Color changes in bulk-fill resin composites as a result of visible light-curing

Masato HOTTA¹, Yuki MURASE², Shojiro SHIMIZU², Shusuke KUSAKABE², Tomohiro TAKAGAKI²
and Toru NIKAI²

¹Asahi University, 1851-1 Hozumi, Mizuho-city, Gifu 501-0296, Japan

²Division of Oral Functional Science and Rehabilitation, Department of Operative Dentistry, Asahi University School of Dentistry, 1851-1 Hozumi, Mizuho-city, Gifu 501-0296, Japan

Corresponding author, Masato HOTTA; E-mail: w7mhotta@dent.asahi-u.ac.jp

We evaluated twelve commercially available bulk-fill resin composites to determine the colorimetric changes that occurred as a result of the photo-polymerization reaction. Samples of the resin composites were prepared as disks 8 mm in diameter and 3 mm in thickness. A colorimeter was used to measure the color of samples on a black background before and after the polymerization process had been initiated. As results, each of the photo-initiated bulk-fill resin composites tested except for Beautifil Bulk A showed a significant color difference more than that of conventional resin composites. Bulk Base Flow became darker, whereas Beautifil Bulk Flow became clearly lighter. All resin composites except for Bulk Base Flow became less yellow. Thus, Beautifil Bulk A exhibited the least color change among all the bulk-fill resin composites. However, this color change showed a marked change (NBS units) as observed by the human naked eye.

Keywords: Bulk-fill resin composites, Color change, Polymerization

INTRODUCTION

The growing demand for esthetic restorations by patients has caused a recent increase in the use of tooth-colored restorative materials. Thus, there is a need for a scientific approach to the selection of the color of resin composites. Success in this selection depends on the original color match, which properties are difficult to control in the clinical environment. The initial appearance matching of uncured restorative materials to its environment is an important clinical task; and once an acceptable match is obtained, the retention of this color match must be maintained after the curing process is completed and after the material has reached equilibrium with its environment. Innovative bulk-fill resin composites that can be placed in a single increment have been introduced by several manufacturers. These materials are claimed to have lower polymerization shrinkage and depths of cure of up to 4 mm¹⁻⁶⁾. However, little data are available regarding the color changes of bulk-fill resin composites that occur during the light-curing process. Such information might assist clinicians in improved color matching of esthetic restorations. In the present study, the color before and after light-curing of bulk-fill low viscosity resin composites and high viscosity resin composites were investigated and compared with conventional low viscosity resin composite and high viscosity resin composites. The null hypotheses were evaluated such that there would be no difference in color before and after light-curing between bulk-fill resin composites and conventional resin composites.

MATERIALS AND METHODS

Materials used in this study

Twelve commercially available bulk-fill resin composites were selected for colorimetric evaluation (Table 1). Two conventional resin composites (low and high viscosity) were used as a control for comparison. The commercial bulk-fill resin composites tested were Bulk Base Hard (shade: Universal, Dentin), Bulk Base Medium Flow, Bulk Base High Flow, Beautifil Bulk Flow (shade: Universal, Dentin), Gracefil Bulk Flow (Universal), SDR (Universal), Tetric N-Ceram Bulk Fill (shade: IVW, IVA), and Beautifil Bulk (shade: Universal, A).

A ring-shaped Teflon mold, with a diameter of 8 mm and thickness of 3 mm, was used to prepare samples of the composite. Before they were cured, the samples were filled with the composite and then covered with a clear polyester strip on the top of the disk and pressed flat between 2 glass slabs (1-mm thickness). The color of samples was measured with the polyester strips in place. The effect of the polyester strip on the color measurements had been determined to be negligible. The tip of the curing light (an exit window of 8 mm diameter) was placed in contact with the polyester strips on the top of the sample. The samples were light-cured from the top for 5–20 s with a visible LED light unit (1,400 mW/cm²: Blue LEX Alpha, Yoshida, Tokyo, Japan) following the manufacturer's recommendations. Conventional resin composite samples were light-cured from the top and bottom for 10 s with the Blue LEX Alpha. The polyester strips were removed, and the samples were measured again without sample surface polishing.

Color measurement

The color and the color difference of each specimen were

Table 1 Bulk-fill resin composites tested in this study

Resin	Shade	Composition	Manufacturer
(Bulk Low Viscosity Resin)			
Bulk Base Hard	Dentin	Methacrylic acid esters (Bis-MPEPP, <i>etc.</i>), Acrylic esters (Urethane acrylate), Barium and strontium silica glasses, Aromatic amine, <i>etc.</i>	Sun Medical (Shiga, Japan)
	Universal		
Bulk Base (Medium Flow)	—	Methacrylic acid esters (Bis-MPEPP), Acrylic esters (Urethane acrylate, <i>etc.</i>), Barium silica glass, Strontium fluoro-aluminosilicate glass, Aromatic amine, <i>etc.</i>	
(High Flow)	—		
Beautifil Bulk Flow	Dentin	Bis-GMA, UDMA, Bis-MPEPP, TEGDMA, Glass powder (S-PRG filler), Reaction initiator, Pigments, <i>etc.</i>	Shofu (Kyoto, Japan)
	Universal		
Gracefil Bulk Flow	Universal	Bis-MEPP, Barium glass	GC (Tokyo, Japan)
SDR	Universal	Modified UDMA, EBPADMA, TEGDMA, Barium and strontium fluoro-alumino- silicate glasses, Photopolymerization initiator, BHT, UV stabilizer, Pigments, <i>etc.</i>	Dentsply (Konstanz, Germany)
(Conventional Low Viscosity Resin)			
Beautifil Flow Plus F00	A3	Bis-GMA, TEGDMA, Glass powder (S-PRG filler), Reaction initiator, Pigments, <i>etc.</i>	Shofu
(Bulk High Viscosity Resin)			
Tetric N-Ceram Bulk Fill	IVW	Bis-GMA, UDMA, Barium glass, Ytterbium trifluoride mixed oxide prepolymer, Catalysis, Stabilizers, Pigments, <i>etc.</i>	Ivoclar Vivadent (Schaan, Liechtenstein)
	IVA		
Beautifil Bulk	A	Bis-GMA, UDMA, Bis-MPEPP, TEGDMA, Glass powder (S-PRG filler), Reaction initiator, Pigments, <i>etc.</i>	Shofu
	Universal		
(Conventional High Viscosity Resin)			
Clearfil Majesty ES-2	A3	Bis-GMA, Other methacrylic monomers, Surface treatment glass powder, Surface treatment organic composite filler, Photopolymerization catalyst, Pigments, <i>etc.</i>	Kuraray Noritake Dental (Tokyo, Japan)

measured by a colorimeter (Micro Spectrophotometer VSS 400, Nippon Denshoku, Tokyo, Japan). The colorimeter was equipped with CIE standard illuminant C against a black background, and the sample port was 0.7mm in diameter. The samples were illuminated by light beams at an angle of 45 degrees from the normal to the sample surface, and a photoelectric sensor was positioned perpendicularly to the sample surface. Before each measurement session, the colorimeter was calibrated according to the manufacturer's recommendations by using the supplied white calibration standard. The color was measured 3 times. Values were recorded by a CIELab color system. The averages for the 3 readings of the L^* , a^* , and b^* values were calculated for each sample. The CIELab systems is an approximately uniform color space with coordinates for white-black (L^*), redness-greenness (a^*), and yellowness-blueness (b^*). L^* , a^* , and b^* values of each specimen before (T_0) and after light-curing (T_1) were obtained 5 times. The mean values of ΔL^* , Δa^* , and

Δb^* after these measurements were calculated where ΔL^* , Δa^* , and Δb^* were the difference in L^* , a^* , and b^* values before (T_0) and after light-curing (T_1). In addition, changes in metric chroma (ΔC^*) before and after curing were calculated. Metric chroma (ΔC^*) is defined by the following formula:

$$C^* = \{(\Delta a^*)^2 + (\Delta b^*)^2\}^{1/2}$$

Color difference (ΔE^*ab) was calculated from the mean ΔL^* , Δa^* , and Δb^* values for each specimen by using the following the formula:

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

To relate the color difference recorded by the colorimeter to a clinical environment, the data were converted to National Bureau of Standards (NBS) units through the equation, NBS units = $\Delta E^*ab \times 0.92$, where critical

Table 2 Description of color changes from the NBS units

NBS unit	Description of color changes
0.0–0.5	Trace: Extremely slight change
0.5–1.5	Slight: Slight change
1.5–3.0	Noticeable: Perceivable change
3.0–6.0	Appreciable: Marked change
6.0–12.0	Much: Extremely marked change
12.0 or more	Very much: Change to another color

$$NBS=0.92 \times \Delta E^{*ab}$$

remarks of color differences were expressed in terms of NBS units. These values are shown in Table 2⁷⁾.

Statistical analysis

Six samples of each of the resin composites were tested. Data for ΔL^* , Δa^* , Δb^* , ΔC^* , and ΔE^{*ab} were analyzed by one-way ANOVA. Means were compared by Scheffe's multiple range test for *post hoc* analysis at 95% probability level. The average color difference of ΔE^{*ab} was permitted by less than 1.5 (Slight change) according to NBS^{8,9)}. Effect size 2.14 (*Cohen's d*) was calculated by following formula in pilot study groups.

$$Cohen's\ d = \frac{Av_1 - Av_2}{\sqrt{\frac{SD_1^2 + SD_2^2}{2}}}$$

$$SD_1=0.7, SD_2=0.7, Av_1-Av_2=1.5 \text{ (Slight change)}$$

And then number of specimens and actual power were decided by statistical power analysis tool (G*Power 3.1 for windows) as follows values¹⁰⁾. Number of specimens=6, α error=0.05, Power (1- β error)=0.95, Actual power=0.96

RESULTS

Differences in the L^* , a^* , b^* , and C^* parameters (ΔL^* , Δa^* , Δb^* , and ΔC^*) and total color differences (ΔE^{*ab} and NBS value) determined by measurement before and after light-curing bulk-fill resin composites when backed by a black background are listed in Tables 3 and 4. A significant difference in ΔE^{*ab} among products was observed from the analysis of variance. Among low viscosity resin composites, Bulk Base High Flow had the highest ΔE^{*ab} value (mean:16.55) when compared with other products, followed by Bulk Base Medium Flow (16.10), and then Beautifil Bulk Flow Universal (15.15), Gracefil Bulk Flow Universal (13.79), Beautifil Bulk Flow Dentin (12.83), SDR Universal (11.40), Bulk Base Hard Universal (10.34), Bulk Base Hard Dentin (9.38), and Beautifil Flow Plus F00 A3 (7.22). The ΔE^{*ab} of Beautifil Flow Plus F00 A3 (conventional low viscosity resin composite) was significantly lower than that of the other bulk-fill resin composites. For high viscosity resin

composites, Tetric N-Ceram Bulk Fill IVA (9.49), Tetric N-Ceram Bulk Fill IVW (7.95), Beautifil Bulk Universal (7.71), Beautifil Bulk A (5.93), and Clearfil Majesty ES-2 A3 (4.91). Beautifil Bulk A and Clearfil Majesty ES-2 A3 (conventional high viscosity resin composite) presented no significant differences in their ΔE^{*ab} .

When the NBS ratings of low viscosity resin composites were evaluated, Bulk Base (High and Medium Flow), Beautifil Bulk Flow Universal, and Gracefil Bulk Flow Universal were in the range of 12.0 or more, which meant that a very much color change (change to another color) was observed by the human naked eye. The NBS ratings of Bulk Base Hard (Dentin and Universal), Beautifil Bulk Flow Dentin, SDR Universal, and Beautifil Flow Plus F00 A3 were in the range of 6.0–12.0, which showed much color change (extremely marked change). Among high viscosity resin composites, this rating for Tetric N-Ceram Bulk Fill (IVW and IVA) and Beautifil Bulk Universal was in the range of 6.0–12.0, which showed much color change (extremely marked change). The NBS ratings of Beautifil Bulk A and Clearfil Majesty ES-2 A3 ranged from 3.0 to 6.0, which showed an appreciable color change (marked change).

These color changes were due to changes in the lightness/darkness (ΔL^*), redness/greenness (Δa^*), yellowness/blueness (Δb^*), and chroma (ΔC^*) parameters. For the low viscosity resin composites, Bulk Base (High and Medium Flow), Beautifil Bulk Flow (Universal, and Dentin) showed large differences in the ΔL^* . The Bulk Base (High and Medium Flow) became darker, whereas Beautifil Bulk Flow (Universal and Dentin) became clearly lighter. Beautifil Flow Plus F00 A3 indicated a significantly smaller difference in the ΔL^* in comparison to the other bulk-fill resin composites. The variation in ΔL^* of the high viscosity resin composites was smaller than that of the low viscosity resin composites. The ΔL^* of Beautifil Bulk A and Clearfil Majesty ES-2 A3 showed significantly smaller differences than the other bulk-fill resin composites. Generally, variations in Δa^* were smaller than those in ΔL^* , Δb^* , and ΔC^* . The Δa^* among all of the bulk-fill resin composites was slight. All resin composites except for Bulk Base (High and Medium Flow) indicated a large decrease in Δb^* ; that is,

Table 3 Bulk-fill low viscosity resin composites color differences determined by measurement before and after light-curing: Mean (S.D.)

Resin	Shade	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔE^*_{ab}	NBS unit
(Bulk Low Viscosity Resin)							
Bulk Base Hard	Dentin	4.12 (0.29) ^{c,d}	-0.71 (0.19) ^{d,e}	-8.38 (0.49) ^{b,c}	-3.02 (0.52) ^e	9.38 (0.39) ^f	8.63
	Universal	4.50 (0.34) ^c	0.35 (0.08) ^{c,d}	-9.29 (0.26) ^{c,d}	7.78 (0.11) ^a	10.34 (0.26) ^{e,f}	9.51
Bulk Base (Medium Flow)	—	-16.01 (0.27) ^g	-1.15 (0.75) ^e	0.84 (0.53) ^a	1.18 (0.46) ^c	16.10 (0.25) ^a	14.81
(High Flow)	—	-16.35 (0.26) ^g	-0.70 (0.60) ^{d,e}	2.33 (0.52) ^a	2.40 (0.71) ^c	16.55 (0.23) ^a	15.22
Beautifil Bulk Flow	Dentin	10.27 (0.49) ^b	1.15 (0.28) ^{a,b,c}	-7.60 (0.35) ^{b,c}	-7.20 (0.31) ^f	12.83 (0.54) ^{c,d}	11.80
	Universal	11.80 (0.24) ^a	1.07 (0.60) ^{a,b,c}	-9.36 (1.15) ^{c,d}	6.87 (0.25) ^{a,b}	15.15 (0.57) ^{a,b}	13.94
Gracefil Bulk Flow	Universal	3.37 (0.41) ^d	1.76 (0.19) ^{a,b}	-13.25 (0.74) ^e	-1.17 (0.68) ^d	13.79 (0.66) ^{b,c}	12.69
SDR	Universal	-2.02 (0.29) ^f	2.34 (0.13) ^a	-10.97 (0.68) ^d	6.34 (0.26) ^b	11.40 (0.70) ^{d,e}	10.49
(Conventional Low Viscosity Resin)							
Beautifil Flow Plus F00	A3	-0.11 (0.27) ^e	0.87 (0.55) ^{b,c}	-7.14 (0.52) ^b	-7.16 (0.52) ^f	7.22 (0.53) ^g	6.64

The difference in letters indicates that the values were statistically significant for ΔL^* , Δa^* , Δb^* , ΔC^* , and ΔE^*_{ab} ($p < 0.05$).

Table 4 Bulk-fill high viscosity resin composites color differences determined by measurement before and after light-curing: Mean (S.D.)

Resin	Shade	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔE^*_{ab}	NBS unit
(Bulk High Viscosity Resin)							
Tetric N-Ceram Bulk Fill	IVW	1.32 (0.33) ^a	3.37 (0.13) ^a	-7.07 (0.28) ^{b,c}	-3.62 (0.28) ^c	7.95 (0.30) ^b	7.31
	IVA	-2.40 (0.29) ^c	2.60 (0.38) ^b	-8.79 (0.62) ^d	-5.26 (0.19) ^d	9.49 (0.67) ^a	8.73
Beautifil Bulk	A	0.12 (0.62) ^b	0.81 (0.14) ^c	-5.84 (1.00) ^{a,b}	4.02 (0.99) ^b	5.93 (0.99) ^c	5.46
	Universal	-2.54 (0.40) ^c	1.23 (0.32) ^c	-7.15 (0.30) ^c	5.71 (0.42) ^a	7.71 (0.29) ^b	7.09
(Conventional High Viscosity Resin)							
Clearfil Majesty ES-2	A3	-0.24 (0.25) ^b	1.13 (0.13) ^c	-4.77 (0.44) ^a	-4.85 (0.43) ^{c,d}	4.91 (0.46) ^c	4.52

The difference in letters indicates that the values were statistically significant for ΔL^* , Δa^* , Δb^* , ΔC^* , and ΔE^*_{ab} ($p < 0.05$).

these brands became less yellow. Among low viscosity resin composites, the Δb^* of Bulk Base Hard (Dentin and Universal), Beautifil Bulk Flow Universal, Gracefil Bulk

Flow Universal, and SDR Universal was significantly lower than that of Beautifil Flow Plus F00 A3. For high viscosity resin composites, the Δb^* of Tetric N-Ceram

Bulk Fill (IVW and IVA) and Beautifil Bulk Universal was significantly lower than that of Clearfil Majesty ES-2 A3. Finally, in the comparison of the ΔC^* , Bulk Base Hard Universal, Bulk Base (High and Medium Flow), Beautifil Bulk Flow Universal, SDR Universal, and Beautifil Bulk (A and Universal) became brighter; whereas Bulk Base Hard Dentin, Beautifil Bulk Flow Dentin, Gracefil Bulk Flow Universal, Beautifil Flow Pluss F00 A3, Tetric N-Ceram Bulk Fill (IVW and IVA), and Clearfil Majesty ES-2 A3 became duller.

DISCUSSION

Specimens of uncured and cured resin composites were evaluated for their ΔE^*ab values. The present study clearly demonstrated that each of the bulk-fill resin composites tested, except for Beautifil Bulk A, showed significantly higher ΔE^*ab values than the conventional resin composites occurring as a result of the polymerization process, regardless of the shade of the underlying structure. Thus, the null hypothesis was rejected. In addition, the corresponding NBS unit were calculated to assess clinical acceptability. When the results for ΔE^*ab were evaluated in terms of NBS units of color difference, Beautifil Bulk A and Clearfil Majesty ES-2 A3 exhibited “appreciable” color changes. Beautifil Bulk A showed the least color change (5.46) among all bulk-fill resin composites; however, it was considered as clinically unacceptable. The upper limit of acceptability in subjective visual evaluations was confirmed by Ruyter *et al.*¹¹⁾ and Um and Ruyter¹²⁾, who suggested it to be a value $\Delta E^*ab=3.3$. However, many unacceptable color changes (ΔE^*ab greater than 3.3) after light-curing of conventional resin composites have been reported^{13,14)}. In the present study, ΔE^*ab values of conventional resin composites indicated 7.22 and 4.91, whereas those values of bulk-fill resin composites indicated 9.38–16.55 and 5.93–9.49.

Optical properties such as color and translucency have become important considerations in the development of esthetic restorative materials. However, color and translucency remain as difficult optical properties to control in the clinical environment. Resin composites are translucent but are light-scattering materials, as a result of light absorption and scattering caused by fillers and other additives¹⁵⁾. The color of the composites reflects the reflectance spectrum of the composites, which are considerably affected by the background color and the thickness of the composites¹⁶⁾. Moreover, matt uncured resin composites are transformed into gloss cured resin composites, and so cured resin composites tend to have greater diffuse reflectance and optical transmittance than uncured resin composites¹⁷⁾.

In the assessment of ΔL^* values, it was determined that Bulk Base (High and Medium Flow) became darker, whereas Beautifil Bulk Flow (Universal and Dentin) became lighter after light-curing. This difference could be explained by the optical properties of these brands. Bulk Base (High and Medium Flow) have no pigment in their composition, and so their light transmission

became higher after light-curing. Beautifil Bulk Flow (Universal and Dentin) is claimed to contain a light diffusion filler (S-PRG filler). Light reflection is significantly influenced by the background color due to translucency of the composites. All resin composites except for Bulk Base (High and Medium Flow) showed a large decrease in the Δb^* ; that is, these brands became less yellow. This decrease can be explained by the reducing agents contained in them, which was probably responsible for the decrease in the Δb^* values of the resin composites^{18,19)}.

Seghi *et al.* reported that lighter shades tended to show more color change than darker ones¹³⁾. The same results were found in our experiment. The difference in shade, such as Dentin and Universal, also affected the color change, though the reason for this difference was not revealed in the present study. The deeper cure in bulk-fill composite is made possible by adjustments in translucency and photo-initiators²⁰⁾. These modifications include an increased filler size and monomer system²¹⁾. Tetric N-Ceram Bulk Fill contains a translucent filler and matrix as a germanium-based photo-initiator, which has a higher photo-curing activity than camphorquinone²⁰⁾. The manufacturer states that SDR contains a high molecular weight polymerization modulator in its matrix structure. The optical properties of a resin composite consisting of 2 different transparent matrix monomers and filler particles are characterized by the differences in optical properties between the resin matrix and filler particles. Especially, differences in optical properties and color appearance among materials are expected to be dominated by filler properties such as particle size, shape, and filler content^{22,23)}. The color of esthetic restorative materials is determined not only by more macroscopic phenomena such as matrix and filler composition, but also by related minor pigment additions and potentially by all other chemical components of these materials, including the initiation component and filler coupling agent. More longitudinal studies are needed to support the color change in bulk-fill resin composites.

CONCLUSION

Twelve commercially available bulk-fill resin composites were evaluated for color changes following light-curing when backed by a black background. Within the limitations of the present study, Beautifil Bulk A exhibited the least color change among all bulk-fill resin composites. This color change was classified as “appreciable”. The color differences for all the other bulk-fill resin composites were marked.

REFERENCES

- 1) Rosatto CMP, Bicalho AA, Verissimo C, Braganca GF, Rodrigues MP, Tantbirojn D, *et al.* Mechanical properties, shrinkage stress, cuspal strain and fracture resistance of molars restored with bulk-fill composites and incremental filling technique. J Dent 2015; 43: 1519-1528.
- 2) Jang JH, Park SH, Hwang IN. Polymerization shrinkage and depth of cure of bulk-fill resin composites and highly filled

- flowable resin. *Oper Dent* 2015; 40-2: 172-180.
- 3) Yap AUJ, Pandya M, Toh WS. Depth of cure of contemporary bulk-fill resin-base composites. *Dent Mater J* 2016; 35: 503-510.
 - 4) Tsujimoto A, Barkmeier WW, Takamizawa T, Latta MA, Miyazaki M. Depth of cure, flexural properties, and volumetric shrinkage of low and high viscosity bulk-fill giomers and resin composite. *Dent Mater J* 2017; 36: 205-213.
 - 5) Kaya MS, Bakkal M, Durmus A, Durmus Z. Structural and mechanical properties of a giomer-based bulk fill restorative in different curing conditions. *J Appl Oral Sci* 2018; 26: e20160662.
 - 6) Comba A, Scotti N, Maravic T, Mazzoni A, Carossa M, Breschi L, *et al.* Vickers hardness and shrinkage stress evaluation of low and high viscosity bulk-fill resin composite. *Polymer (Basel)* 2020; 12: 1447.
 - 7) Koksall T, Dikbas I. Color stability of different denture teeth materials against various staining agents. *Dent Mater J* 2008; 27: 139-144.
 - 8) Daniele V, Macera L, Taglieri G, Di Giambattista A, Spagnoli G, Massaria A, *et al.* Thermoplastic disks used for commercial orthodontic aligners: complete physicochemical and mechanical characterization. *Materials* 2020; 22: 13: 2386.
 - 9) Porojan L, Vasiliu RD, Porojan SD, Birdeanu MI. Surface quality evaluation of removable thermoplastic dental appliances related to staining beverages and cleaning agents. *Polymers* 2020; 12: 1736.
 - 10) Paul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007; 39: 175-191.
 - 11) Ruyter IE, Nilner K, Moller B. Color stability of dental composite resin materials for crown and bridge veneers. *Dent Mater* 1987; 3: 246-251.
 - 12) Um CM, Ruyter IE. Staining of resin-based veneering materials with coffee and tea. *Quintessence Int* 1991; 22: 377-386.
 - 13) Seghi RR, Gritz MD, Kim J. Colorimetric changes in composites resulting from visible-light-initiated polymerization. *Dent Mater* 1990; 6: 133-137.
 - 14) Eldiwany M, Friedl KH, Powers JM. Color stability of light-cured and post-cured composite. *Am J Dent* 1995; 8: 179-181.
 - 15) Suzuki H, Taira M, Wakasa K, Yamaki M. Refractive-index-adjustable fillers for visible-light-cured dental resin composites: Preparation TiO₂-SiO₂ glass powder by the sol-gel process. *J Dent Res* 1991; 70: 883-888.
 - 16) Miyagawa Y, Powers JM, O'Braian WJ. Optical properties of direct restorative materials. *J Dent Res* 1981; 60: 890-894.
 - 17) Taira M, Okazaki M, Takahashi J. Studies on optical properties of two commercial visible-light-cured composite resins by diffuse reflectance measurements. *J Oral Rehabil* 1999; 26: 329-337.
 - 18) Tanoue N, Koishi Y, Yanagida H, Atsuta M, Shimada K, Matsumura H. Color stability of acrylic resin adhesives with different initiation modes. *Dent Mater J* 2004; 23: 368-372.
 - 19) Del Mar Perez M, Saleh A, Pulgar R, Paravina RD. Light polymerization-dependent changes in color and translucency of resin composites. *Am J Dent* 2009; 22: 97-101.
 - 20) Moszner N, Fischer UK, Ganster B, Liska R, Rheinberger V. Benzoyl germanium derivatives as novel visible light photoinitiators for dental materials. *Dent Mater* 2008; 24: 901-907.
 - 21) Ilie N, Stark K. Curing behavior of high-viscosity bulk-fill composites. *J Dent* 2014; 42: 977-985.
 - 22) Enami N, Sjodahl M, Soderholm KJM. How filler properties, filler fraction, sample thickness and light source affect light attenuation in particulate filled resin composites. *Dent Mater* 2005; 21: 721-730.
 - 23) Arikawa H, Kanie T, Fujii K, Takahashi H, Ban S. Effect of filler properties in composite resins on light transmittance characteristics and color. *Dent Mater J* 2007; 26: 38-44.