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COLOR MATCHING OF SINGLE-SHADE COMPOSITE COMPARED TO MULTI-SHADE COMPOSITE AFTER AGING AND BLEACHING: AN IN VITRO STUDY

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ABSTRACT

Materials and methods: A total of 40 human sound premolars were randomly divided into two groups according to the materials' assignment either; single-shade or multi-shade composite (n=20), then each group was divided into two subgroups according to the storage medium either; distilled water or coffee (n=10) and then each subgroup was divided into two classes according to the shade either; A2 or A3 (n=5). Circular class V cavities were prepared on labial surfaces of each tooth and teeth were restored using either composites according to the manufacturers' instructions. The color of each tooth and restoration was recorded using VITA Easyshade V following aging and bleaching. The shade difference between the restoration and the tooth was calculated.

Results: Intergroup comparison of ΔE and ΔE_{00} between both composites have shown significant difference at baseline, one day and 12 days ($P \leq 0.05$) within both storage media and shades. Intragroup comparison of ΔE and ΔE_{00} within Omnichroma or Filtek Z350XT have shown statistically significant effect of time on ΔE ($P \leq 0.016$). Intergroup comparison of ΔE and ΔE_{00} between both composites have shown statistically significant difference before bleaching, immediately after bleaching and after two weeks ($P \leq 0.05$) within both shades. Intragroup comparison within Omnichroma or Filtek Z350XT have shown statistically significant difference between different time periods ($P \leq 0.016$).

Conclusions: Multi-shade composite showed superior immediate shade matching ability as compared to the single-shade one. Both materials showed low color stability following aging and poor color matching after bleaching.

KEYWORDS Single-shade; multi-shade; color difference; color blending; bleaching

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INTRODUCTION

Resin composites are commonly used in dentistry as tooth-colored direct aesthetic restorative materials, due to increased aesthetic demands, clinicians are challenged to replicate the color of natural teeth[1,2]. Color has three dimensions, namely hue, chroma, and value, which are used to describe the shades of commercially available resin composites[3]. The presence of multi-shade systems may complicate the color matching process and increase chairside time and costs [4,5]. To label the shade of their products, most resin composites manufacturers use the VITA classical shade system (VITA Zahnfabrik, Sackingen, Germany), the letters A, B, C, and D represent the hue, while the numbers 1, 2, 3, and 4 represent the chroma and value [6].

Universal shade resin composite restoration with color adjustment, blending, shifting, and assimilation potentials has been developed to replace different shades and provide shade matching for all tooth colors [7, 8]. The capacity of resin composite materials to adjust their color to the color of surrounding enamel and dentin is described in esthetic dentistry by the term "chameleon effect" [5].

Omnichroma single-shade composite was recently developed to match all Vita classic shades from A1 to D4 with the highest visual color adjustment potential when compared to multi-shade composite systems [9]. It was claimed that Omnichroma possesses the ability to blend in with surrounding enamel and dentin even after bleaching, improving aesthetics and simplifying the shade matching procedure [10]. However, in previous trials Omnichroma was inferior to multi-shade composite systems in shade matching ability, which may hinder their use in highly aesthetically demanding areas[5]. The color stability and shade matching of resin composites is one of the most important factors determining the clinical longevity of aesthetic restorations, particularly in anterior teeth [11].

A significant disadvantage of resin composite restorations is their susceptibility to discoloration and staining caused by the aging process in the oral environment. Color instability is one of the main reasons for replacing restorations, particularly in anterior teeth [11]. There are several factors that affect the color stability of resin composite including intrinsic factors, namely the chemical make-up of the materials [12]. Moreover, other extrinsic factors including smoking and poor oral hygiene, as well as the absorption of dyes from consuming foods and beverages in the oral cavity influence the color stability of resin composite restorations [11].

Spectrophotometers are among the most precise, practical, and adaptable color matching instruments in dentistry. Upon comparison to human-eye observations or conventional procedures, spectrophotometers provided a 33% increase in accuracy and a more objective match in 93.3% of situations [13]. Perceptibility threshold (PT) refers to the smallest color difference that could be noticed by an observer, while acceptability threshold (AT) refers to the difference in color that observers could consider unacceptable, requiring color correction [14, 15].

Immersion in staining solutions is one of several in vitro techniques used to simulate oral aging. Because 24 hours of immersion in vitro was said to simulate one month in vivo, immersion was carried out at 37^{o}C for 12 days, representing one year clinically [9, 16, 17]. Bleaching agents are commonly used for tooth whitening, and the active ingredient in most bleaching products is hydrogen peroxide (H_2O_2) or its precursor, carbamide peroxide[18, 19]. Current bleaching agents rely on the ability of H_2O_2 to diffuse into the enamel and dentin to oxidize the organic chromophores in teeth [20]. However, following the application of bleaching agents, the color of the composite resin-based restoration may not always match the adjacent bleached tooth structure [10].

Based on our knowledge, there is insufficient evidence-based information regarding single-shade composites [21]. Thus, the aim of the current in vitro study is to evaluate color matching ability and stability of two commercial resin composites, single-shade resin composite (Omnichroma) versus multi-shade (Filtek Z350 XT) to natural tooth structure after aging and bleaching. The following null hypotheses were tested: the first null hypothesis was there was no difference between both composites in immediate color matching; the second null hypothesis was there was no difference between both composites in color matching after aging; the third null hypothesis was there was no difference between storage media; the fourth null hypothesis was there was no difference between shades with each composite and the fifth null hypothesis was there was no difference between both composites after bleaching.

MATERIALS AND METHODS

The materials used in the current study are described in table 1.

Sample Size calculation:

In a previous study[22] the response within multi-shade composite was normally distributed with mean of 4.59 and standard deviation of 0.68. If the response within single-shade composite was normally distributed with mean of 3.31 and standard deviation of 0.45, it was needed to study 5 experimental teeth per group to reach a total of 40 teeth to be able to reject the null hypothesis that the population means of the experimental and control groups are equal with probability (power) 0.8. The Type I error probability associated with this test of this null hypothesis is 0.05. Sample size calculation was done using G* Power, version 3.1.9.6 for MS Windows (Franz Faul, Universität Kiel, Germany).

TABLE (1) Materials' manufacturer, filler type, filler content, matrix composition and shade:

Product	Manufacturer	Filler type	Filler content (weight)	Matrix composition	Shade	Lot number
Omnichroma (single-shade composite)	Tokuyama Dental, Tokyo, Japan	Uniform sized supra-nano spherical filler (260 nm spherical SiO2-ZrO2) and composite filler	79%	UDMA, TEGDMA	Universal	134S3
Filtek Z350XT (multi-shade composite)	3M ESPE, St. Paul, USA	non-agglomerated/non-aggregated 20 nm silica filler, non-agglomerated/non-aggregated 4 to 11 nm zirconia filler, and aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4 to 11 nm zirconia particles	78.5%	Bis-GMA, UDMA, TEGDMA, Bis-EMA and PEGDMA	A2B A3B	NC93014 N932955
Scotchbond Etchant	3M ESPE, St. Paul, USA			Water, Phosphoric acid, Synthetic amorphous silica, Polyethylene glycol, Aluminum oxide (Concentration: 32%, pH: ~0.1%).		692513
Single Bond Universal	3M ESPE, St. Paul, USA			MDP Phosphate Monomer, Dimethacrylate resins Vitrebond Copolymer, HEMA, Filler, Ethanol, Water, Initiators, Silane (pH: ~2.7).		527602

Samples preparation:

A total of 40 human sound premolars extracted due to orthodontic reasons were collected, washed, cleaned, scaled and polished using rubber cup and pumice. Carious, restored and discolored teeth or teeth with cracks and any acquired lesions were excluded. The color of each tooth was recorded using a VITA Easy shade digital spectrophotometer (VITA Zahnfabrik, Bad Sackingen, Germany) on a white background and teeth with A2 and A3 shades were included. Teeth were stored in distilled water and kept in a deep freezer for 24 hours (-10°C) before the baseline color measurement [23]. Previous trials found that other storage media, such as thymol, can alter the teeth's optical properties [24].

Teeth were mounted vertically by embedding roots in acrylic resin blocks to show only the coronal portion of the teeth and to make handling easier [22]. Circular class V cavities were prepared on labial surfaces of each tooth, the cavity diameter of 5 mm was drawn with a pencil 1 mm above the cervical line. Following the outline, the cavities were prepared with #330 carbide burs (SS White, New Jersey, USA) to a depth of 2 mm, a 45^o short bevel was done at the incisal enamel margins using red coded tapered with round end diamond finishing stone (SS White, New Jersey, USA). After 5 cavities, the bur was discarded [10].

Teeth were randomly divided into two groups using simple randomization according to the materials' assignment either; single-shade or multi-shade composite (n=20), then each group was divided into two subgroups according to the storage medium either; distilled water or coffee (n=10) and then each subgroup was divided into two classes according to the shade either; A2 or A3 (n=5).

All cavities were etched using 32% phosphoric acid (Scotchbond Etchant, 3M ESPE, St. Paul, USA) for 15 seconds, rinsed for 15 seconds using triple way syringe, then dried with oil free compressed air. The adhesive (Single Bond Universal, 3M ESPE, St. Paul, USA) was applied using a micro-brush, air-thinned, and light cured for 10 seconds using I-LED curing light (Woodpecker, Guangxi, China) with maximum intensity of 3000 mw/cm^2 and built in radiometer for regular check of intensity. The cavities were restored either using Omnichroma composite (Tokuyama Dental, Tokyo, Japan) or Filtek Z350XT (3M ESPE, St. Paul, USA) either in A2 or A3 shades according to the previous shade determination. Composite was applied in 2 mm increments with the help of the Teflon coated plastic instrument, then clear cervical matrix (TDV, Santa Catarina, Brazil) was applied on the final layer of composite, followed by removal of excess composite using sharp explorer, then composite was light cured for 20 seconds using LED light curing unit. The restorations were polished using opti1step (Kerr, Orange, CA, USA).

Baseline assessment:

The color of each tooth from the lingual surface (control) and each restoration from the labial surface was recorded using VITA Easy shade V digital spectrophotometer (VITA Zahnfabrik, Bad Sackingen, Germany) immediately after restoration, shade was recorded on a white background [23].

Storage:

The specimens were divided in the storage media either distilled water (AQUA chemicals, Egypt) or coffee (Al-YEMENI CAFÉ, Egypt) at 37°C for 12 days, immersion was carried out at 37^{o}C, in an incubator, simulating the mouth temperature, for 12 days, representing one year clinically [9, 16, 17]. The coffee solution was prepared by combining 25 g of powder with 250 ml of water. Each class (n=5) was stored into a specimen collection cup, containing 100 ml of the storage solution, both solutions were renewed every 24 hours [25]

Color difference assessment:

The color of each tooth and restoration was recorded using VITA Easy shade V digital spectrophotometer (VITA Zahnfabrik, Bad Sackingen, Germany) at 24 hours and 12 days after immersion in storage media. The shade difference provided by the classic CIELab (ΔE) and the CIEDE2000 (ΔE_{00}) between the restoration and the tooth was calculated using the CIELAB color space (L*a*b*) using ColorTools 2 Microsoft Excel add-in for windows, where (L) represents the color's lightness, (a) represents the color's redness-greenness, and (b) represents the color's yellowness-blueness.

Bleaching

Specimens immersed in coffee were bleached after the 12 days immersion period. Bleaching was done by using in-office bleaching system three times in a row using 40% H_2O_2 (Opalescence Boost, Ultradent Products, Inc.; USA) according to the manufacturer's instructions for 20 minutes each time.

Color difference assessment

The color of each tooth and restoration was recorded using VITA Easy shade V digital spectrophotometer (VITA Zahnfabrik, Bad Sackingen, Germany). The shade difference (ΔE) and (ΔE_{00}) between the restoration and the tooth was calculated immediately after bleaching and after two weeks.

Statistical analysis

Data was analyzed using Medcalc software, version 19 for windows (MedCalc Software Ltd, Ostend, Belgium). Data was explored for normality using Kolmogrov Smirnov test and Shapiro Wilk test. Continuous data showed normal distribution and were described using mean and standard deviation. Intergroup comparison was performed using independent T test, P value less than or equal to 0.05 was considered statistically significant. Intragroup comparison between time periods was performed using repeated measures ANOVA followed by tukey post-hoc test and the P value was Bonferroni corrected at P less than or equal to 0.016 and all tests were two tailed. Regression analysis was used to determine the relationship between ΔE and ΔE_{00} with regression line and line of equality.

RESULTS

1. Color difference

The color difference measurements following aging are shown in table 2.

1.1. Effect of composite type and time on color match within each shade in water and coffee immersion solutions:

Intergroup comparison of ΔE and ΔE_{00} between both composites have shown statistically significant difference at baseline, one day and 12 days ($P \leq 0.05$) within both storage media and both shades. Intragroup comparison of ΔE and ΔE_{00} within single-shade composite or multi-shade composite have shown statistically significant effect of time on ΔE ($P \leq 0.016$).

1.2. Effect of immersion solution on color match within each composite and shade at each time:

Intergroup comparison of ΔE and ΔE_{00} between both immersion solutions have shown no statistically significant difference at baseline ($P > 0.05$) within both materials and both shades, while there was statistically significant difference between immersion solutions at one day and 12 days ($P \leq 0.05$).

1.3. Effect of shade on color match within each composite and immersion solution at each time:

Intergroup comparison of ΔE between both shades has shown statistically significant difference at baseline, one day and 12 days ($P \leq 0.05$) within both storage media in single-shade group. Intergroup comparison of ΔE_{00} between both shades has shown statistically significant difference at baseline, one day and 12 days ($P \leq 0.05$) within water storage media in single-shade group. Intergroup comparison of ΔE_{00} between both shades within coffee storage medium in single-shade group have shown statistically significant difference at baseline and one day ($P \leq 0.05$) and no statistically significant difference after 12 days ($P > 0.05$).

Intergroup comparison of ΔE between both shades within both storage media in multi-shade group have shown no statistically significant difference at baseline, one day and 12 days (P > 0.05). Intergroup comparison of ΔE_{00} between both shades within water storage media in multi-shade group have shown no statistically significant difference at baseline, one day and 12 days (P > 0.05). Intergroup comparison of ΔE_{00} between both shades within coffee storage medium in single-shade group have shown no statistically significant difference at baseline (P > 0.05) and statistically significant difference after one and 12 days (P ≤ 0.05)

TABLE (2) Mean and standard deviation of ΔE and ΔE_{00} showing effect of composite type and time on color match within each shade in water and coffee immersion solutions:

ΔE

Shade	Group / Time	Water: Single-shade composite Mean	SD	Water: Multi-shade composite Mean	SD	P value (comp.)	Coffee: Single-shade composite Mean	SD	Coffee: Multi-shade composite Mean	SD	P value (comp.)	P value (storage): Single-shade composite	P value (storage): Multi-shade composite
A2	Baseline	2.98^a	0.39	1.57^a	0.38	<0.0001*	3.00^a	0.28	1.60^a	0.37	<0.0001*	= 0.8986	= 0.8856
	1 day	3.18^a	0.33	2.08^a	0.48	<0.0001*	4.02^b	0.40	3.58^b	0.25	=0.0097*	= 0.0001*	<0.0001*
	12 days	3.50^b	0.23	2.78^b	0.35	<0.0001*	5.52^c	0.16	8.34^c	0.68	<0.0001*	<0.0001*	<0.0001*
	P value (time)	=0.015*		<0.001*			<0.001*		<0.001*				
		Mean	SD	Mean	SD		Mean	SD	Mean	SD			
A3	Baseline	4.56^a	0.41	1.69^a	0.39	<0.0001*	4.45^a	0.35	1.65^a	0.31	<0.0001*	=0.5161	=0.7817
	1 day	4.62^a	0.42	2.09^b	0.49	<0.0001*	5.43^b	0.38	3.52^b	0.72	<0.0001*	=0.0003*	=0.0001*
	12 days	5.50^b	0.43	2.96^b	0.42	<0.0001*	6.30^c	0.35	8.28^c	0.82	<0.0001*	=0.0003*	<0.0001*
	P value (time)	<0.001*		<0.001*			<0.001*		<0.001*				
P value (Shade)	Baseline	<0.0001*		=0.5008			<0.0001*		=0.7526				
	1 day	<0.0001*		=0.9461			<0.0001*		=0.7883				
	12 days	<0.0001*		=0.3168			=0.0010*		=0.8615				

ΔE_{00}

Shade	Group / Time	Water: Single-shade composite Mean	SD	Water: Multi-shade composite Mean	SD	P value (comp.)	Coffee: Single-shade composite Mean	SD	Coffee: Multi-shade composite Mean	SD	P value (comp.)	P value (storage): Single-shade composite	P value (storage): Multi-shade composite
A2	Baseline	2.32^a	0.31	1.23^a	0.30	<0.0001*	2.34^a	0.22	1.25^a	0.29	<0.0001*	=0.9028	=0.8883
	1 day	2.48^a	0.26	1.62^a	0.37	<0.0001*	3.13^b	0.31	2.79^b	0.20	=0.0096*	=0.0001*	<0.0001*
	12 days	2.73^b	0.18	2.17^b	0.27	<0.0001*	4.31^c	0.40	6.50^c	0.53	<0.0001*	<0.0001*	<0.0001*
	P value (time)	=0.015*		<0.001*			<0.001*		<0.001*				
		Mean	SD	Mean	SD		Mean	SD	Mean	SD			
A3	Baseline	3.15^a	0.28	1.17^a	0.27	<0.0001*	3.07^a	0.24	1.14^a	0.22	<0.0001*	=0.5131	=0.7819
	1 day	3.18^a	0.29	1.43^b	0.33	<0.0001*	3.75^b	0.26	2.42^b	0.49	<0.0001*	=0.0003*	=0.0001*
	12 days	3.79^b	0.30	2.04^b	0.29	<0.0001*	4.34^c	0.24	5.71^c	0.56	<0.0001*	=0.0003*	<0.0001*
	P value (time)	<0.001*		<0.001*			<0.001*		<0.001*				
P value (shade)	Baseline	<0.0001*		=0.6504			<0.0001*		=0.3619				
	1 day	<0.0001*		=0.2538			=0.0002*		=0.0428*				
	12 days	<0.0001*		=0.3353			=0.8029		=0.0049*				

Means that do not share a letter vertically are significantly different, * corresponds to statistically significant difference, P value (comp.) shows statistical significance difference between composites within each time period, P value (time) shows statistical significance difference between time periods within each composite, P value (storage) shows statistical significance difference between storage media within each composite at each time period & P value (shade) shows statistical significance difference between each shade within each composite at each time period.

2. Effect of bleaching on color difference:

The color difference measurements following bleaching are shown in table 3.

2.1. Effect of composite type on ΔE within each shade before and after bleaching:

Intergroup comparison of ΔE and ΔE_{00} between both composites have shown statistically significant difference before bleaching, immediately after bleaching and after two weeks ($P \leq 0.05$) within both shades. Intragroup comparison within single-shade or multi-shade composites have shown statistically significant difference between different time periods ($P \leq 0.016$).

2.2. Effect of shade on ΔE within each composite type before and after bleaching:

Intergroup comparison of ΔE between both shades have shown statistically significant difference before bleaching, immediately after bleaching and after two weeks ($P \leq 0.05$) within single-shade group, while multi-shade group has shown no difference between shades ($P > 0.05$). Intergroup comparison of ΔE_{00} between both shades have shown no statistically significant difference before bleaching ($P > 0.05$) within single-shade group, while for immediately after bleaching and after two weeks, there was statistically significant difference ($P \leq 0.05$). Intergroup comparison of ΔE_{00} between both shades have shown statistically significant

TABLE (3)**: Mean and standard deviation of ΔE showing effect of composite type on color match within each shade before and after bleaching:**

ΔE												
	A2					A3					P value (shade)	
Group / Time	Single-shade composite		Multi-shade composite		P value (comp.)	Single-shade composite		Multi-shade composite		P value (comp.)	Single-shade composite	Multi-shade composite
	Mean	SD	Mean	SD		Mean	SD	Mean	SD			
Before	5.52[a]	0.16	8.34[a]	0.68	<0.0001*	6.30[a]	0.35	8.28[a]	0.82	<0.0001*	=0.0010*	P = 0.8615
Immediate	3.41[b]	0.31	5.30[b]	0.21	<0.0001*	4.45[b]	0.32	5.58[b]	0.42	<0.0001*	<0.0001*	P = 0.0843
2 weeks	3.72[b]	0.49	5.42[b]	0.38	<0.0001*	4.75[b]	0.44	5.60[b]	0.34	<0.0001*	=0.0001*	P = 0.2825
P value (time)	<0.001*		< 0.001*			<0.001*		<0.001*				

ΔE_{00}												
	A2					A3					P value (shade)	
Group / Time	Single-shade composite		Multi-shade composite		P value (comp.)	Single-shade composite		Multi-shade composite		P value (comp.)	Single-shade composite	Multi-shade composite
	Mean	SD	Mean	SD		Mean	SD	Mean	SD			
Before	4.31[a]	0.40	6.50[a]	0.53	<0.0001*	4.34[a]	0.24	5.71[a]	0.82	<0.0001*	=0.8029	=0.0049*
Immediate	2.66[b]	0.24	4.14[b]	0.16	<0.0001*	3.07[b]	0.22	3.85[b]	0.28	<0.0001*	=0.0010*	=0.0130*
2 weeks	2.90[b]	0.38	4.23[b]	0.30	<0.0001*	3.27[b]	0.31	4.03[b]	0.23	<0.0001*	=0.0270*	=0.1140
P value (time)	<0.001*		< 0.001*			<0.001*		<0.001*				

*Means that do not share a letter vertically are significantly different, * corresponds to statistically significant difference, P value (comp.) shows statistical significance difference between composites within each time period, P value (time) shows statistical significance difference between time periods within each composite & P value (shade) shows statistical significance difference between each shade within each composite at each time period.*

difference before bleaching and immediately after bleaching ($P \leq 0.05$) within multi-shade group, while after two weeks there was no statistically significant difference ($P > 0.05$).

3. Relationship between ΔE and $\Delta E_{00:}$

There was very strong positive correlation between ΔE and ΔE_{00} with coefficient of determination $R^2 = 0.9814$, $P < 0.0001$ (Figure 1). $\Delta E/\Delta E_{00}$ ratio was 1.36 (95% CI 1.35-1.37) and $\Delta E_{00}/\Delta E$ ratio was 0.73 (95% CI 0.72-0.74)

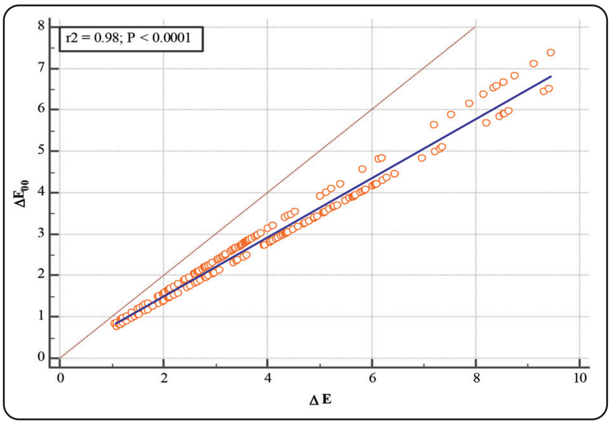

Fig. (1): Scatter diagram with regression line and line of equality showing relation between ΔE and ΔE_{00}.

DISCUSSION

The color matching and color stability of resin composites restorations, particularly in highly esthetic areas, such as in anterior teeth, are among the critical parameters that affect their clinical success [9, 11]. In the current study, the color matching ability and color stability of the newly introduced single-shade composite (Omnichroma) following aging and bleaching, as compared to multi-shade composite (Filtek Z350XT) was evaluated using VITA Easy shade V digital spectrophotometer. Based on the results of the current study, the first, second, third and fifth null hypotheses were rejected, as composite material, aging, storage medium and bleaching affected the color matching of both composites. The fourth null hypothesis was rejected within multi-shade composite in coffee and within single-shade composite in water, however it was accepted within multi-shade composite in water and single-shade composite in coffee, as shade affected color matching of both composites except for multi-shade composite in water and single-shade composite in coffee.

VITA Easy shade V digital spectrophotometer (VITA Zahnfabrik, Bad Sackingen, Germany) was used to assess color matching in the current study, limitations in spectrophotometer devices can be overthrown by implementing the related perceptibility and acceptability thresholds. [26]. Easy shade V showed in vitro repeatability of 0.992 to 0.994 and in vivo repeatability of 0.858 to 0.971 with an overall accuracy of 93.75% [13]

Perceptibility and acceptability thresholds were concluded by Paravina et al. [14, 15] when 50% of observers perceived the color difference (PT) or considered it unacceptable (AT), i.e., 50% of positive and 50% negative answers. The CIELab 50:50% PT was ΔE = 1.2, whereas the 50:50% AT was ΔE = 2.7. The corresponding CIEDE2000 (ΔE_{00}) values were 0.8 (PT) and 1.8 (AT), respectively [14].

CIEDE2000 represents the newest color difference formula intended to correct the differences between the measurement result and visual evaluation, which was the weak point in its predecessor CIELab [27]. CIEDE2000 is proposed to better reflect the color differences perceived by the human eye than the CIELab formula [28]. Data of the current study revealed strong positive correlation between ΔE and ΔE_{00}, indicating linear relationship between both formulas, with $\Delta E/\Delta E_{00}$ ratio of 1.36, and $\Delta E_{00}/\Delta E$ ratio of 0.73. This was in agreement with Gómez-Polo et al. [28], reporting $\Delta E/\Delta E_{00}$ ratio lying between 1.11 and 2.15, while the $\Delta E_{00}/\Delta E$ ratio was between 0.46 and 0.90.

The color matching ability at baseline was evaluated through calculating the color difference between the color of each tooth from the lingual surface (control) and each restoration from the labial surface. The Filtek Z350XT multi-shade composite revealed superior shade matching ability to teeth with A2 and A3 shades, as compared to the single-shade material, their shade matching was considered acceptable using both ΔE and ΔE_{00}, however it exceeded the PT. On the contrary, the single-shade (Omnichroma) showed inferior color matching ability, representing higher color differences (ΔE and ΔE_{00}), which was significantly higher than the multi-shade restorations at baseline (Table 2). These color differences exceeded both the PT and AT in both A2 and A3 teeth shades.

The color matching ability of recent single-shade composites is based on color assimilation, also known as blending effect, described when the perceived color difference between an area and its surrounding decreases [29]. The shade matching ability of the material is related to two main aspects: the blending effect and the material's translucency [29-31]. The blending ability of the material is enhanced with decreased cavity size, increased material's translucency, and decreased color difference between the material and the tooth when viewed in isolation [32]. Single-shade composite exhibited lower ΔE and ΔE_{00} values, indicating better color matching, for lighter A2 shade, as compared to the darker A3 shade, which is in agreement with previous reports [7, 8, 22]. This could be attributed to the high translucency of the material reflecting the shade of the surrounding walls. While the lower color matching ability in darker shade may be attributed to the lower light reflected from the darker tooth structure, thus affecting the ability of single-shade composites to blend with the surrounding tooth structure [22]. In the current study, the cavity diameter was 5 mm representing moderate-sized cavity, this could attribute to the lower color matching ability of Omnichroma exceeding the PT and AT.

Both composites displayed significant discoloration in both immersion media at 12 days, indicating poor color stability. Immersion in distilled water acted as the control for storage, distilled water has neutral pH of ≈ 7 and no coloring agents [33]. Immersion in distilled water for 12 days had minimal effect on ΔE and ΔE_{00} values (<1) for single-shade composite [34] and slightly higher color change in multi-shade composite. This may be attributed to Bis-GMA composition which allowed more water sorption and solubility [35]. Immersion in coffee resulted in significant staining as compared to distilled water, which increased significantly with aging. Coffee is rich in yellow stains, with high compatibility of the polymer phase with such yellow stains [25, 36]. In addition to the low polarity of such stains, which are able to penetrate easily deep into the polymer matrix and cause discoloration [36]. In addition, coffee has about 22 types of acids in their composition with citric acid, acetic acid, malic acid, and other high molecular weight acids contributing to most of its total acidity [37, 38], with pH ranges around 5 [39] to 6.8 [40], acidic drinks may increase surface erosion and increase the staining susceptibility [41]. Although coffee does not exhibit high acidity in comparison to other drinks such as soda drinks and wine, yet chromogens/stains seem to result in higher color change than the presence of acids [39].

The multi-shade composite showed marked discoloration following aging in coffee for 12 days, as evident by the significantly higher color change, as compared to the single-shade one. The lower color stability of Filtek Z350XT may be attributed to the composition of its organic matrix (Table 1), as materials containing Bis-GMA have showed lower color stability compared with those containing UDMA [36, 37, 42]. Bis-GMA have higher water sorption than UDMA and TEGDMA, resulting in increased water sorption and higher susceptibility to staining of Bis-GMA containing composite resins as compared to Bis-GMA free materials. Bis-GMA has hydrogen bonds between the hydroxyl group, while UDMA has carbamate linkages, this caused high viscosity of Bis-GMA with low degree of conversion and subsequently more water sorption, solubility and discoloration [35, 43]. Despite the so called chameleon effect of single-shade composites, Omnichroma blending may be unstable due to the decline in value and the increase in chroma with time [44]. Moreover, although TEGDMA has low molecular weight and better degree of conversion than Bis-GMA, it still increases water sorption resulting in discoloration [35].

The current study aimed to evaluate the effect of bleaching following aging of the specimens in coffee for 12 days using in-office bleaching system containing 40% H_2O_2. Bleaching significantly reduced the discoloration of the restoration of both materials in both teeth shades (Table 3), as evident by the lower color difference of the bleached samples, as compared to the discolored baseline samples. The bleaching effect was stable, as there was no significant color change detected between immediately after bleaching and two weeks post-bleaching. Upon comparing two weeks post-bleaching restorations to the baseline (before aging), there was statistically significant difference between them ($P \le 0.05$). The effect of the bleaching agents on resin composites is still controversial, bleaching agents can eliminate extrinsic stains, but the intrinsic bleaching mechanism is different than that occurring in tooth structure. Thus, bleached restorations commonly do not match the color of the surrounding bleached tooth structure [45, 46]. This was in agreement with the present study, as although bleaching successfully reduced the discoloration of both materials, still the color difference of both single-shade and multi-shade materials was above the PT and AT, representing inadequate color matching to the surrounding tooth structure. Yet, it should be noted that the bleaching effect was more significant in the single-shade material as compared to the multi-shade composite, this could also be related to the effect of the Bis-GMA free organic matrix composition and the supra-nano spherical filler (260 nm) which have structural color, thus improving color adaptation [44]. Post-bleaching color blending in A2 group within single-shade composite was superior to A3 group, this was in agreement with previous research [10], where single-shade composites appeared lighter in shade after bleaching of the surrounding tooth structure.

Limitations of the current study include short-term aging period, limited number of composite types and brands and limited number of shades. Further studies with longer aging time, varieties of composite types and brands, and shades covering the A1-D4 VITA classic color range are recommended to confirm the current results.

CONCLUSION

Within the limitations of the current study, it could be concluded that multi-shade composite showed superior immediate shade matching ability as compared to the single-shade one. In addition, single-shade composites exhibited higher color matching ability to lighter teeth shade as compared to darker teeth shades. Both materials showed low color stability following aging simulating one-year clinical service, with coffee immersion resulting in significant discoloration. Bleaching of the coffee-stained restorations significantly lowered the discoloration of the restorations but failed to match the color of the surrounding bleached tooth structure.

Ethical approval and consent to participate:

Approval was granted from Research Ethics Committee, Faculty of Dentistry, Cairo University (Ref: 32-2-23). No humans, human samples, animals, animal samples or plant samples were involved in the current study.

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Competing interest:

The authors declare no conflict of interest.

Authors' contribution:

Conceptualization: O.S and A.E, Experimental work: O.S and A.E., Statistical analysis: O.S., Interpretation of data: A.E. and O.S., Writing original draft: A.E. and O.S., Review and editing: A.E. and O.S. All authors have read and agreed to the published version of the manuscript.

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