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Color match using instrumental and visual methods for single, group, and multi-shade composite resins

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Abstract

Objective: To evaluate the shade match of three composite resin restorative materials to bi-layered acrylic teeth instrumentally and visually.

Materials and methods: Three composite materials—Omnichroma [OM], Tetric EvoCeram [TE], and TPH Spectra ST [TS] were placed into occlusal preparations (5 mm diameter, 2 mm depth) on 15 bi-layered acrylic teeth per each shade A2, B1, B2, C2, and D3. The composites were placed in a single increment and cured using Bluephase G2 light. The L^*, a^*, and b^* readings were obtained using VITA Easyshade V for the teeth and restorations; mean ΔE_{00} values were calculated and assessed using two-way analysis of variance with a test of simple effects with multiple comparisons for significance ($P < .05$). Three teeth were restored to anatomical form with each of the composites for the five shades and were subjectively graded by 30 evaluators as 1—best match, 2—intermediate, and 3—poorest match.

Results: In the instrumental evaluation, OM and TS showed lower ΔE_{00} values for lighter shades, whereas TE showed lower and similar ΔE_{00} values for all shades. In the visual evaluation, TE exhibited the best shade match for darker shades C2 and D3. OM and TS matched better with lighter shades.

Conclusion: Shade matching is composite and shade-dependent. Overall, TE matched the multiple shades better than the other two materials.

Clinical significance: Single and group shade composites displayed shade matching ability inferior to a multi-shade composite material, which may limit their use in highly esthetic clinical situations.

KEYWORDS
blending, color, composite resin, esthetics, shade match

1 | INTRODUCTION

In the replacement of missing tooth structure, it is a primary objective to restore proper tooth form, function, and esthetics. To ensure an esthetic outcome, an imperceptible match of the color of the restorative material to that of the tooth is of utmost importance. The polychromatic nature of natural teeth makes shade selection more challenging.[1] Composite resins have been developed commercially in multiple enamel and dentin shades of differing translucencies and opacities,[2,3] as measured according to the VITA Classical shade guide. This complicates the shade matching procedure, requires more inventory, and results in an increase in cost and chairside time. "Blending effect" (BE) or "chameleon effect" describes the ability of a material to acquire a color similar to that of its surrounding tooth structure.[4,5] This has enabled the introduction of composite materials with modified optical properties and thus, a reduced number of shades.

Sanchez et al evaluated the instrumental and visual color adjustment potential (CAP-I and CAP-V) of five composites (Omnichroma [OM], Filtek Supreme Ultra, TPH Spectra, Herculite Ultra, and Tetric EvoCeram [TE]) across the 16 VITA classical A1-D4 shades. They found that OM (a single-shade material) had a more positive CAP-I and CAP-V than the other materials which had been developed for specific shades. This meant that OM blended in with the surrounding tooth structure, resulting in a reduced color difference between the two.[6] Abdelraouf et al[7] assessed the color match and BE of a universal shade composite (X-TraFil) placed in composite resin models of different shades (Grandio; A1, A2, A3, A3.5, and A4) and cavity sizes, and in natural teeth. Spectrophotometric analysis was carried out to calculate the color difference (ΔE) between the universal shade and the other shades and visual scoring (VS) was done by seven observers. It was seen that in models, ΔE increased, and VS decreased as the shades became darker. In natural teeth, the color match of the universal shade composite was found to be satisfactory, although not imperceptible.

Because natural daylight is variable, it cannot be used reliably to judge color.[8] For this reason, the Commission Internationale de l'Eclairage (CIE, International Commission on Illumination) proposed the use of "standard illuminants" in 1931. The CIE Standard Illuminant D_{65} represents average daylight having a color temperature of 6500 K. To allow for the quantification of color, CIE introduced the CIELAB color space, which converts the tristimulus values of a sample into L^*, a^*, and b^* coordinates. L^* stands for lightness, represented on a scale of 0 (black) to 100 (white); a^* and b^* represent the hue and chroma values of the sample; a^* is the red (+)/green (–) coordinate, and b^* is the yellow (+)/blue (–) coordinate.[9] The total color difference between two specimens is represented by ΔE. The majority of studies on assessment of dental color and color difference utilize the 1976 CIELAB color difference formula (total color difference represented by ΔE_{ab}). The CIEDE2000 formula (total color difference represented by ΔE_{00}) was developed in an attempt to decrease the variation between the computed and perceived color differences.[9]

To compensate for the non-uniformity of the CIELAB color space, the CIEDE2000 formula incorporates specific corrections: Weighting functions (S_L, S_C, S_H), a rotation term (R_T) to reduce the interaction between chroma and hue differences in the blue region, a modification of the a^* axis of the CIELAB for the correction of neutral colors, and parametric factors (K_L, K_C, K_H) which are correction terms for variations of experimental conditions.[10] Many studies have reported a better fit of the CIEDE2000 formula in evaluating visual tolerances (95% agreement with visual findings, as opposed to 75% for the CIELAB 1976 formula),[11] thus supporting its use in dental color research.[12,13,14] Several studies have attempted to obtain perceptibility and acceptability threshold values (PT and AT, respectively) for ΔE_{00}.[11,12,15,16] A 50:50% PT and AT of 0.8 and 1.8 respectively, have been reported by Paravina et al,[16] and the latter value has been used as reference for the AT in this study.

There are two methods of measuring color: instrumental and visual.[17] The instrumental method uses a spectrophotometer, which has an integrated, standardized illumination (6500 K). Spectrophotometers measure the amount and spectral composition of the reflected light from the object and convert it into quantifiable data. They are more reliable than colorimeters, as they are not affected by object metamerism.[18] VITA Easyshade V (VITA Zahnfabrik, Bäd Sackingen, Germany) is an intraoral spectrophotometer with a 5-mm probe tip that illuminates the tooth with a 6500 K light for color matching and displays the results as L^*, a^*, and b^* values and matches to visual shade guides. The device provides reliability and accuracy as documented in a study done by Dozic et al, which found VITA Easyshade to be the most precise among five other commercially available devices, both in vitro (VITA shade tabs) and in vivo.[19] In another study by Kim-Pusateri et al, VITA Easyshade was the only color-measuring device which showed values for reliability and accuracy of more than 90%.[20] Klotz et al compared the two spectrophotometers VITA Easyshade 4.0 and VITA Easyshade V and found both to be clinically acceptable for determining tooth color.[21] Sarafianou et al also found the VITA Easyshade to have high repeatability of measurements.[22]

When a tooth is restored with composite resin, several factors can affect the shade match, including the filler content and size, matrix composition, the size of the restoration, layering of the composites, and the shade and the brand of the composite itself.[4,5,23-26] In a study by Arikawa et al, composites with smaller and irregular-shaped fillers showed higher light transmittance as compared to the ones with larger particles.[24] They also found that with irregularly shaped fillers, the a^* value decreased and b^* value increased, while it was the opposite with spherical fillers. Azzopardi et al found a positive correlation between the amount of Bis-GMA in composite resin samples and the translucency of the composite material.[25] Composition of the material is important also because composites contain color pigments and metal oxides. Titanium oxide fillers increase the opalescence and give a more enamel-like appearance.[26] In a study conducted by Paravina et al, they concluded that the BE increased with a decrease in restoration size, a decrease in the color difference, and an increase in translucency.[4] Paravina et al also showed in another study that the BE was dependent on the shade and composite.[5] The difference in the refractive index between the filler-matrix and coupling agent should be minimal. Otherwise, the material appears opaque, as it does not allow sufficient light to pass through.[26]

In this study, the term "single-shade composite" has been used to denote a composite material available as a single universal shade, that has been developed to blend with all 16 VITA classical shades, thus providing a shade match for every tooth color. A "group-shade composite" implies a composite system available in fewer shades, with each shade being used for a recommended set of VITA classical shades. A "multi-shade composite" denotes a composite system that has a composite shade for each of the 16 VITA classical shades. The purpose of this study was to evaluate and compare the shade matching ability of single, group, and multiple-shade composite resin restorative materials to bi-layered acrylic teeth using both an instrumental and a visual method.

2 | MATERIALS AND METHODS

The first part of this study was an instrumental evaluation of the shade match of the three composite restorative materials using a contact spectrophotometer. The second part was a visual study wherein clinical observers evaluated and rated the shade match.

2.1 | Instrumental evaluation

The shade match of the three composite materials was tested relative to bi-layered acrylic teeth (provided by Tokuyama Dental, Japan) of five different shades (A2, B1, B2, C2, and D3), using instrumental readings.

The commercially available composite materials evaluated in this study are listed in Table 1. OM (Tokuyama Dental, Japan) is a single-shade material, with composition and optical properties that enable it to blend in with the entire spectrum of tooth color, from A1 to D4. TPH Spectra ST (TS; Dentsply Sirona, York, Pennsylvania) is available as five "*cloud shades*," with each "*cloud shade*" meant to match a specific group of VITA shades. This allows the system to achieve a shade match with the full range of VITA shades. Accordingly, in this study, *cloud shade* composite A1 was used for tooth shade B1, *cloud shade* A2 was used for tooth shades A2 and B2, and *cloud shade* A3 was used for tooth shades C2 and D3, as recommended by the manufacturer. TE (Ivoclar Vivadent, Amherst, New York) is a multi-shade composite system available as enamel, dentin, and bleach shades. Enamel shades A2, B1, B2, C2, and D3 were used for the corresponding tooth shades in this study.

Fifteen left mandibular first molar acrylic teeth, each of VITA shades A2, B1, B2, C2, and D3, were used to evaluate the shade match with the three composite resins, totaling 75 teeth. The five shades were chosen by order of value (higher/lighter; lower/darker), viz., B1, B2, A2, C2, and D3. The acrylic teeth were bi-layered to replicate natural teeth as closely as possible and make the color readings more realistic. The color parameters (*L*, *a*, and *b* values) of the acrylic teeth were measured on the flat buccal surface (Baseline measurement of unrestored tooth) using an intraoral spectrophotometer (VITA Easyshade V, VITA Zahnfabrik, Bäd Sackingen, Germany). A neutral grey paper was used as a background during the measurements, and the device was calibrated after every three measurements.

Circular preparations, 2 mm in depth (measured at the lingual groove on the occlusal surface) and 5 mm in diameter, were cut on the occlusal surfaces of all the teeth using a No. 245 carbide bur (Figure 1A). For each composite material, five teeth were restored per

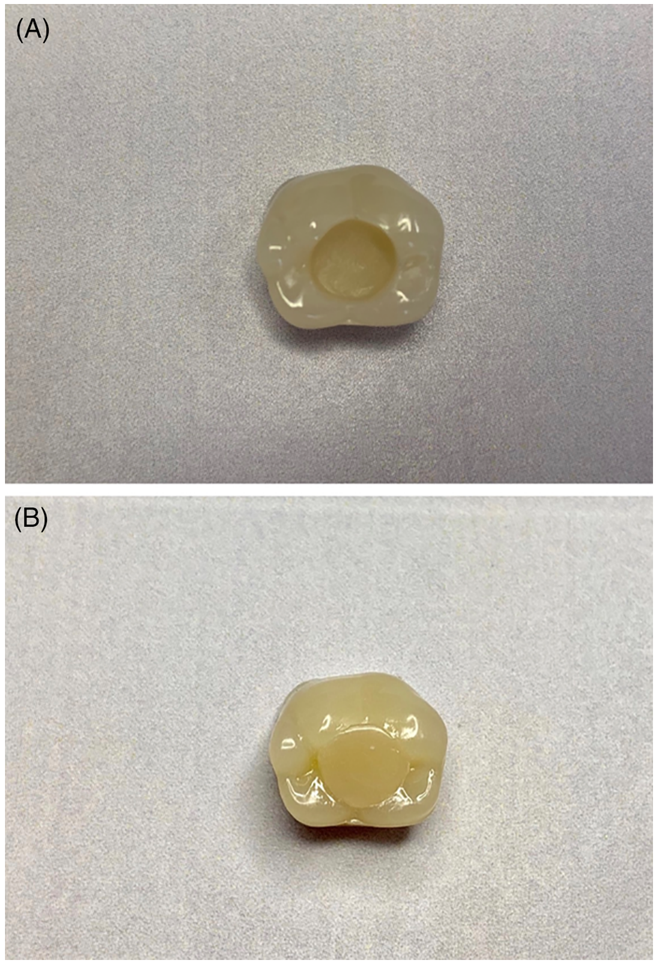

FIGURE 1 Instrumental evaluation: Preparation in the acrylic tooth, A; restoration to a flat surface with composite, B

TABLE 1 Composite materials evaluated in this study

Material	Manufacturer	Filler type	Filler content wt%	Filler content vol%	Particle size	Monomer	Shades
Omnichroma (OM)	Tokuyama Dental, Tokyo, Japan	Spherical Silica-Zirconia and Composite fillers	79	68	260 nm	UDMA, TEGDMA	Universal shade
Tetric EvoCeram (TE)	Ivoclar Vivadent Inc., Amherst, New York	Barium glass, pre-polymerized fillers, ytterbium trifluoride, spherical mixed oxides	75-76	53-55	550 nm	Bis-GMA, UDMA Ethoxylated Bis-EMA	A2, B1, B2, C2, and D3
TPH Spectra ST (TS)	Dentsply Sirona Inc., York, Pennsylvania	Spherical barium glass, pre-polymerized fillers and ytterbium fluoride	78-80	60-62	15 μm	Urethane modified Bis-GMA, TEGDMA	"*Cloud shades*" A1, A2, A3

Abbreviations: Bis-EMA, bisphenol A polyethylene glycol diether dimethacrylate; Bis-GMA, bisphenol A diglycidylmethacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

tooth shade A2, B1, B2, C2, and D3. OM, being a single universal shade, was placed into the preparations on the teeth of all shades. The composites were applied in a single increment, and the occlusal surface of the restoration was flattened to allow measurement of shade by the spectrophotometer. This was the closest approximation to the flat buccal surface from which the Baseline reading was taken. The composite restorations were polymerized with a light-curing unit (Bluephase G2; Ivoclar Vivadent, Amherst, New York) for 20 seconds at an energy level between 1280 and 1300 mW/ cm^2. The output of the unit was verified after every three uses using a radiometer (Bluephase Meter II; Ivoclar Vivadent, Amherst, New York). After curing, the restorations were dry polished with a two-step polishing system (BrioShine Feather Lite, Brasseler, Savannah, GA) using a slow speed handpiece at 6000 rpm for 30 seconds per step (Figure 1B). Color parameters of the restorations were measured using the intraoral spectrophotometer by placing its measuring tip perpendicular to the occlusal restoration. Three readings were taken for each composite restoration of each shade, and the values were averaged as a single data point. Calculation of the CIEDE2000 color difference (ΔE_{00}) was done using an Excel spreadsheet implementation of the CIEDE2000 color difference formula provided by Sharma.[27] The parametric factors of the formula were set to 1.

A ΔE_{00} value greater than 1.8[11,15] was chosen to indicate a clinically unacceptable match. The five ΔE_{00} values obtained for each shade were averaged to obtain one mean ΔE_{00} value for each of the five shades of the three composite materials. Mean ΔE_{00} values were compared to assess which of the three materials was the closest match for each shade of the acrylic teeth using a two-way analysis of variance (ANOVA) test to determine if there was a significant difference for material vs shade or an interaction between them. A test of simple effects using estimated marginal means was used to make pairwise comparisons with a Bonferroni adjustment at $P < .05$ for significance.

2.2 | Visual evaluation

For the visual color assessment, circular preparations similar to those used for the instrumental evaluation were cut into the occlusal surfaces of a total of 15 teeth, three teeth for each of the five shades. A putty matrix of the occlusal surface of an unprepared tooth was made to obtain uniform occlusal anatomy on the composite restorations. The three composite materials were placed into the preparations in slight excess and the putty matrix was pressed on the occlusal surface using finger pressure. The custom matrix was lifted off of the surface, and excess composite was carefully removed. The restorations were then light cured for 20 seconds. Following this, the restorations were dry polished for 30 seconds in two steps in the same manner as described above (Figure 2).

Visual color assessments were made by 30 dental professionals—10 each of graduate students, undergraduate students, and faculty. All evaluators were tested for color deficiency using Ishihara's Test for Color Blindness.[28] The evaluators were asked to rank the shade match of the composite restorations with the surrounding tooth structure for each of the five shades. The restored teeth were placed on a neutral grey paper, under consistent clinical lighting, and at an angle of 90° to the sample surface to simulate clinical conditions. The observers were allowed 25 seconds to rank the three specimens of each shade as either: (a) best match, (b) intermediate match, and (c) poorest match, one in each category. After evaluation of each shade, the observers were allowed to look at a neutral blue background to avoid eye fatigue.

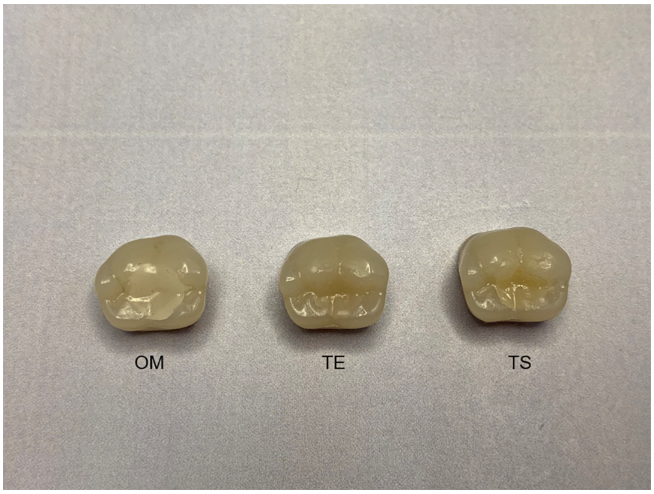

FIGURE 2 Visual evaluation: acrylic teeth restored with the three composite materials to anatomical form. OM, Omnichroma; TE, Tetric EvoCeram; TS, TPH Spectra ST

3 | RESULTS

Mean color differences (ΔE_{00}) and the SDs between baseline tooth and restored composite for each of the five shades and the three composite materials are presented in Table 2.

3.1 | Instrumental evaluation

The two-way ANOVA revealed a significant difference between materials ($P < .001$), a significant difference between shades ($P < .001$) and a significant interaction between material and shade ($P < .001$). When the ΔE_{00} values for the five shades of the three composite materials were compared using the simple effects tests for multi-comparison (Table 2), for shade match within each material, OM showed a greater range of color difference (4.08-10.34) than either TE (3.58-5.30) or TS (4.77-8.84). In general, OM and TS showed a trend for lower ΔE_{00} values with the lighter shades (B1, B2, and A2) than with the darker shades (C2 and D3), whereas TE showed similar color differences among the shades. When evaluating the materials within each shade, OM was a significantly better match for B1 and TE was the best

TABLE 2 Mean color differences (ΔE_{00}) and SD for the five shades of the three composite materials tested in the study

	A2	B1	B2	C2	D3
OM	8.02 (0.444)^{a1}	4.08 (0.340)^{b1}	7.19 (0.568)^{a1}	9.3 (1.162)^{ac1}	10.34 (0.636)^{c1}
TE	3.58 (0.605)^{a2}	5.3 (0.058)^{b2}	4.6 (0.354)^{ab2}	5.24 (0.705)^{b2}	4.89 (0.626)^{ab2}
TS	4.77 (1.129)^{a2}	7.75 (0.660)^{b3}	5.61 (0.182)^{a2}	8.84 (0.663)^{b1}	8.56 (1.649)^{b3}

Note: No significant differences were observed if the mean color difference is marked with the same superscript letter per each row and same superscript number per each column.

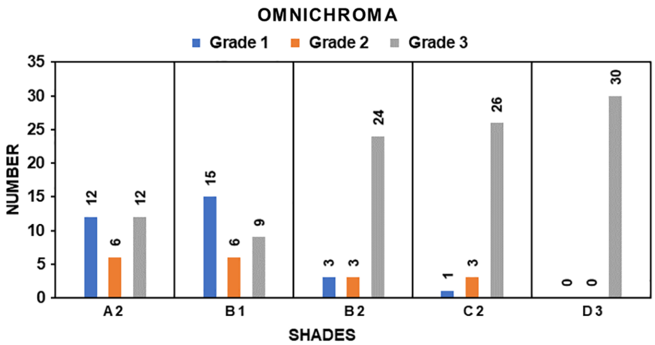

FIGURE 3 Number of evaluators that ranked Omnichroma as 1, 2, and 3 across the five shades. Scale: 1 interval = 5 evaluators

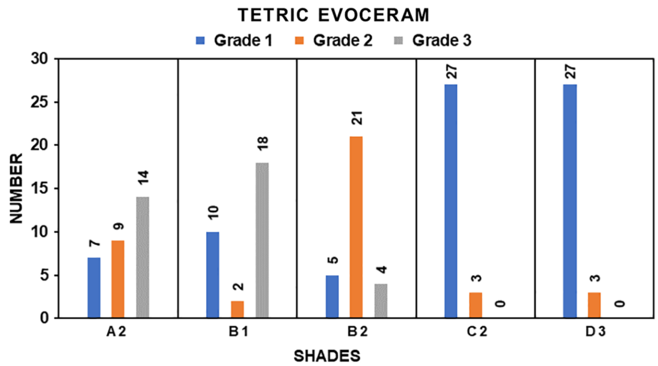

FIGURE 4 Number of evaluators that ranked Tetric EvoCeram as 1, 2, and 3 across the five shades. Scale: 1 interval = 5 evaluators

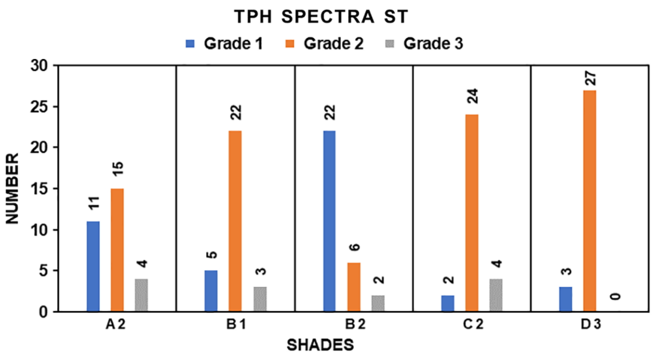

FIGURE 5 Number of evaluators that ranked TPH Spectra ST as 1, 2, and 3 across the five shades. Scale: 1 interval = 5 evaluators

match for all other shades. None of the materials showed a value below 1.8 for any material/shade combination.

3.2 | Visual evaluation

A total of 30 evaluators ranked the three composite materials for each VITA shade as best, intermediate and poorest shade match, which is graphically represented in Figures 3–5.

In general, for OM, the percentage of evaluators that graded it as "1" decreased significantly from shades A2 and B1 (40% and 50%, respectively) to shades B2, C2, and D3 (10%, 3.33%, and 0%, respectively). TE was graded "1" by 90% of the evaluators for shades C2 and D3 and only 23.33%, 33.33%, and 16.67% for shades A2, B1, and B2, respectively. TS was graded as "1" by 36.67%, 16.67%, 6.67%, and 10% of the evaluators for shades A2, B1, C2, and D3. However, 73.33% evaluators graded B2 as "1." The consensus for visual evaluation tended to support the results of the instrumental evaluation regarding best matches.

4 | DISCUSSION

The instrumental evaluation performed with the intraoral spectrophotometer demonstrated that the shade matching ability is composite and shade-dependent. For OM, the increase in the ΔE_{00} with a decrease in shade value from B1 to D3 suggests that single-shade composite systems may tend to match teeth of higher shade values better. On the other hand, the relative consistency in the ΔE_{00} values of TE for all the shades implies that it may provide a more reliable match for lighter as well as darker shades. The high ΔE_{00} values obtained for TS with shades C2 and D3 may be attributable to the use of "*cloud shade*" A3 for these two shades. It also appears as though, for OM and TS, the ΔE_{00} values increase with the addition of a grey component of color (VITA shades C and D). However, these findings may imply that for teeth exhibiting lower value, and where esthetic demands are high, it is better to use a multi-shade composite system to achieve the best possible esthetic outcome.

It is important to note that the color of the composite resin also depends on its surroundings. Since this study was performed in-vitro on bi-layered acrylic teeth, a color change was observed with values of L^* decreasing from shade A2 to D3 and higher b^* values corresponding to the same. Though the values of ΔE_{00} obtained are high, the shift in color was observed with the b^* values which could be due to the acrylic teeth contributing to a darker shade of the composite as the tooth shades became darker. This could have affected the way the composite material shifted toward its basic color, in accordance with an earlier study by I Bakti et al.[29] The overall high ΔE_{00} values, greater than the clinical threshold of 1.8, might be attributable to the use of acrylic teeth. It would be worthwhile to perform the same experiment on natural teeth in vivo. It is also important to note that purely "objective" color-measuring devices have been developed based on the visual response of the "standard observer"; therefore, they are good only if they match that response. Also, a numerically small ΔE value does not necessarily correspond to the best match because of the uneven eye sensitivity to hue, value, and chroma differences.[18]

The results obtained from the visual evaluation of shade match seem to concur with the instrumental evaluation in the finding that the performance of single-shade composite systems became unpredictable with a decrease in value and increase in the chroma of the acrylic teeth. This is in opposition to a previous study, where OM exhibited the most pronounced CAP (blended in the best) throughout the VITA shade range.[6] In this experiment, the size of the restoration was kept constant as opposed to a previous study by Paravina et al.[4] It might be interesting to perform a similar evaluation with a single-shade composite system to see if a decrease in the restoration size increases the BE of such a composite.

A contact spectrophotometer was used in this study on simulated clinical samples, which could contribute to the high ΔE_{00} values. Although the Easyshade V is not specifically recommended for reading shades on composite, it was the best instrument to get L^*, a^*, b^* readings on clinical size samples. The use of a non-contact spectrophotometer might have provided lower ΔE_{00} values closer to the threshold (1.8); however, the "trend" observed in the increase and decrease of the ΔE_{00} values from lighter to darker shades for the three composite materials was the highlight of this study. Also, though less accurate than a non-contact spectrophotometer, a contact spectrophotometer has been shown to perform comparably in precision.[30]

TS was graded as 1 by approximately 73% of the evaluators only for shade B2, which was striking because it was the only shade for which it performed the best. Since the evaluators were forced to grade each composite differently with no ties, this rigidity could explain this occurrence. The results may have been different had the evaluators been asked to just rate the samples as a "match" or a "mismatch."

Previous research has shown that the filler content, shape, and size have an effect on the color of the composite.[23,24,26] This occurs as some of the light is absorbed by the material while a part of it is reflected, which contributes to the color of the material. OM has been developed with a smart chromatic technology which, rather than relying on red and yellow pigments that are added to impart color, it uses the concept of structural color where the material itself weakens or amplifies specific wavelengths of light to blend in. OM is composed of 260 nm supranano-spherical fillers of silicon dioxide (SiO_2) and zirconium dioxide (ZrO_2). The red-to-yellow color from the material combines with the reflected color of the patient's surrounding dentition, to provide an ideal shade match for any tooth shade.[6]

The resin matrix has been said to have an effect on the translucency of the composite resin, with composites containing Bis-GMA being more translucent than those without.[25] Translucency has been positively correlated with BE.[4] Among the three composite materials used in this study, OM is the only one without Bis-GMA in its resin matrix (as interpreted from the individual safety data sheets), which could decrease its translucency and BE.

In the oral cavity, multiple factors influence the way shade match is perceived, including the morphology of the tooth, the area where the tooth is restored, the influence of the surrounding soft tissues, among other factors. In addition, natural teeth are polychromatic, multilayered, translucent, and curved, which affects the way light is reflected or scattered. All these factors may affect the way composite materials behave in vivo as well as how they are evaluated with an instrument.

Single and group shade composite resins have been introduced to streamline the process of shade matching. However, further research is required to evaluate their predictability, by using natural teeth in vivo and testing a wider range of shades.

5 | CONCLUSION

Within the limitations of this study, the following can be concluded:

1. Shade matching is composite material and shade-dependent.
2. In the instrumental evaluation, OM and TS exhibited lower ΔE_{00} values for lighter shades, whereas TE showed lower and similar ΔE_{00} values across all shades.
3. In the visual evaluation, TE exhibited the best shade match for darker shades C2 and D3. OM and TS matched better in the lighter shades A2, B1, and B2.

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REFERENCES

1. Joiner A. Tooth colour: a review of the literature. *J Dent*. 2004;32: 3-12.
2. Kim D, Park SH. Color and translucency of resin-based composites: comparison of A-shade specimens within various product lines. *Oper Dent*. 2018;43:642-655.
3. Johnston WM, Reisbick MH. Color and translucency changes during and after curing of esthetic restorative materials. *Dent Mater*. 1997; 13:89-97.

4. Paravina RD, Westland S, Imai FH, Kimura M, Powers JM. Evaluation of blending effect of composites related to restoration size. *Dent Mater J*. 2006;22:299-307.
5. Paravina RD, Westland S, Kimura M, Powers JM, Imai FH. Color interaction of dental materials: blending effect of layered composites. *Dent Mater J*. 2006;22:903-908.
6. Pereira Sanchez N, Powers JM, Paravina RD. Instrumental and visual evaluation of the color adjustment potential of resin composites. *J Esthet Restor Dent*. 2019;31:465-470.
7. 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;2016:1-8.
8. Burkinshaw SM. Colour in relation to dentistry. Fundamentals of colour science. *Brit Dent J*. 2004;196:33-41.
9. International Commission on Illumination (CIE). *Colorimetry—technical report*, 3rd ed. Commission Internationale de L'Eclairage, Bureau Central de la CIE, Vienna, CIE Pub. No. 15; 2004.
10. Luo MR, Cui G, Rigg B. The development of the CIE 2000 color difference formula: CIEDE2000. *Color Res Appl*. 2001;26:340-350.
11. 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.
12. Ghinea R, Pérez MM, Herrera LJ, et al. Color difference thresholds in dental ceramics. *J Dent*. 2010;38:57-64.
13. Perez MM, Saleh A, Yebra A, Pulgar R. Study of the variation between CIELAB ΔE^* and CIEDE2000 color-differences of resin composites. *Dent Mater J*. 2007;26:21-28.
14. Polo CG, Muñoz MP, Luengo ML, et al. Comparison of the CIELab and CIEDE2000 color difference formulas. *J Prosthet Dent*. 2016;115:65-70.
15. Perez MM, Ghinea R, Herrera LJ, et al. Dental ceramics: a CIEDE2000 acceptability thresholds for lightness, chroma and hue differences. *J Dent*. 2011;39:37-44.
16. Paravina RD, Ghinea R, Herrera LJ, et al. Color difference thresholds in dentistry. *J Esthet Restor Dent*. 2015;27:S1-S9.
17. Igiel C, Lehmann KM, Ghinea R, et al. Reliability of visual and instrumental color matching. *J Esthet Restor Dent*. 2017;29:303-308.
18. Chu SJ, Trushkowsky RD, Paravina RD. Dental color matching instruments and systems: review of clinical and research aspects. *J Dent*. 2010;38:2-16.
19. Dozić A, Kleverlaan CJ, El-Zohairy A, et al. Performance of five commercially available tooth color-measuring devices. *J Prosthodont*. 2007;16:93-100.
20. Kim-Pusateri S, Brewer JD, Davis EL, Wee AG. Reliability and accuracy of four dental shade-matching devices. *J Prosthet Dent*. 2009;101:193-199.
21. Klotz A-L, Habibi Y, Corcodel N, et al. Laboratory and clinical reliability of two spectrophotometers. *J Esthet Restor Dent*. 2018;30:1-5.
22. Sarafianou A, Kamposiora P, Papavasiliou G, Goula H. Matching repeatability and interdevice agreement of 2 intraoral spectrophotometers. *J Prosthet Dent*. 2012;107:178-185.
23. Suh YR, Ahn JS, Ju SW, Kim KM. Influences of filler content and size on the color adjustment potential of non-layered resin composites. *Dent Mater J*. 2017;36:35-40.
24. Arikawa H, Kanie T, Fujii K, et al. Effect of filler properties in composite resins on light transmittance characteristics and color. *Dent Mater J*. 2007;26:38-44.
25. Azzopardi N, Moharamzadeh K, Wood D, et al. Effect of resin matrix composition on the translucency of experimental dental composite resins. *Dent Mater J*. 2009;25:1564-1568.
26. Seyed Mostafa M. Effect of filler content on mechanical and optical properties of dental composite resins. In: Cuppoletti J, ed. *Metal, Ceramic and Polymeric Composites for Various Uses*. Europe: InTech Open; 2011.
27. Sharma G. The CIEDE2000 color-difference formula. Excel spreadsheet implementation of the CIEDE2000 color-difference formula (including test data). http://www.ece.rochester.edu/wgsharma/ciede2000/
28. Ishihara S. *Ishihara's Test for Color Blindness*. Tokyo, Japan: Kanehara & Co., Ltd.; 1993.
29. Bakti I, Santosa AS, Irawan B, Damiyanti M. Chameleon effect of nano-filled composite resin restorations in artificial acrylic teeth of various shades. *J Phys Conf Ser*. 2018;1073(5).
30. Hu X, Johnston WM, Seghi RR. Measuring the color of maxillofacial prosthetic material. *J Dent Res*. 2010;89:1522-1527.

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