness and polymerization shrinkage and translucency of bulk-fill composites? Clin Oral Investig. 2017; 21:559-65.
2. Barutcigil Ç, Barutcigil K, Ôzarslan MM, Dündar A, Yilmaz B. Color of bulk-fill composite resin restorative materials. J esthet Rest Dent 2017 Sep 28. Doi: 10.1111/jerd. 12340. [Epub ahead of print].
3. El-Damanhoury H, Platt J. Polymerization shrinkage stress kinetics and related properties of bulk-fill resin composites. Oper Dent 2014; 39:374-82.
4. Ilie N, Bucuta S, Draenert M. Bulk-fill resin-based composites: an in vitro assessment of their mechanical performance. Oper Dent 2013; 38:618–25.
5. Kim SJ, Son HH, Cho BH, Lee IB, Um CM. Translucency and masking ability of various opaque-shade composite resins. J Dent 2009; 37:102-7.
6. Ikeda T, Sidhu SK, Omata Y, Fujita M, Sano H. Colour and translucency of opaque shades and body-shades of resin composites. Eur J Oral Sci 2005; 113: 170–3.
7. Paravina RD, Ontiveros JC, Powers JM. Curing-dependent changes in color and translucency parameter of composite bleach shades. J Esthet Restor Dent 2002; 14:158–66.
8. Lee SH, Lee YK, Lim BS. Influence of thermocycling on the optical properties of laboratory resin composites and an all-ceramic material. J Mater Sci Mater Med 2004; 15:1221-6.
9. Fujita M, Kawakami S, Komatsu H, Sano H. Translucency and characteristics of newly developed polymer based dental tooth coating material. Dent Mater J 2005; 24: 111-6.
10. Ikeda T, Murata Y, Sano H. Translucency of opaque-shade resin composite.Am J Dent. 2004; 17:127-30.
11. Kamishima N, Ikeda T, Sano H. Color and translucency of

resin composites for layering techniques. Dental Mater J 2005; 24:428–32.

12. Lee YK, Lim BS, Rhee SH, Yang HC, Powers JM. Color and translucency of A2 shade resin composites after curing, polishing and thermocycling. Oper Dent. 2005; 30: 436-42.

13. Shortall AC, Palin WM, Burtscher P. Refractive index mismatch and monomer reactivity influence composite curing depth. J Dent Res. 2008; 87:84–8.

14. Filtek bulk-fill One. Filtek bulk-fill One technical product profile.https://multimedia.3m/ mws/media/1317671O/ filtek-one-bulk-fill-technical-product-profile.pdf

15. An JS, Son HH, Qadeer S, Ju SW, Ahn JS. The influence of a continous increase in thickness of opaque shade composite resin on masking ability and translucency. Acta Odontol Scand. 2013; 71:120-9.

16. Yu B, Lee YK. Influence of color parameters of resin composites on their translucency. Dent Mater. 2008; 24:1236-42.

17. International Commission on Illumination. Colorimetry: official recommendations of the International Commission on Illumination. 2nd ed. Vienna: Bureau Central de la CIE; 1986.

18. Craig RG & Powers JM Restorative Dental Materials 11th ed St Louis CV Mosby 2001; p 39-42.

19. Cengiz S, Yüzbaşioğlu E, Cengiz MI, Velioğlu N, Sevimli G. Color stability and surface roughness of a laboratory-processed composite resin as a function of mouthrinse. J Esthet Restor Dent. 2015; 27:314-21.

20. 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 Rest Dent 2015; 27(suppl 1):s1-9.

21. Ragain Jr JCJ. Color acceptance of direct dental restorative materials by human observers. Colour Research and Application 2000; 25:278–85.

22. Joiner A. Tooth colour: a review of the literature. J Dent 2004; 32(Suppl. 1):3–12.

23. Lee YK, Lu H, Powers JM. Measurement of opalescence of resin composites. Dent Mater 2005; 21:1068–74.

24. O'Brien WJ, Johnston WM, Fanian F, Lambert S. The surface roughness and gloss of composites. J Dent Res 1984; 63:685–8.

25. Johnston WM, Ma T, Kienle BH. Translucency parameter of colorants for maxillofacial prostheses. Int J Prosthodont 1995; 8:79–86.

26. Douglas RD, Brewer JD. Acceptability of shade differences in metal ceramic crowns. J Prosthet Dent 1998; 79:254–60.

27. Miletic V, Pongprueksa P, De Munck J, Brooks NR, Van Meerbeek B. Curing characteristics of flowable and sculptable bulk-fill composites. Clin Oral Investig 2017; 21: 1201-12.

28. Lassila LV, Nagas E, Vallittu PK, Garoushi S. Translucency of flowable bulk-filling composites of various thicknesses. Chin J Dent Res. 2012; 15:31-5.

29. Awad D, Stawarczyk B, Liebermann A, Ilie N. Translucency of esthetic dental restorative CAD/CAM materials and composite resins with respect to thickness and surface roughness. J Prosthet Dent. 2015; 113:534-40.

30. Kim EH, Jung KH, Son SA, Hur B, Kwon YH, Park JK. Effect of resin thickness on the microhardness and optical properties of bulk-fill resin composites. Restor Dent Endod. 2015; 40:128-35.

31. Yeh CL, Powers JM, Miyagawa Y. Color of selected shades of composites by reflection spectrophotometry. J Dent Res 1982; 61:1176–9.

32. Li Y. Tooth color measurement using Chroma Meter: techniques, advantages, and disadvantages. J Esthet Restor Dent 2003; 15:S33–41.

33. Browning WD. Use of shade guides for color measurement in tooth-bleaching studies. J Esthet Restor Dent 2003; 15:S13–20.

34. Miller LL. Shade matching. J Esthet Dent 1993; 5:143–53.

35. O'Brien WJ, Groh CL, Boenke KM. A new, small-colordifference equation for dental shades. J Dent Res 1990; 69:1762–4.

36. Ruyter IE, Nilner K, Moller B. Color stability of dental composite resin materials for crown and bridge veneers. Dent Mater 1987; 3:246–51

37. Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. J Dent Res 1989; 68:819–22.

38. 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; 26:1090-7.