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 mm. 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 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, etc.), Acrylic esters (Urethane acrylate), Barium and strontium silica glasses, Aromatic amine, etc. | Sun Medical (Shiga, Japan)     |
| Bulk Base              | Universal| —                                                                             |                                |
| (Medium Flow)          |       | Methacrylic acid esters (Bis-MPEPP), Acrylic esters (Urethane acrylate, etc.), Barium silica glass, Strontium fluoro-alumino-silicate glass, Aromatic amine, etc. |                                |
| (High Flow)            |       | —                                                                           |                                |
| **Beautifil Bulk Flow**| Dentin| Bis-GMA, UDMA, Bis-MPEPP, TEGDMA, Glass powder (S-PRG filler), Reaction initiator, Pigments, etc. | Shofu (Kyoto, Japan)           |
| **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, etc. | Dentsply (Konstanz, Germany)   |
| (Conventional Low Viscosity Resin) |       |                                                                             |                                |
| **Beautifil Flow**     | Plus F00 A3| Bis-GMA, TEGDMA, Glass powder (S-PRG filler), Reaction initiator, Pigments, etc. | Shofu                          |
| (Bulk High Viscosity Resin) |       |                                                                             |                                |
| **Tetric N-Ceram Bulk Fill** | IVW| Bis-GMA, UDMA, Barium glass, Ytterbium trifluoride mixed oxide prepolymer, Catalysis, Stabilizers, Pigments, etc. | Ivoclair Vivadent (Schaan, Liechtenstein) |
| **Beautifil Bulk**     | A     | Bis-GMA, UDMA, Bis-MPEPP, TEGDMA, Glass powder (S-PRG filler), Reaction initiator, Pigments, etc. | Shofu                          |
| (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, etc. | 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 $\Delta L^*$, $\Delta a^*$, and $\Delta b^*$ after these measurements were calculated where $\Delta L^*$, $\Delta a^*$, and $\Delta b^*$ were the difference in $L^*$, $a^*$, and $b^*$ values before ($T_0$) and after light-curing ($T_1$). In addition, changes in metric chroma ($\Delta C^*$) before and after curing were calculated. Metric chroma ($\Delta C^*$) is defined by the following formula:

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

Color difference ($\Delta E^*ab$) was calculated from the mean $\Delta L^*$, $\Delta a^*$, and $\Delta b^*$ values for each specimen by using the following the formula:

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

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=$\Delta E^*ab\times0.92$, where critical
Table 2  Description of color changes from the NBS units

| NBC 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×ΔE*ab

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 deference of ΔE*ab was permitted by less than 1.5 (Slight change) according to NBS\(^{20}\). 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{SD_1^2+SD_2^2}} \times 2

SD_1=0.7, SD_2=0.7, Av_1–Av_2=1.5 (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 values\(^{10}\). 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 Beautiful Bulk Flow Universal (15.15), Gracefil Bulk Flow Universal (13.79), Beautiful Bulk Flow Dentin (12.83), SDR Universal (11.40), Bulk Base Hard Universal (10.34), Bulk Base Hard Dentin (9.38), and Beautiful Flow Plus F00 A3 (7.22). The ΔE*ab of Beautiful 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), Beautiful Bulk Universal (7.71), Beautiful Bulk A (5.93), and Clearfil Majesty ES-2 A3 (4.91), Beautiful 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), Beautiful 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), Beautiful Bulk Flow Dentin, SDR Universal, and Beautiful 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 Beautiful Bulk Universal was in the range of 6.0–12.0, which showed much color change (extremely marked change). The NBS ratings of Beautiful 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), Beautiful Bulk Flow (Universal, and Dentin) showed large differences in the ΔL*. The Bulk Base (High and Medium Flow) became darker, whereas Beautiful Bulk Flow (Universal and Dentin) became clearly lighter. Beautiful 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 Beautiful 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          | ∆L*  | ∆a*  | ∆b*  | ∆C*  | ∆E*ab | NBS unit |
|----------------------|------|------|------|------|-------|----------|
| **(Bulk Low Viscosity Resin)** |      |      |      |      |       |          |
| Dentin               | 4.12 | −0.71| −8.38| −3.02| 9.38  | 8.63     |
|                      | (0.29) | (0.19) | (0.49) | (0.52) | (0.39) |          |
| Universal            | 4.50 | 0.35 | −9.29| 7.78 | 10.34 | 9.51     |
|                      | (0.34) | (0.08) | (0.26) | (0.11) | (0.26) |          |
| **Bulk Base Hard**   |      |      |      |      |       |          |
| —                    | −16.01| −1.15| 0.84 | 1.18 | 16.10 | 14.81    |
|                      | (0.27) | (0.75) | (0.53) | (0.46) | (0.25) |          |
| **(Medium Flow)**    |      |      |      |      |       |          |
| —                    | −16.35| −0.70| 2.33 | 2.40 | 16.55 | 15.22    |
|                      | (0.26) | (0.60) | (0.52) | (0.71) | (0.23) |          |
| **(High Flow)**      |      |      |      |      |       |          |
| —                    | −11.80| 1.07 | −9.36| 6.87 | 15.15 | 13.94    |
|                      | (0.24) | (0.60) | (1.15) | (0.25) | (0.57) |          |
| **Gracefil Bulk Flow** |      |      |      |      |       |          |
| —                    | 3.37 | 1.76 | −13.25| −1.17| 13.79 | 12.69    |
|                      | (0.41) | (0.19) | (0.74) | (0.68) | (0.66) |          |
| **SDR**              |      |      |      |      |       |          |
| —                    | −2.02 | 2.34 | −10.97| 6.34 | 11.40 | 10.49    |
|                      | (0.29) | (0.13) | (0.68) | (0.26) | (0.70) |          |
| **(Conventional Low Viscosity Resin)** |      |      |      |      |       |          |
| Beautifil Flow Plus F00 | 0.12 | 0.87 | −7.14| −7.16| 7.22  | 6.64     |
| A3                   | (0.27) | (0.55) | (0.52) | (0.52) | (0.53) |          |

The difference in letters indicates that the values were statistically significant for ∆L*, ∆a*, ∆b*, ∆C*, and ∆E*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          | ∆L*  | ∆a*  | ∆b*  | ∆C*  | ∆E*ab | NBS unit |
|----------------------|------|------|------|------|-------|----------|
| **(Bulk High Viscosity Resin)** |      |      |      |      |       |          |
| Tetric N-Ceram Bulk Fill |      |      |      |      |       |          |
| IVW                  | 1.32 | 3.37 | −7.07| −3.62| 7.95  | 7.31     |
|                      | (0.33) | (0.13) | (0.28) | (0.28) | (0.30) |          |
| IVA                  | −2.40| 2.60 | −8.79| −5.26| 9.49  | 8.73     |
|                      | (0.29) | (0.38) | (0.62) | (0.19) | (0.67) |          |
| A                    | 0.12 | 0.81 | −5.84| 4.02 | 5.93  | 5.46     |
|                      | (0.62) | (0.14) | (1.00) | (0.99) | (0.99) |          |
| Beautifil Bulk Universal | −2.54| 1.23 | −7.15| 5.71 | 7.71  | 7.09     |
|                      | (0.40) | (0.32) | (0.30) | (0.42) | (0.29) |          |
| **(Conventional High Viscosity Resin)** |      |      |      |      |       |          |
| Clearfil Majesty ES-2 | 0.24 | 1.13 | −4.77| −4.85| 4.91  | 4.52     |
| A3                   | (0.25) | (0.13) | (0.44) | (0.43) | (0.46) |          |

The difference in letters indicates that the values were statistically significant for ∆L*, ∆a*, ∆b*, ∆C*, and ∆E*ab (p<0.05).

these brands became less yellow. Among low viscosity resin composites, the ∆b* 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 ∆b* 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 ∆C*, 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, Gracefill Bulk Flow Universal, Beautifil Flow Plus 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 ΔE*ab=3.3. However, many unacceptable color changes (ΔE*ab greater than 3.3) after light-curing of conventional resin composites have been reported13,14. 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 9.93–9.49.

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 additives15,16. 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 ∆L* 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 ∆b*; 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 ∆b* values of the resin composites18,19.

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 content22,23. 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.

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