Restor Dent Endod. 2023 Feb;48(1):e7
https://doi.org/10.5395/rde.2023.48.e7
pISSN 2234-7658·eISSN 2234-7666

Restorative Dentistry & Endodontics

Research Article

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Effects of surrounding and underlying shades on the color adjustment potential of a single-shade composite used in a thin layer

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Received: Aug 2, 2022
Revised: Oct 20, 2022
Accepted: Oct 21, 2022
Published online: Dec 29, 2022

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Funding
This study was supported by the Coordination for the Improvement of Higher Educational Personnel -, Brazil (grant CAPES/PROCAD #3001/2014, and Finance Code 001).

Conflict of Interest
No potential conflict of interest relevant to this article was reported.

Author Contributions
Conceptualization: Faria-e-Silva AL. Data curation: Barros MS, Silva PFD, Santana MLC,

ABSTRACT

Objectives: This study aimed to evaluate the surrounding and underlying shades' effect on the color adjustment potential (CAP) of a single-shade composite used in a thin layer.
Materials and Methods: Cylinder specimens (1.0 mm thick) were built with the Vittra APS Unique composite, surrounded (dual specimens) or not (simple specimens) by a control composite (shade A1, A2, or A3). Simple specimens were also built only with the control composites. Each specimen's color was measured against white and black backgrounds or the simple control specimens with a spectrophotometer (CIELAB system). The whiteness index for dentistry (WI_D) and translucency parameters (TP_{00}) were calculated for simple specimens. Differences (ΔE_{00}) in color between the simple/dual specimens and the controls were calculated. The CAP was calculated based on the ratios between data from simple and dual specimens.
Results: The Vittra APS Unique composite showed higher WI_D and TP_{00} values than the controls. The highest values of ΔE_{00} were observed among simple specimens. The color measurements of Vittra APS Unique (simple or dual) against the control specimens presented the lowest color differences. Only surrounding the single-shade composite with a shaded composite barely impacted the ΔE_{00}. The highest CAP values were obtained using a shaded composite under simple or dual specimens.
Conclusions: The CAP of Vittra APS Unique was strongly affected by the underlying shade, while surrounding this composite with a shaded one barely affected its color adjustment.

Keywords: Color; Composite resins; Dental materials; Dental restoration, Permanent; Esthetics, Dental

INTRODUCTION

Restoring anterior teeth with direct composites is challenging for clinicians mainly because the color stratification strongly impacts the final esthetic result [1,2]. In addition to the proper color selection, the stratification of a restoration also relies on the clinician's experience in understanding the relationship between composite translucency and the

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thickness of the applied layer [3-6]. Moreover, the shades of most commercially available composites are based on the Vitapan Classical shade guide, which covers only a small fraction of natural tooth colors [7]. However, the composite tends to adjust its color toward the dental hard tissues when the restoration takes place, compensating for small color differences [8-11]. The ability of a composite to change its color toward the surrounding structure is usually called its color adjustment potential (CAP). Moreover, the composite's translucency may also adjust to the remaining tooth structure [10].

Several restorative materials have been developed based on these concepts to reduce the technical sensitivity and facilitate esthetic restorations. Multi-shade universal composites are provided in a universal opacity and limited options of shades [9]. Therefore, although esthetic restorations can be obtained by using a single increment, the results still depend on the clinician's ability to adequately select the composite shade. However, single-shade composites have also been developed to eliminate the color selection step since adequate color matching is achieved with materials presenting enhanced CAP [8-13]. The color of regular composites is mainly based on the presence of pigments, which exchange energy with the incident light to determine the visualized color [14]. In contrast, color adjustment to the surrounding structure requires the composite to present some structural color and increased translucency [10,13,15-18].

Structural color can be defined as that produced by interactions between incident light and structured materials with different refractive indices [19]. In dentistry, structural color can be achieved by adding well-distributed spherical nano-fillers smaller than 380 nm (corresponding to the lower bound of wavelengths of visible light) to the composite [15]. This approach improves the material's CAP and allows color-matched restoration using single-shade composites. Moreover, color adjustment can also be related to the composite's translucency. More translucent resin-based materials allow the underlying substrate color to strongly affect the restoration's final color [10,17].

Single-shade composites can also be helpful in repairing esthetic restorations considering their improved ability to adjust the color of both surrounding and underlying composite layers. In resin restoration repairs, using single-shade composites with high CAP facilitates the restorative procedure by eliminating the shade selection step and could yield more predictable results. However, most studies evaluating the CAP of composites have used specimens with 2 mm or more of thickness, while thin composite layers are commonly used to repair restorations [11]. Additionally, the combined effect of underlying and surrounding shades on CAP values has barely been evaluated. Therefore, the present study aimed to evaluate the effect of the surrounding and underlying shades on the CAP of a single-shade composite. We hypothesized that both the surrounding and underlying shades would have a similar effect on CAP values.

MATERIALS AND METHODS

Experimental design

The single-shade Vittra APS Unique composite (FGM, Joinville, SC, Brazil) was evaluated in the present study. The independent variables were the composite shade (A1, A2, or A3) and the location where these shades were placed: 1) underlying, 2) surrounding, and 3) both (underlying and surrounding). The dependent variables evaluated were the color difference (ΔE_{00}) from the control composites and the CAP. The ΔE_{00} between the evaluated

Table 1. Monomeric composition and filler content of the evaluated resin composites

Material (manufacturer)	Monomers*	Fillers*
Vittra APS Unique (FGM, Joinville, SC, Brazil)	UDMA, TEGDMA	Silica and zirconia fillers
Forma (Ultradent, Indaiatuba, SP, Brazil)	Bis-GMA, TEGDMA, Bis-EMA, UDMA	Silica and zirconia fillers, and barium glass.

Bis-GMA, bisphenol A glycidylmethacrylate; Bis-EMA, ethoxylated bisphenol-A dimethacrylate; TEGDMA, triethylenglycol dimethacrylate; UDMA, urethane dimethacrylate.
*As provided by the manufacturers.

single-shade composite without any surrounding or underlying shade was also measured to calculate the CAP.

Production of specimens

Disc-shaped specimens were built-up with the evaluated composite surrounded (dual specimens) or not (simple specimens) by the control Forma composite (Ultradent, Indaiatuba, SP, Brazil). The manufacturers and the monomeric and filler composition of composites studied are presented in **Table 1**. Control composites (A1D, A2D, and A3D) were used to obtain 3 different surrounded shades. Simple specimens were also built using only each shade of the control composite. These simple specimens were used as underlying and control shades for the ΔE_{00} calculations.

Silicon matrixes with a 10-mm diameter and 1.0-mm depth were used to create the simple specimens. The composites were inserted in a single increment and polymerized for 40 seconds using the light-curing unit (LCU) Radii-Cal (SDI, Victoria, Australia). The irradiance reaching the specimens was approximately 800 mW/cm^2 since the LCU tip was placed approximately 2 mm from the specimens to allow the light to reach the entire surface. Three simple specimens were built for each composite shade of Forma used (A1D, A2D, and A3D), while 12 simple specimens were built-up for Vittra APS Unique. Of these 12 simple specimens, 9 were used to obtain dual specimens: 3 for each surrounding shade (Forma A1D, A2D, and A3D). For this purpose, the simple specimens were fixed in the center of another silicon matrix with a diameter of 24 mm and a depth of 1.0 mm. The empty area surrounding the cylinder of Vittra APS Unique was filled with the Forma composite at shades A1, A2, or A3. The Forma composite was polymerized with four 40-s photoactivations, with the position of the LCU tip changed between each photoactivation to cover the entire surface of the specimen.

Color readings

Color readings were carried out in triplicate using a spherical spectrophotometer (SP60; X-Rite, Grand Rapids, MI, USA). A spectrophotometer with an 8-mm-diameter reading aperture was used in reflectance mode. The observer angle was defined as 2°, and a D65 illuminant was used during the color measurements. The color of the simple specimens was determined over a black background of a grayscale (ColorChecker Grayscale; X-Rite). For Vittra APS Unique, the simple specimens were also placed over the control specimens before the color readings to define the effect of the underlying shade on the ultimate color. The color of the dual specimens was measured over a black background and control specimens (the same shade of the surrounding shade was used for the underlying composite). Finally, the color of simple specimens was also measured under a white background (ColorChecker Grayscale; X-Rite) to allow calculation of the translucency parameters (TP_{00}) of the materials. No coupling agent was placed between the specimen and the background.

Whiteness index and translucency parameter

The whiteness index for dentistry (WI_D) of composites was calculated using the color coordinates of simple specimens measured against a black background, since the equation was developed using this background color. The following equation was used [20]:

Equation 1: $WI_D = 0.551 \times L^* + 2.324 \times a^* + 1.1 \times b^*$

The difference in color coordinates of simple specimens measured against the black and white backgrounds was used to calculate the TP_{00} of the specimens [21]. The CIEDE2000 color difference was calculated with the following equation [22,23]:

Equation 2: $$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T \frac{\Delta C'}{K_C S_C} \frac{\Delta H'}{K_H S_H}}$$

Where ΔL′, ΔC′, and ΔH′ are the changes in luminosity, chroma, and hue, respectively. S_L, S_C, and S_H are the weighted functions for each component. K_L, K_C, and K_H are the weighted factors for lightness, chroma, and hue, respectively ($K_L = K_C = K_H = 1$). R_T is the interactive term between chroma and hue differences.

Actual color difference

The color of simple specimens of the Vittra APS Unique composite and controls (shaded composites) was measured against a black background. The color differences were calculated using the formula CIEDE 2000 according to equation 3 [22,23] and called ΔE_{00_1}.

Equation 3: $$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T \frac{\Delta C'}{K_C S_C} \frac{\Delta H'}{K_H S_H}}$$

Where ΔL′, ΔC′, and ΔH′ are the changes in luminosity, chroma, and hue, respectively. S_L, S_C, and S_H are the weighted functions for each component. K_L, K_C, and K_H are the weighted factors for lightness, chroma, and hue, respectively ($K_L = K_C = K_H = 1$). R_T is the interactive term between chroma and hue differences.

CAP

Three other color differences (ΔE_{00_2}) were calculated to make it possible to estimate CAP values according to the local where the Forma composite was placed (**Figure 1**):

Surrounding: For each shade (A1, A2, or A3), the color of the central area of the dual specimens, corresponding to the Vittra APS Unique composite, was measured against a black background. The difference between this last color and that of the shaded composites over black background was calculated ($\Delta E_{00\_2^*surrounding}$).

Underlying: Single specimens of the Vittra APS Unique composite were placed over the specimens of shaded composites (A1, A2, or A3) before the color measurement. Two shaded specimens (same shade) were superposed, and the color of the upper specimen was measured. For an underlying shade, the color difference between the Vittra APS Unique and the shaded composite was calculated ($\Delta E_{00\_2^*underlying}$).

https://doi.org/10.5395/rde.2023.48.e7

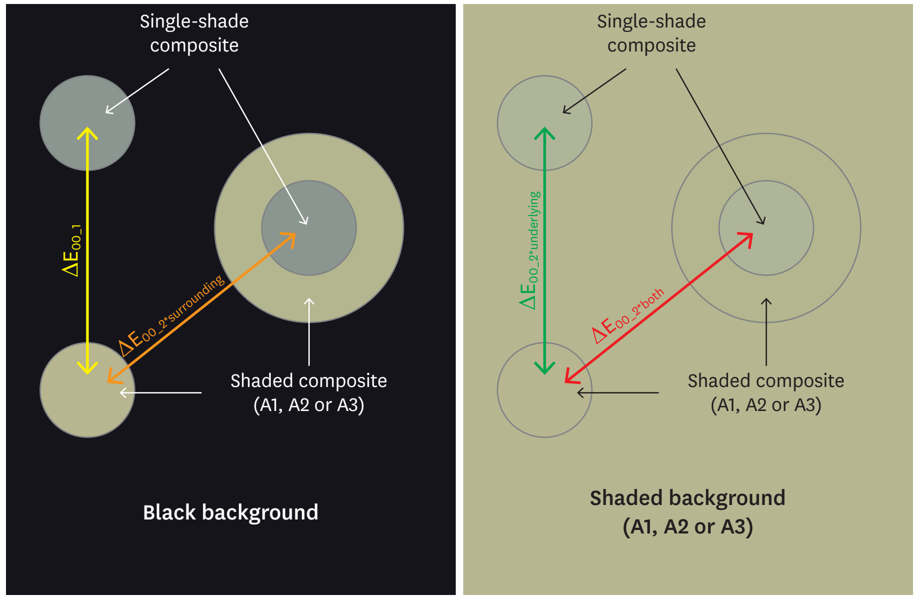

Figure 1. Schematic illustration showing the specimens` arrangement to calculate color differences. The actual color difference (yellow arrow: ΔE_{00_1}) among the composites was calculated by comparing the color of simple specimens built with shaded composites and with a single shade over a black background. Comparing the color of dual specimens with the shaded composites over a black background estimated the surrounding shade effect (orange arrow: ΔE_{00_2}*surrounding). The effect of the background (green arrow: ΔE_{00_2}*underlying) was estimated by comparing simple specimens of the shaded composites with those of the single shade. Finally, the combined impact of the background and surrounding shades (red arrow: ΔE_{00_2}*both) was calculated by the color difference between shaded composites and dual specimens measured over the shaded backgrounds.

Both: The color of the central area of the dual specimens was measured over a specimen of the shaded composite. The same surrounding shade was used for the underlying specimen. The difference between this color and that measured for the superposed shaded specimens was calculated (ΔE_{00_2*both}).

For each location where these shades were placed (underlying and/or surrounding), the CAP was calculated using the following equation [12]:

$$\text{Equation 4: } CAP = 1 - (\Delta E_{00\_2}/\Delta E_{00\_1})$$

Data analyses

The data were analyzed for a normal distribution (Shapiro-Wilk test) and homogeneity of variance (Levene's test). One-way analysis of variance (ANOVA) was used to analyze the WI_D and TP data. Two-way repeated-measures ANOVA was used to analyze the ΔE_{00} and CAP data. The independent variables were shade and location (i.e., where these shades were placed), defined as a repetition factor. Pairwise comparisons were performed using Tukey's test, and a significance level of 95% was set for all analyses.

RESULTS

Whiteness index and translucency parameter

One-way ANOVA showed that the composite significantly affected both WI_D ($p < 0.001$) and TP_{00} ($p < 0.001$), and the results are presented in **Table 2.** The whitest composite was Vittra APS Unique, followed by Forma shade A1D, and the darkest was Forma shade A3D. Regarding

https://doi.org/10.5395/rde.2023.48.e7

Table 2. Means (standard deviations) of the whiteness index and translucency parameters of composites

Composite	Outcome	
	WI_D*	TP_{00}
Forma		
A1D	33.0 (0.23)[B]	6.48 (0.48)[B]
A2D	29.3 (0.61)[C]	8.22 (0.98)[B]
A3D	22.2 (0.38)[D]	7.34 (0.22)[B]
Vittra APS Unique	40.9 (1.76)[A]	15.20 (2.12)[A]

WI_D, whiteness index for dentistry; TP_{00}, translucency parameter.
For each outcome, distinct letters indicate statistical differences in Tukey's test ($p < 0.05$).
*Measured over a black background.

the TP_{00}, Vittra APS Unique was the most translucent material, and no significant difference among the shades of the Forma composite was observed.

Color differences

Repeated-measures ANOVA demonstrated that both independent variables—shade ($p < 0.001$) and location ($p < 0.001$)—affected the values of ΔE_{00}, but the interaction between the factors was not significant ($p = 0.234$). The results are presented in **Figure 2**. Irrespective of the shade, the highest values were observed for ΔE_{00_1} followed by $\Delta E_{00\_2*surrounding}$. The smallest color discrepancies from the controls were observed for $\Delta E_{00\_2*underlying}$ and ΔE_{00_2*both}, and no significant difference was observed between them. For all delta values, the highest and lowest mismatches were observed for shades A3 and A1, respectively.

CAP

Location was the only independent variable that significantly ($p < 0.001$) affected the values of CAP. The p-values calculated by repeated-measures ANOVA for both shade ($p = 0.191$) and the interaction between shade and location ($p = 0.607$) were not significant. The results are presented in **Figure 3**. Regardless of the shade, the lowest CAP values were obtained when the control composite only surrounded the Vittra APS Unique composite. No significant difference was found between the underlying location and the underlying and surrounding location.

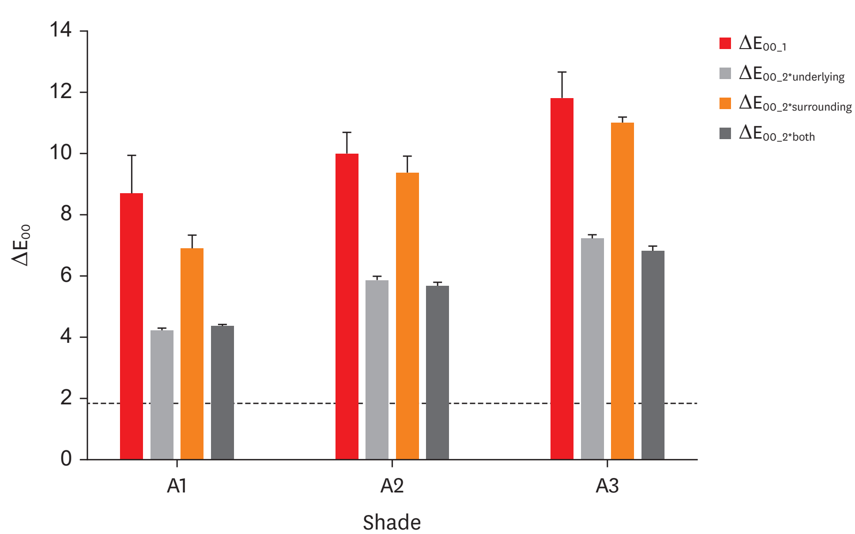

Figure 2. Mean values (with standard deviations) for the values of ΔE_{00} calculated for different comparisons and composite shades. For all shades, $\Delta E_{00\_1} > \Delta E_{00\_2*surrounding} > \Delta E_{00\_2*underlying} = \Delta E_{00\_2*both}$. Irrespective of the calculation arrangement, A3 > A2 > A2. The dashed horizontal line indicates the 50:50% acceptability threshold.

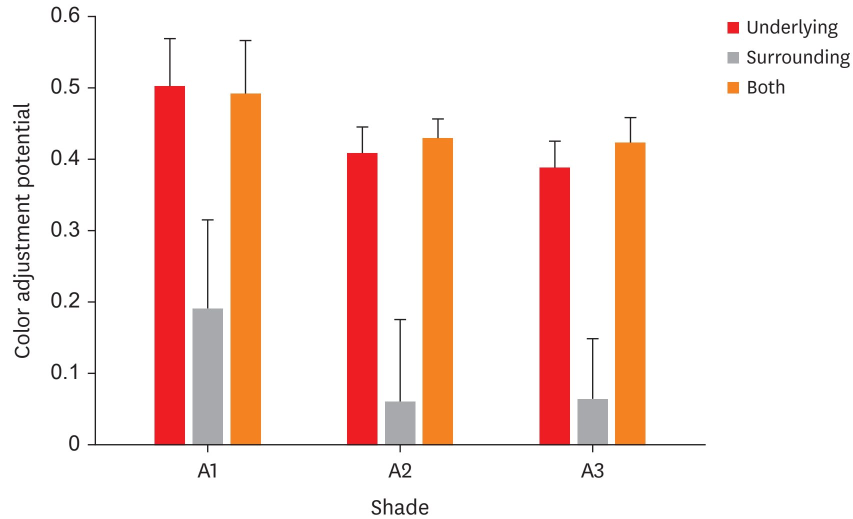

Figure 3. Mean values (with standard deviations) of color adjustment potentials calculated for different composite shades and the locations where these shades were placed. For all shades, underlying = both > surrounding. The shade did not affect the color adjustment potential values.

DISCUSSION

Esthetic restorations using direct composites are traditionally built using the stratification technique, which requires composites with different translucency levels (*e.g.*, dentin and enamel) and shades [1,2]. An additional clinical challenge using this technique is to define the thickness of each increment by combining opaquer and more translucent materials [6]. The development of universal composites facilitates this procedure since these materials present a single translucency [9]. However, the most promising change in the simplification of the restorative procedure was the development of single-shade materials, which eliminated the color selection step. Single-shade composites have been designed to increase their color adjustment ability. Consequently, improved matching between the composite and the surrounding substrate is expected. Then, single-shade composites could also be an interesting approach to repair defective resin restorations in esthetic areas when only a thin composite is sometimes used.

In the present study, the color of simple specimens built with either Vittra APS Unique or shaded composites was compared to determine the "true" color differences among these materials. In this scenario, any possible effect of the surrounding substrate on the ultimate color of specimens is eliminated. Then, using a standard black background permits a fair estimation of any color difference among the materials. The measured color of the Vittra APS Unique composite was whiter than those observed for all shaded composites. The difference between the averages of WI_D (7.8 units) calculated for Vittra APS Unique and the whitest shaded composite A1D was higher than the difference (5.9 units) defined as clinically unacceptable by a prior study [24]. It is essential to emphasize that the A1 shade is the second lightest tab in the Vita Classical shade guide. Usually, composites darker than that are required to obtain adequate color matching, and adequate esthetic restorations using Vittra APS Unique rely significantly on its CAP.

As expected, placing a shaded composite under or around the Vittra APS Unique specimens reduced their color discrepancy from the control specimens. Regardless of the shade, the reduction on ΔE_{00} caused by only using underlying shaded composites (−4.6 to −4.1) was more pronounced than that observed when placing the same composite around (−1.8 to −0.7) the Vittra APS Unique. Moreover, combining both approaches (−5.0 to −4.3) barely increased the color adjustment reached using only the underlying shaded composite. The reduction in ΔE_{00} values indicates improved color matching of the single-shade composite to the adjacent substrate. The CAP value is directly proportional to the color difference reduction, and the color adjustment for Vittra APS Unique relied mainly on the underlying shade. Therefore, the hypothesis of the study was rejected.

Matching the color of the composite to that of an adjacent substrate can be achieved based on the structural-color phenomenon or by increasing the material`s translucency [10,11,17]. In dentistry, structural color in resin composites has been reached by using 260 nm spherical fillers that generate a red-to-yellow color (*e.g.*, Omnichroma from Tokuyama Dental, Tokyo, Japan) [15,25]. Interestingly, the relationship between the refractive indexes of the organic matrix and filler contents affects both structural color and translucency [17]. While similar refractive indexes increase a composite`s translucency, the structural color becomes stronger as the refractive index of fillers exceeds that of the organic matrix. The manufacturer of Vittra APS Unique states that its color adjustment ability is due mainly to its translucency increasing after polymerization. The conversion of monomers to polymers tends to increase the refractive index of the organic matrix, reducing its mismatch with that of inorganic filler [26,27].

Vittra APS Unique barely adjusted its color to that of the surrounding substrate, since the CAP values as a function of underlying shade ranged from 0.19 (for A1D) to 0.06 (for other shades). The low values are similar to those observed for regular composites in a prior study [12]. However, the CAP values due to changing the background shade ranged from 0.39 (A3D) to 0.50 (A1D). Using shaded composites under and around the Vittra APS Unique resulted in CAP values from 0.42 (A3D) to 0.49 (AD1), showing that the surrounding color barely modified its color adjustment ability. Instead, its color adjustment ability was strongly dependent on the underlying shade. The TP_{00} measured for Vittra APS Unique was at least 7.0 units higher than the controls, which were developed to have a similar translucency to tooth dentin. This difference is more than 2-fold higher than the 50:50% acceptability threshold (2.62) [28], which demonstrates the high translucency of this single-shade composite.

The present study's findings show that the ultimate color obtained with the single-shade Vittra APS Unique composite used in a thin layer strongly depends on the underlying shade. When repairing a composite restoration, the shade of the remaining composite on the floor of the prepared cavity is usually similar to the required final color restoration. In this scenario, however, a thin layer of Vittra APS Unique resulted in ΔE_{00} of at least 4.3, which is higher than the 50:50% acceptability threshold [24]. Therefore, these results indicate that using the single-shade Vittra APS Unique to repair some defective restorations in esthetic areas is an unreliable approach. It is important to emphasize that no optical solution was placed between the specimen and the background. Different results could be observed when bonding a single-shade composite to the underlying older resin [29]. Furthermore, only a single material was evaluated in the present study, and the results cannot be extrapolated to other single-shade composites.

CONCLUSIONS

The present study's findings demonstrated that the CAP of a single-shade composite used in a thin layer was more strongly affected by the underlying shade than by the surrounding shade.

REFERENCES

1. Reis A, Higashi C, Loguercio AD. Re-anatomization of anterior eroded teeth by stratification with direct composite resin. J Esthet Restor Dent 2009;21:304-316.
   PUBMED | CROSSREF
2. Pontons-Melo JC, Furuse AY, Mondelli J. A direct composite resin stratification technique for restoration of the smile. Quintessence Int 2011;42:205-211.
   PUBMED
3. Olms C, Klinke T, Pirek P, Hannak WB. Randomized multi-centre study on the effect of training on tooth shade matching. J Dent 2013;41:1259-1263.
   PUBMED | CROSSREF
4. Sinmazisik G, Trakyali G, Tarcin B. Evaluating the ability of dental technician students and graduate dentists to match tooth color. J Prosthet Dent 2014;112:1559-1566.
   PUBMED | CROSSREF
5. Najafi-Abrandabadi S, Vahidi F, Janal MN. Effects of a shade-matching light and background color on reliability in tooth shade selection. Int J Esthet Dent 2018;13:198-206.
   PUBMED
6. Santos SM, Silva PD, Faria-E-Silva AL. Color changes caused by reduction on the dentin shade composite thickness. Braz Dent J 2018;29:469-474.
   PUBMED | CROSSREF
7. Ruiz-López J, Perez MM, Lucena C, Pulgar R, López-Toruño A, Tejada-Casado M, Ghinea R. Visual and instrumental coverage error of two dental shade guides: an in vivo study. Clin Oral Investig 2022;26:5961-5968.
   PUBMED | CROSSREF
8. Kobayashi S, Nakajima M, Furusawa K, Tichy A, Hosaka K, Tagami J. Color adjustment potential of single-shade resin composite to various-shade human teeth: Effect of structural color phenomenon. Dent Mater J 2021;40:1033-1040.
   PUBMED | CROSSREF
9. de Abreu JL, Sampaio CS, Benalcázar Jalkh EB, Hirata R. Analysis of the color matching of universal resin composites in anterior restorations. J Esthet Restor Dent 2021;33:269-276.
   PUBMED | CROSSREF
10. Durand LB, Ruiz-López J, Perez BG, Ionescu AM, Carrillo-Pérez F, Ghinea R, Pérez MM. Color, lightness, chroma, hue, and translucency adjustment potential of resin composites using CIEDE2000 color difference formula. J Esthet Restor Dent 2021;33:836-843.
    PUBMED | CROSSREF
11. Ismail EH, Paravina RD. Color adjustment potential of resin composites: Optical illusion or physical reality, a comprehensive overview. J Esthet Restor Dent 2022;34:42-54.
    PUBMED | CROSSREF
12. 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.
    PUBMED | CROSSREF
13. Lucena C, Ruiz-López J, Pulgar R, Della Bona A, Pérez MM. Optical behavior of one-shaded resin-based composites. Dent Mater 2021;37:840-848.
    PUBMED | CROSSREF
14. Brainard DH, Cottaris NP, Radonjić A. The perception of colour and material in naturalistic tasks. Interface Focus 2018;8:20180012.
    PUBMED | CROSSREF
15. Arai Y, Kurokawa H, Takamizawa T, Tsujimoto A, Saegusa M, Yokoyama M, Miyazaki M. Evaluation of structural coloration of experimental flowable resin composites. J Esthet Restor Dent 2021;33:284-293.
    PUBMED | CROSSREF
16. Saegusa M, Kurokawa H, Takahashi N, Takamizawa T, Ishii R, Shiratsuchi K, Miyazaki M. Evaluation of color-matching ability of a structural colored resin composite. Oper Dent 2021;46:306-315.
    PUBMED | CROSSREF

17. Oivanen M, Keulemans F, Garoushi S, Vallittu PK, Lassila L. The effect of refractive index of fillers and polymer matrix on translucency and color matching of dental resin composite. Biomater Investig Dent 2021;8:48-53.
PUBMED | CROSSREF
18. Kobayashi S, Nakajima M, Furusawa K, Tichy A, Hosaka K, Tagami J. Color adjustment potential of single-shade resin composite to various-shade human teeth: Effect of structural color phenomenon. Dent Mater J 2021;40:1033-1040.
PUBMED | CROSSREF
19. Kinoshita S, Yoshioka S, Miyazaki S. Physics of structural colors. Rep Prog Phys 2008;71:76401.
CROSSREF
20. Pérez MM, Ghinea R, Rivas MJ, Yebra A, Ionescu AM, Paravina RD, Herrera LJ. Development of a customized whiteness index for dentistry based on CIELAB color space. Dent Mater 2016;32:461-467.
PUBMED | CROSSREF
21. Johnston WM, Ma T, Kienle BH. Translucency parameter of colorants for maxillofacial prostheses. Int J Prosthodont 1995;8:79-86.
PUBMED
22. Luo MR, Cui BR, Rigg B. The development of the CIE 2000 colour-difference formula: CIEDE2000. Color Res Appl 2001;26:340-350.
CROSSREF
23. Sharma G, Wu W, Dalal EN. The CIEDE2000 color-difference formula: Implementation notes, supplementary test data, and mathematical observations. Color Res Appl 2005;30:21-30.
CROSSREF
24. Paravina RD, Ghinea R, Herrera LJ, Bona AD, Igiel C, Linninger M, Sakai M, Takahashi H, Tashkandi E, Perez MM. Color difference thresholds in dentistry. J Esthet Restor Dent 2015;27 Suppl 1:S1-S9.
PUBMED | CROSSREF
25. Yamaguchi S, Karaer O, Lee C, Sakai T, Imazato S. Color matching ability of resin composites incorporating supra-nano spherical filler producing structural color. Dent Mater 2021;37:e269-e275.
PUBMED | CROSSREF
26. Shortall AC, Palin WM, Burtscher P. Refractive index mismatch and monomer reactivity influence composite curing depth. J Dent Res 2008;87:84-88.
PUBMED | CROSSREF
27. Faria-E-Silva AL, Pfeifer CS. Impact of thio-urethane additive and filler type on light-transmission and depth of polymerization of dental composites. Dent Mater 2017;33:1274-1285.
PUBMED | CROSSREF
28. Salas M, Lucena C, Herrera LJ, Yebra A, Della Bona A, Pérez MM. Translucency thresholds for dental materials. Dent Mater 2018;34:1168-1174.
PUBMED | CROSSREF
29. Nogueira AD, Della Bona A. The effect of a coupling medium on color and translucency of CAD-CAM ceramics. J Dent 2013;41 Suppl 3:e18-e23.
PUBMED | CROSSREF