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Instrumental and visual evaluation of the color adjustment potential of different single-shade resin composites to human teeth of various shades

Hanife Altınışık[1] · Esra Özyurt[2]

Abstract

Objective The study aims to evaluate the color adjustment potential (*CAP-I*, *CAP-V*) of different single-shade resin composites.

Materials and methods The shades of 40 human incisors were determined using a spectrophotometer, with the teeth divided into four groups of the same shade ($n = 10$). The following single-shade resin composites were tested: Omnichroma, Charisma Diamond One, Vittra Unique, and Essentia Universal. The specimens were prepared as "dual" and "single." Standardized cavity preparations (diameter, 7 mm; depth, 2 mm) were prepared in human incisor teeth and then restored for dual specimens. Composite duplicates of human incisors were prepared with resin composites for single specimens ($n = 10$). The color match of these specimens to that of unrestored human incisors was compared, and the color difference (ΔE^*) was calculated. Independent observers conducted a visual evaluation of the specimens and scored them. *CAP-I* and *CAP-V* values were determined. A one-way analysis of variance test was used for statistical analysis ($p < 0.05$).

Results There was no statistically significant difference between the *CAP-V* and *CAP-I* values of the tested single-shade resin composites ($p > 0.05$). All the materials tested had acceptable color-matching potential.

Conclusions In terms of color matching, there were no significant differences between the different tooth shades of all the tested resin composites.

Clinical relevance Single-shade resin composites have acceptable *CAP*. The use of single-shade resin composites can reduce in-chair clinical times by minimizing the time spent on shade selection.

Keywords Color adjustment potential · Blending · Chameleon effect · Single shade · Resin composite

Introduction

Composite resin restorations are widely used today to fulfill the esthetic demands of patients due to developments in adhesive resin technologies [1]. However, there are a limited number of shades of resin composites, and it can be difficult to match the colors of these composites to those of a patient's teeth because multiple factors, such as tooth type, size, and age, influence tooth color [2]. Therefore, color-matching techniques, such as multilayer applications of various shades of composite resins and shade selection, are required [3]. The success of these techniques depends on the clinician's level of experience, and color matching requires more in-chair clinical time [4]. Composite resins and restorative techniques that can simplify clinical practice procedures are needed [5, 6].

In restorative dentistry, a phenomenon known as the "chameleon effect" (blending effect) refers to the ability of a material to obtain a similar color to its surrounding structures [7, 8]. This effect is believed to be caused by a color shift due to reflected light and the color of adjacent dental structures [9]. An advantage of single-shade composite resins as compared to group-shade composites, which have only a narrow range of colors, is their ability to simulate all

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shades [10]. Another advantage of single-shade composites is their enhanced color adjustment potential (*CAP*), which refers to the interaction between perceptual and physical components. As the perceptual component is subjective, it cannot be measured by any device and so is evaluated visually. The visual *CAP* (*CAP-V*) method is one of the simplest ways to quantify the color adjustment potential in clinical practice [11]. However, various clinician-related factors (e.g., technical expertise and color perception), patient-related factors (e.g., age, make-up, clothes color), and external factors (e.g., room lighting) can affect *CAP-V* values [11, 12]. The translucency of the resin composites can be evaluated using the instrumental *CAP* (*CAP-I*). A variety of color-measuring devices, such as spectrophotometers, colorimeters, spectroradiometers, or digital cameras, can be used for this purpose [11]. Various formulae have been proposed to evaluate color matching instrumentally in dentistry. The CIELAB is the most widely used for dental restorative materials and quantifies color in three spatial coordinates (*L**, *a**, and *b**) [13].

Sancez et al. [5] evaluated the *CAP* (*CAP-I* and *CAP-V*) of five composites: Omnichroma (Tokuyama Dental, Tokyo, Japan), Filtek Supreme Ultra (3 M, Saint Paul, MN, USA), TPH Spectra (Dentsply Caulk, Milford, DE, USA), Herculite Ultra (Kerr Corporation, Orange, CA, USA), and Tetric Evo-Ceram (Ivoclar Vivadent, Amherst, NY, USA) versus those of 16 VITA classical shades (A1–D4). They reported that the *CAP-I* and *CAP-V* of Omnichroma, which is a recently introduced single-shade resin composite, were better than those of the other composites. Omnichroma, a pigment-free universal resin composite, contains uniformly spaced and arranged spherical particles that facilitate light transmission throughout the restoration. Thus, the color of the restoration appears to match that of its surroundings, as the particle size and structure are designed in such a way that they increase translucency after polymerization [14]. The material's optical properties are attributed to the use of "smart chromatic technology," in which the material responds to light at a specific frequency [10]. Two other new single-shade composites, Charisma Diamond One (Heraeus Kulzer, Hanau, Germany) and Charisma Topaz One (Heraeus Kulzer, Hanau, Germany), incorporate "adaptive light matching," in which the correct shade is obtained by absorbing the light reflected from the tooth [15].

In the dental literature, only a limited number of studies have evaluated the color compatibility of single-shade composite resins with different properties and compared single-shade composite resins with each other [3–5, 7, 8]. Thus, this study aimed to evaluate and compare the *CAP* of different single-shade composite resins by *CAP-V* and *CAP-I* methods using human incisors of various shades to provide useful clinical information for dentistry professionals. The null hypothesis was that there would be no difference in the *CAP* of single-shade resin composites, regardless of the evaluation method.

Materials and methods

Specimen preparation and color measurements

Forty human central incisors extracted for periodontal reasons from patients aged 45–69 years and without any restoration were stored in water until the experiment. The research was approved by the Scientific Research Ethics Committee of Trakya University Faculty of Medicine (ethical protocol no.: 2022–124). Teeth with caries, cracks, demineralized surfaces, or opaque lesions were not included. The periodontal ligaments and gingival tissues were cleaned using a scalpel. Natural tooth shade was determined according to the VITA classical A1–D4 shade system in the base shade determination mode using a VITA Easyshade Compact V spectrophotometer (VITA Zahnfabrik, Bad Sackingen, Germany). The teeth were divided into four groups of teeth of the same shade ($n = 10$ in each group) (shade distribution: A1-2, A3-2, B1-2, C2-2, D2-2). In each tooth, the crown was separated from the root using a diamond cutting disk. The specimens were washed in an ultrasonic bath to eliminate residues on the enamel surface.

Four single-shade resin composites including various types of fillers were evaluated in this study. The details of these composites are listed in Table 1. Three types of specimens were prepared as follows: control (unrestored human central incisor tooth), single (human central incisor tooth replicated in the tested single-shade resin composites), and dual specimens (human central incisor tooth restored with the tested single-shade resin composites) (Fig. 1). In the single specimen group, each central incisor was replicated with the tested single-shade resin composites using a clear silicone mold ($n = 10$).

In the control specimen group (unrestored central incisors) and single specimen group (duplicated composite specimens), the teeth were embedded side by side in translucent acrylic resin. Removable plates were prepared on an acrylic block using an Essix plate (1.0 mm Essix C; Dentsply, FL, USA) on a vacuum press machine (Ministar, Scheu, Iserlohn, Nordrhein-Westfalen Germany) to standardize the color measurement site on the specimens. Standard windows ($R = 7$ mm) were then prepared on the plate corresponding to the areas to be measured on the specimens. Color measurements of each unrestored tooth (control specimens) were performed using a spectrophotometer with the aid of removable plates. The spectrophotometer was calibrated before each measurement.

In the dual specimen group, a standardized cavity (depth, 2 mm; diameter, 7 mm) was prepared in the

Table 1 Single-shade resin composites tested in this study

Resin composite	Manufacturer	Type	Organic matrix	Inorganic filler	Filler wt/vol
Omnichroma	Tokuyama, Tokyo, Japan	Supra-nano spherical	UDMA, TEGDMA	260 nm spherical SiO_2-ZrO_2	79/68
Charisma Diamond One	Kulzer, Germany	Nanohybrid	TCD-Urethaneacrylate, UDMA, TEGDMA	Barium Aluminium Boro Fluor Silicate Glass, 5 nano mikron-20 mikron	80/64
Vittra Unique	FGM, Joinville, SC, Brazil	Nanohybrid	UDMA, TEGDMA	Active ingredients: photoinitiator composition (APS), co-initiators, stabilizer and silane. Inactive ingredients: The nanospheres of a complex of silica-zirconia	72–80/60
Essentia Universal	GC Corporation, Tokyo, Japan	Microhybrid	UDMA, Bis-EMA, Bis-GMA, Bis- MEPP, TEGDMA	17 μm prepolymerized filler (strontium glass + lanthanoid fluoride) 16 μm silica, 0,85 μmFAlSi glass, 16 μm fumed silica	81/-

UDMA, urethane dimetacrylate; *TEGDMA*, triethylene glycol dimethacrylate; *Bis-GMA*, bisphenol A diglycidylmethacrylate; *Bis-EMA*, bisphenol A polyethylene glycol diether dimetacrylate; *Bis-MEPP*, 2,2-bis 4-methacryloxypolyethoxyphenyl propane; *TCD-Urethaneacrylate*, Tricyclodecane-Urethaneacrylate
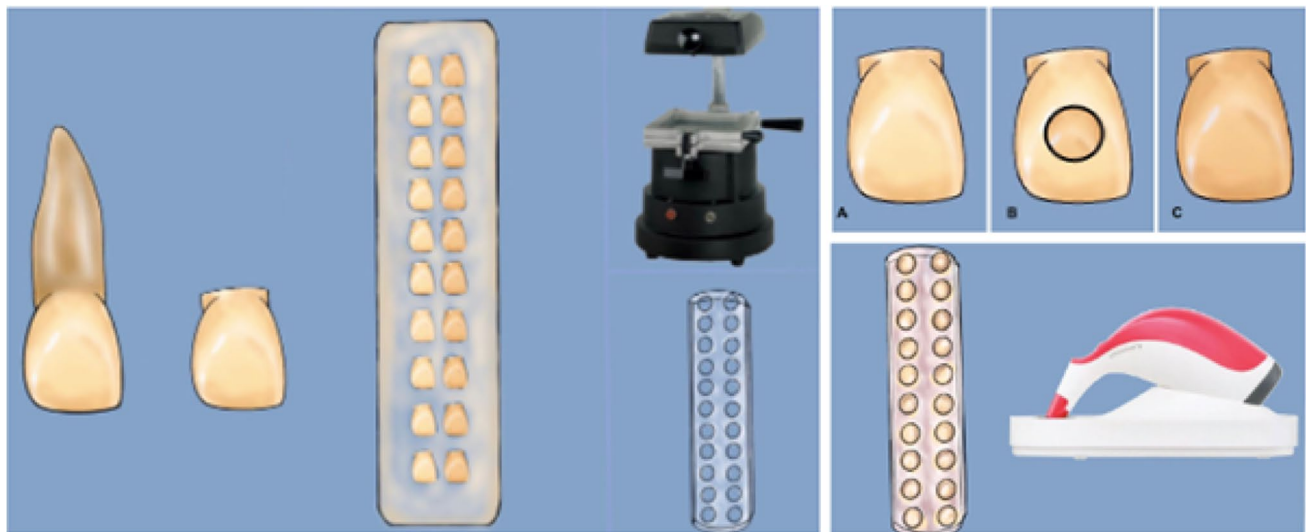

Fig. 1 Specimen preparation and types. **A** Control specimen—Unrestored human central incisor tooth (control specimen). **B** Dual specimen—human central incisor tooth restored with tested single shade resin composites. **C** Single specimen—human central incisor tooth replicated in tested resin composites

mid-facial aspect of each tooth using a diamond fissure bur (ISO806314, 014, Hager & Meisinger GmbH, Neuss, Germany) and a water-cooled electric high-speed handpiece. A new bur was used for each preparation. The windows on the removable plates were used as a guide to standardize the tooth preparations, and dimensions were verified using a digital caliper (Teknikel, Istanbul, Turkey). The preparations were rinsed with an air–water spray and gently dried with compressed air. A bonding agent (GLUMA Bond Universal; Heraeus Kulzer, Hanau, Germany) was then applied to the cavities, and they were restored using the tested single-shade resin composites and polymerized for 20 s using an LED light device (D-Light Pro; GC Corporation, Tokyo, Japan). Subsequently, the dual and single

specimens were polished with a two-step finishing and polishing system (Clearfil Twist Dia; Kuraray, Tokyo, Japan).

Instrumental evaluation

For the dual specimens, the final color measurements were made on the restoration's surfaces. For the single specimens, the final color measurements were made on the duplicated resin composite surface (Fig. 2). In the CIELAB system, ΔL^* corresponds to brightness, a^* is the red-green coordinate, and b^* is the difference in the yellow-blue coordinate The color differences were calculated as follows:

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

where ΔE^*_{DUAL} is the color difference between the non-restored human central incisors and dual specimens in which a human central incisor was restored with the tested single-shade resin composites, and $\Delta E^*_{\text{SINGLE}}$ is the color difference between the non-restored human central incisors and single specimens reproduced with the tested single-shade resin composites.

CAP-I was calculated as follows:

$$CAP - I = 1 \left(\Delta E^*_{\text{DUAL}} / \Delta E^*_{\text{SINGLE}} \right)$$

Visual evaluation

Visual color evaluations were performed by 10 restorative dentistry specialists, all of whom were tested for color blindness prior to the evaluations using Ishihara's color blindness test [16]. The observers were asked to score the color match of each single-shade resin composite restoration to that of human teeth of various shades (Fig. 2). All the evaluations were conducted under natural light conditions. The specimens were placed on a neutral gray paper under consistent clinical illumination at a 90° angle to the specimen's surface. The time allowed for the evaluation was 25 s. To avoid eye strain, the evaluators were asked to look at a neutral blue paper after each evaluation. Color differences were given a score of 0 to 4 as follows: 0 = an excellent color match, 1 = a very good color match, 2 = not a very good color match (border zone mismatch), 3 = an obvious mismatch, and 4 = a significant mismatch.

CAP-V was calculated as follows:

$$CAP - V = 1 - \left(V_{\text{DUAL}} / V_{\text{SINGLE}} \right),$$

where V_{DUAL} is the visual rating between the non-restored human central incisors and dual specimens in which a human central incisor was restored with a tested single-shade resin composite, and V_{SINGLE} is the visual rating between the non-restored human central incisors and single specimens reproduced with the tested single-shade resin composite.
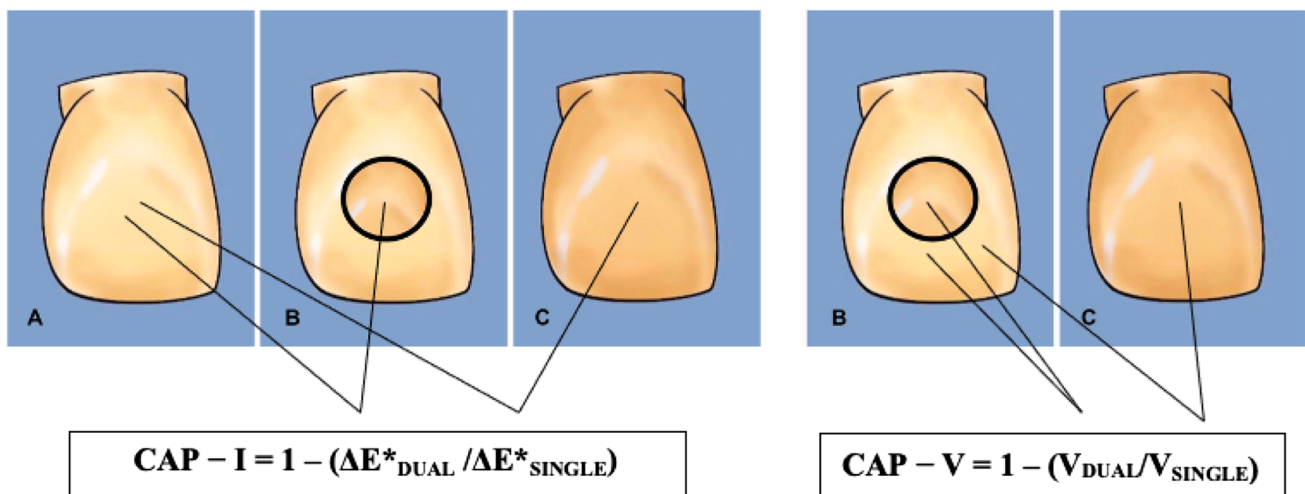

Fig. 2 Specimen scheme. Instrumental (*CAP-I*) and visual (*CAP-V*) color adjustment potential equation (where ΔE^*_{DUAL} is the color difference between non-restored human central incisors and dual specimen in which a human central incisor was restored with tested single-shade resin composites, $\Delta E^*_{\text{SINGLE}}$ is the color difference between non-restored human central incisors and single specimen reproduced with the tested single shade resin composites, V_{DUAL} is the visual rating between non-restored human central incisors and dual specimen in which a human central incisor was restored with a tested single shade resin composite, and V_{SINGLE} is the visual rating between non-restored human central incisors and single specimen reproduced with the tested single shade resin composite) and measurement areas

Statistical analysis

The statistical analysis was performed using the SPSS 22 program (IBM Corp., Armonk, NY, USA). Kolmogorov–Smirnov and Shapiro–Wilk's tests were used to evaluate the normality of the data distribution. A one-way analysis of variance test was used to compare parameters between groups. Dunn's test and the Kruskal–Wallis test were used to compare the distribution of data that did not have a normal distribution. Correlation analysis was performed to determine the relationships between the parameters ($p < 0.05$).

Results

The mean color differences (ΔE^*) and standard deviations for the dual and single specimens and associated *CAP-I* values are shown in Table 2. The performance of the tested single-shade composite resins was analyzed instrumentally with the shade of human teeth. For effective blending, a *CAP* value of 0.20 was accepted as the threshold, as this value corresponds to a 20% ΔE^* reduction in the double column compared to the single column in Table 2. The *CAP-I* of the tested single-shade composite resins ranged from 0.34 to 0.43. All materials had acceptable color-matching potential, with *CAP-I* values greater than 0.20. There was no statistically significant difference between the *CAP-I* values of the tested single-shade composite resins.

The visual ratings and standard deviations for the dual and single specimens and the associated *CAP-V* are shown in Table 3. Similar to the *CAP-I*, when the performance of the tested single-shade composite resin was visually analyzed according to tooth shade, a *CAP* value of 0.20 (corresponding to a 20% ΔV reduction in the double column compared to the single column in Table 3) was adopted as a threshold for effective blending. The *CAP-V* of the tested single-shade composite resins ranged from 0.43 to 0.53. All the materials

Table 2 Mean and standard deviations of color differences among single and dual specimens and instrumental color adjustment potential (CAP-I)

	ΔE^*_{DUAL}	$\Delta E^*_{\text{SINGLE}}$	CAP-I
Omnichroma	5.43 ± 1.04^a	8.21 ± 0.36^a	0.34 ± 0.13^a
Charisma Diamond One	5.25 ± 0.55^a	8.11 ± 0.59^a	0.35 ± 0.05^a
Vittra Unique	4.75 ± 1.09^{ab}	744 ± 1.14^a	0.37 ± 0.11^a
Essentia Universal	3.17 ± 1.72^b	5.25 ± 1.36^b	0.43 ± 0.22^a
p	0.008*	0.000*	0.717

Kruskal–Wallis's test

*$p < 0.05$

Different letters in the columns indicate the difference between groups

Table 3 Visual scoring and standard deviations among dual and single specimens and visual color adjustment potential (CAP-V)

	V_{DUAL}	V_{SINGLE}	CAP-V
Omnichroma	1.24 ± 0.40^a	2.22 ± 0.39^a	0.43 ± 0.17^a
Charisma Diamond One	1.60 ± 0.29^a	2.95 ± 0.51^b	0.44 ± 0.14^a
Vittra Unique	1.46 ± 0.80^a	2.85 ± 0.50^b	0.47 ± 0.30^a
Essentia Universal	1.12 ± 0.46^a	2.52 ± 0.53^{ab}	0.53 ± 0.21^a
p	0.187	0.008*	0.712

One-way ANOVA test

*$p < 0.05$

Different letters in the columns indicate the difference between groups

had acceptable color-matching potential, with *CAP-V* values greater than 0.20. There was no statistically significant difference between the *CAP-V* values of the tested single-shade composite resins.

Discussion

Different factors, such as color properties (lightness, chroma, and hue) and translucency, affect the color appearance of composite resins [9]. In addition, the light diffusion and transmission properties of resin composites, enamel margin configuration, and age of the tooth may lead to a color shift in resin composite restorations [17–20]. Clinically, color differences between a tooth and a composite resin restoration are less perceptible when viewed together than when viewed separately [21]. The color appearance of restorations is improved when composite resins assimilate the color of the surrounding tooth structures [22]. This phenomenon, known as the "chameleon effect," is commonly used, together with blending [23]. Blending has physical and perceptual components. The interaction between them denotes the CAP [5]. In previous studies that determined the threshold for effective blending, the authors assumed that the highest value represented the best CAP [5, 12]. In this study, the $\Delta E^*_{\text{SINGLE}}$ values between the single specimens and non-restored teeth ranged from 5.25 to 8.21, and the ΔE^*_{DUAL} values between the dual specimens and non-restored teeth ranged from 3.17 to 5.43. The reduction of the ΔE^*_{DUAL} value compared to that of the $\Delta E^*_{\text{SINGLE}}$ value is a good illustration of the importance of blending and CAP in esthetic dentistry.

Previous studies reported that patient age affected both tooth shade and the CAP of composite resins, as the physiological aging process causes changes in the light transmission properties of dentin [18, 24]. Thus, in the present study, we evaluated the shades of incisors extracted from patients aged 45–69 years for periodontal reasons and formed experimental groups composed of equal numbers of teeth of the

same shade in each group (shade distribution: A1-2, A3-2, B1-2; C2-2, D2-2). The results obtained in this study showed that all the tested single-shade composite resins exhibited CAP-I and CAP-V. This finding can be attributed to the high translucency of the single-shade composite resins. As a result, they reflected the shades of the surrounding cavity walls, although the teeth used were of different shades and translucencies. The null hypothesis of the present study was accepted, as there was no significant difference in the CAP-I and CAP-V of the single-shade composite resins.

A previous study found that the blending effect increased in accordance with an increase in translucency [24]. Studies on Bis-GMA and UDMA/TEGDMA-based resins found that Bis-GMA has higher translucency, finding a positive correlation between the amount of Bis-GMA in the composite resin and its translucency [25, 26]. A study also revealed that a positive correlation was found between the amount of Bis-GMA in the composite resin and its translucency [25]. Suh et al. [27] reported a positive relationship between the filler content and the blending effect. In their study, when the filler size remained unchanged, the increase in the blending effect of composite resins was remarkable, especially when the filler content reached 80%. The filler contents of the single-shade composite resins in this study varied between 79 and 81 wt%, according to the manufacturers' reports. Essentia Universal contains Bis-GMA monomer in its resin matrix and a filler content of more than 80 wt%. According to an earlier study, the color-matching abilities of experimental composites improved with an increase in the filler content [13]. This may explain the higher *CAP-I* of Essentia Universal as compared to that of the other single-shade composite resins, although the finding was not statistically significant.

The color of an object is perceived differently, depending on the wavelengths that are reflected and absorbed by the object. When a light beam hits an object, some wavelengths are absorbed, and other wavelengths are reflected from the surface or in deeper layers for translucent objects. The reflected wavelengths make up the perceived color [5]. The perception of color is complex due to the various factors that affect its appearance. In terms of tooth color perception, these factors include the angle at which the tooth is viewed: lighting conditions; tooth shade, surface roughness, and surface gloss; and the optical properties of the material itself [5, 13, 22, 23, 28]. The size and shape of resin composite fillers determine the final surface properties of restorations [29]. Removing filler particles by polishing can leave small or large defects, depending on filler size [30, 31] The tested single-shade composite materials in this study had different filler sizes. Omnichroma contains uniformly spaced and arranged supra-nano spherical particles, Charisma Diamond One and Vittra Unique are considered nanohybrid composites, and Essentia Universal is a microhybrid. As reported previously, nanofilled and nanohybrid resin composites have superior polish and gloss retention properties compared with those of traditional microhybrid resin composites [30]. According to Suh et al. [27], the filler content affects the blending effect of composite resins more strongly than the filler size. Chen et al. [32] reported that Essentia Universal showed improved diffuse transmission and straight-line transmission properties, thus facilitating shade matching with reflection from both the cavity floor and cavity walls. This may explain the higher CAP-V of Essentia Universal compared to that of the other single-shade composite resins in this study, although the finding was not statistically significant.

Omnichroma does not contain pigments, according to the manufacturer, and its color properties are based on its structural properties and smart chromatic technology that controls the optical properties of the composite resin [5]. The uniform spacing and arrangement of the spherical particles of Omnichroma facilitate light transmission throughout the restoration. Thus, the composite reflects the color of the cavity surrounding the restoration and results in improved blending [5]. The translucency of Omnichroma increases after polymerization due to the difference in the refractive index of the monomers before and after polymerization [5]. A study that compared the color qualities and translucency adjustment potential of Omnichroma with two other popular brands of composite resins confirmed the positive blending effect of Omnichroma [9]. These findings are consistent with the results of the present study.

In recent years, composite resin restorative materials have been modified using Advanced Polymerization System (APS) technology to achieve better performance. The application of APS technology improves the properties of composite resins by increasing the degree of conversion and bond strength while enhancing the esthetic quality of the profile [33, 34]. Pedrosa et al. [35] reported that the Vittra Unique APS, which features a combination of different photoinitiators, increases the material's translucency after polymerization due to minimal differences in the refractive index of the matrix and filler particles during photopolymerization. Charisma Diamond One (Heraeus Kulzer), which utilizes "adaptive light matching," in which the shade is obtained by absorbing light reflected from the tooth [15], is composed of urethane methacrylates, which cause a decrease in the refractive index as the size of the side alkyl chain increases [36]. According to the literature, this causes an increase in translucency after curing [35]. These findings support the results of our study, as the blending effect increased with increasing translucency.

The present in vitro study shows that single-shade composite resins exhibit acceptable CAP to human incisor teeth of various shades. The findings of this study can partially fill the data gap on the use of new-generation single-shade composites in the restoration of human teeth in various shades.

Further research is required to analyze various parameters, such as translucency parameter, optical scatter, and color stability, of single-shade composites. In addition, clinical trials are required to apply the results of this in vitro analysis.

Conclusion

In the present study, there was no significant difference between the CAP-I and CAP-V values of the tested single-shade composite resins. Within the limitations of this study using extracted human teeth of different shades, we conclude that all the tested single-shade composite resins show positive *CAP-I* and *CAP-V*.

Declarations

Conflict of interest The authors declare no competing interests.

References

1. Sidhu SK, Ikeda T, Omata Y, Fujita M, Sano H (2006) Change of color and translucency by light curing in resin composites. Oper Dent 31(5):598–603
2. Joiner A (2004) Tooth colour: a review of the literature. J Dent 32(Suppl 1):3–12
3. Kobayashi S, Nakajima M, Furusawa K, Tichy A, Hosaka K, Tagami J (2021) Color adjustment potential of single-shade resin composite to various-shade human teeth: effect of structural color phenomenon. Dent Mater J 40(4):1033–1040
4. de Abreu JLB, Sampaio CS, Benalcázar Jalkh EB, Hirata R (2021) Analysis of the color matching of universal resin composites in anterior restorations. J Esthet Restor Dent 33(2):269–276
5. Pereira Sanchez N, Powers JM, Paravina RD (2019) Instrumental and visual evaluation of the color adjustment potential of resin composites. J Esthet Restor Dent 31(5):465–470
6. Oivanen M, Keulemans F, Garoushi S, Vallittu PK, Lassila L (2021) The effect of refractive index of fillers and polymer matrix on translucency and color matching of dental resin composite. Biomater Investig Dent 8(1):48–53
7. Iyer RS, Babani VR, Yaman P, Dennison J (2021) Color match using instrumental and visual methods for single, group, and multi-shade composite resins. J Esthet Restor Dent 33(2):394–400
8. Paravina RD, Westland S, Johnston WM, Powers JM (2008) Color adjustment potential of resin composites. J Dent Res 87(5):499–503
9. Durand LB, Ruiz-López J, Perez BG, Ionescu AM, Carrillo-Pérez F, Ghinea R, Pérez MM (2021) Color, lightness, chroma, hue, and translucency adjustment potential of resin composites using CIEDE2000 color difference formula. J Esthet Restor Dent 33(6):836–843
10. Lucena C, Ruiz-López J, Pulgar R, Della Bona A, Pérez MM (2021) Optical behavior of one-shaded resin-based composites. Dent Mat 37(5):840–848
11. Choi J-H, Park J-M, Ahn S-G, Song K-Y, Lee M-H, Jung J-Y, Wang X (2010) Comparative study of visual and instrumental analyses of shade selection. J Wuhan Univ Technoly-Mat Sci Ed 25(1):62–67
12. Akgül S, Gündoğdu C, Bala O (2022) Effects of storage time and restoration depth on instrumental color adjustment potential of universal resin composites. J Oral Sci 64(1):49–52
13. Arai Y, Kurokawa H, Takamizawa T, Tsujimoto A, Saegusa M, Yokoyama M, Miyazaki M (2021) Evaluation of structural coloration of experimental flowable resin composites. J Esthet Restor Dent 33(2):284–293
14. Ismail EH, Paravina RD (2021) Color adjustment potential of resin composites optical illusion or physical reality, a comprehensive overview. J Esthet Restor Dent 34(1):42–54
15. Kulzer GmbH. Charisma diamond/topaz one shade technical report. https://www.kulzer-turkey.com/charisma-diamond-topaz-one
16. Ishihara S. (1985) Ishihara's test for colour-blindness: Kanehara Shuppan Company
17. Tsubone M, Nakajima M, Hosaka K, Foxton RM, Tagami J (2012) Color shifting at the border of resin composite restorations in human tooth cavity. Dent Mater 28(8):811–817
18. Tanaka A, Nakajima M, Seki N, Foxton RM, Tagami J (2015) The effect of tooth age on colour adjustment potential of resin composite restorations. J Dent 43(2):253–260
19. Aida A, Nakajima M, Seki N, Kano Y, Foxton RM, Tagami J (2016) Effect of enamel margin configuration on color change of resin composite restoration. Dent Mater J 35(4):675–683
20. Kano Y, Nakajima M, Aida A, Seki N, Foxton RM, Tagami J (2018) Influence of enamel prism orientations on color shifting at the border of resin composite restorations. Dent Mater J 37(2):341–349
21. Hall NR, Kafalias MC (1991) Composite colour matching: the development and evaluation of a restorative colour matching system. Aust Prosthodont J 5:47–52
22. Hatayama T, Kano Y, Aida A, Chiba A, Sato K, Seki N, Hosaka K, Foxton RM, Tagami J, Nakajima M (2020) The combined effect of light-illuminating direction and enamel rod orientation on color adjustment at the enamel borders of composite restorations. Clin Oral Invest 24(7):2305–2313
23. Trifkovic B, Powers JM, Paravina RD (2018) Color adjustment potential of resin composites. Clin Oral Invest 22(3):1601–1607
24. Paravina RD, Westland S, Imai FH, Kimura M, Powers JM (2006) Evaluation of blending effect of composites related to restoration size. Dent Mater 22(4):299–307
25. Azzopardi N, Moharamzadeh K, Wood DJ, Martin N, van Noort R (2009) Effect of resin matrix composition on the translucency of experimental dental composite resins. Dent Mater 25(12):1564–1568
26. Miletic V, Jakovljevic N, Manojlovic D, Marjanovic J, Rosic AA, Dramićanin MD (2017) Refractive indices of unfilled resin mixtures and cured composites related to color and translucency of conventional and low-shrinkage composites. J Biomed Mater Res B Appl Biomater 105(1):7–13

27. Suh YR, Ahn JS, Ju SW, Kim KM (2017) Influences of filler content and size on the color adjustment potential of nonlayered resin composites. Dent Mater J 36(1):35–40

28. Kakaboura A, Fragouli M, Rahiotis C, Silikas N (2007) Evaluation of surface characteristics of dental composites using profilometry, scanning electron, atomic force microscopy and glossmeter. J Mater Sci Mater Med 18(1):155–163

29. Guler S, Unal M (2018) The evaluation of color and surface roughness changes in resin based restorative materials with different contents after waiting in various liquids: an SEM and AFM study. Microsc Res Tech 81(12):1422–1433

30. Sang EJ, Song JS, Chung SH, Jin BH, Hyun HK (2021) Influence of a new polishing system on changes in gloss and surface roughness of resin composites after polishing and brushing. Dent Mater J 40(3):727–735

31. Hosoya Y, Shiraishi T, Odatsu T, Nagafuji J, Kotaku M, Miyazaki M, Powers JM (2011) Effects of polishing on surface roughness, gloss, and color of resin composites. J Oral Sci 53(3):283–291

32. Chen F, Toida Y, Islam R, Alam A, Chowdhury A, Yamauti M, Sano H (2021) Evaluation of shade matching of a novel supra-nano filled esthetic resin composite employing structural color using simplified simulated clinical cavities. J Esthet Restor Dent 33(6):874–883

33. Geha O, Inagaki LT, Favaro JC, González AHM, Guiraldo RD, Lopes MB, Berger SB (2021) Effect of chemical challenges on the properties of composite resins. Int J Dent 2021:4895846

34. Basílio M, Gregorio R, Câmara JV, Serrano L, Campos PR, Pierote JJ, Groisman S, Pereira G, Barreto S (2021) Influence of different photoinitiators on the resistance of union in bovine dentin: experimental and microscopic study. J Clin Exp Dent 13(2):e132–e139

35. Pedrosa MDS, Nogueira FN, Baldo VO, Medeiros IS (2021) Changes in color and contrast ratio of resin composites after curing and storage in water. Saudi Dent J 33(8):1160–1165

36. Fugolin AP, de Paula AB, Dobson A, Huynh V, Consani R, Ferracane JL, Pfeifer CS (2020) Alternative monomer for BisGMA-free resin composites formulations. Dent Mater 36(7):884–892