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ORIGINAL ARTICLE

Color stability of different composite resins after polishing

Stefano Ardu[1] · O. Duc[2] · E. Di Bella[3] · I. Krejci[2] · René Daher[4]

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Abstract

The goals of the present study were to evaluate, in vitro, the staining of different composite resins submitted to different common beverages, and to compare the staining effect of each of these solutions. A total of 288 specimens were randomly divided into six groups and immersed for 4 weeks in five staining solutions represented by red wine, orange juice, coke, tea and coffee or in artificial saliva as a control group. When analyzed over a black background, mean $\Delta E00$ values varied from 0.8 for Venus Diamond, Saremco Microhybrid and ELS in saliva and Estelite Posterior in coke to 37.6 for Filtek Supreme in red wine. When analyzed over a white background, mean $\Delta E00$ values varied from 0.5 for Saremco Microhybrid in saliva to 51.1 for Filtek Supreme in red wine. All materials showed significant changes in color after 4 weeks of immersion in staining solutions. Significant differences were found between the tested composite resins and also between the staining solutions.

Keywords Composite · Staining · Color difference · Spectrophotometer · $L*a*b$

Introduction

Composite resins are becoming standard restorative materials due to their capacity to easily reproduce tooth-like appearance [1–3]. The combination of composite resins with adhesive systems allows for a minimally invasive treatment when compared to traditional prosthetic approach based on ceramic crowns. Moreover, composite resin-based adhesive procedures are usually cost-effective, rational and allow for good esthetic results which are well accepted by patients. However, it has been shown that even the latest composite resin formulations have a staining potential much higher than ceramics [4, 5]. In fact, this higher susceptibility to staining is a main reason why some dentists opt directly for ceramic-based restorations instead of composite resins. Specifically, most esthetically demanding patients do not tolerate well color changes of their restorations throughout time and the need for periodical appointments for polishing or even the replacement of the superficial layer of the restoration. Despite being a key factor of long-term esthetic success, there is a lack of information provided by manufacturers concerning the staining susceptibility of composite resins. Specifically, little data are available on their behavior in oral environment and their possible interactions with food colorants. Discoloration is a "hot topic" and there have been several articles within the last 2 years dealing with this specific subject [6–15]. The goals of the present study were to evaluate, in vitro, the staining effect of different common food coloring liquids, and the staining susceptibility of different composite resins after polishing and immersion in these liquids. The results may help to better understand the staining of current composite resins and even if limited, it could serve as an in vivo indicator for the long-term clinical behavior. Furthermore, in order to fill a complete lack in the literature concerning the influence of polishing on color stability of composites, the results obtained with the "polished"

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✉ Stefano Ardu
stefano.ardu@unige.ch

[1] Treatment Plan Unit and Division of Cariology and Endodontology, Clinique Universitaire de Médecine Dentaire (CUMD), University of Geneva, Rue Barthélemy-Menn 19, 1205 Geneva, Switzerland

[2] Division of Cariology and Endodontology, Clinique Universitaire de Médecine Dentaire (CUMD), University of Geneva, Geneva, Switzerland

[3] Department of Economics and Business Studies, University of Genoa, Genoa, Italy

[4] Teaching and Research Assistant, Division of Cariology and Endodontology, Clinique Universitaire de Médecine Dentaire (CUMD), University of Geneva, Geneva, Switzerland

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samples in the present study were faced with "unpolished" samples from the literature that were subjected to a similar test. The first null hypothesis was that there is no difference in the staining effect of the tested staining solutions. The second null hypothesis was that there is no difference in the staining susceptibility of the tested composite resins after a four-week immersion in staining solutions.

Materials and methods

The detailed description of the used methodology was explained in a precedent publication [16]. To summarize, two-hundred and eighty-eight disc-shaped specimens of 10 mm diameter were fabricated by pressing the material of eight composite materials between two glass slides to the thickness of 1.2 mm (Table 1). As materials' degree of conversion may be a crucial point, all composites tested were of enamel translucency A2 shade. In case A2 was not available, the manufacturers were asked to provide an A2 equivalent shade. Composite resin samples were light cured for 20 s at a distance of 1 mm with an LED curing device (Valo, Ultradent) used in "standard mode" with a power density of more than 1000 mW/cm^2 verified by an LED radiometer (Demetron LED radiometer 910726, Kerr Corporation). Specimens were then polished with 500-, 1200-, 2400- and 4000- grit SiC abrasive paper successively, and the final thickness was of 1 mm was controlled for all the samples. After 24 h of dry storage in an incubator set at 37 °C (INP-500, Memmert), initial color of each specimen was assessed with a calibrated reflectance spectrophotometer (SpectroShade, Handy Dental Type 713000, Serial No. HDL0090, MHT). These measurements were performed backed by a white as well as a black background.

Specimens of each composite material were then randomly divided into six groups and immersed in either artificial saliva as a control solution or in one of five staining solutions represented by red wine (Côtes du Rhône DOC, Les Arénes), orange juice (Hohes C, Eckes-Granini), coke (Coca-Cola, Coca-Cola Beverages AG), tea (Twinings Earl Gray tea) and coffee (Arpeggio, Nespresso, Nestlé). All samples were kept in an incubator at 37 °C in the dark for 28 days. Staining solutions were changed every week to avoid bacteria or yeast contamination. After 28 days of storage, samples were cleaned for 60 s with a high pressure-hot water airbrush at 0.4 MPa and 135 °C (Minivapor 93, Effegi Brega s.r.l.) and air dried. Spectrophotometric measurements were repeated for each sample to determine the color changes according to the classical CIEDE 2000 ($\Delta E00$) formula based on lightness (ΔE_L), chroma (ΔE_C) and hue (ΔE_H):

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L} \right)^2 + \left(\frac{\Delta C'}{K_C S_C} \right)^2 + \left(\frac{\Delta H'}{K_H S_H} \right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C} \right) \left(\frac{\Delta H'}{K_H S_H} \right) \right]^{1/2},$$

where

$$\Delta E_L = \frac{\Delta L'}{\left(K_L \cdot S_L\right)},$$

$$\Delta E_C = \frac{\Delta C'}{\left(K_C \cdot S_C\right)},$$

$$\Delta E_H = \frac{\Delta H'}{\left(K_H \cdot S_H\right)}.$$

Table 1 Tested materials, % charge by weight and by volume

Composite	Manufacturer	% Charge by weight	% Charge by volume	Composition
Estelite posterior	Tokuyama Dental	84	70	Silica zirconia filler (mean particle size 2 µm, range 1–10 µm). Bis-GMA, TEG-DMA, Bis-MPEPP
ELS	Saremco	74	49	Inorganic fillers (size 50–3000 nm). Bis GMA, Bis-EMA
Saremco microhybrid	Saremco	76	52	Inorganic fillers (size 4–3000 nm). Bis-GMA, Bis-EMA, TEG-DMA
Filtek supreme	3M Espe	72	56	Silica filler and aggregated zirconia fillers (size 4–20 nm) clusters 0.6–10 µm. Bis-GMA, UDMA,TEG-DMA, PEG-DMA, Bis-EMA
Inspiro SN	Edelweiss	82	65	Barium alumino fluoride glass (size 0.02–2 µm), Bis-GMA based
Venus diamond	Heraeus Kulzer	81	64	Barium alumino fluoride glass TCD-DI-HEA, UDMA
Miris 2 NR	Coltene–Whaledent	80	65	Barium alumino fluoride glass Bis-GMA, TEG-DMA, UDMA
Tetric bulk fill	Ivoclar–Vivadent	80 (17% prepolymers)	60	Barium alumino fluoride glass, prepolymer filler (monomer, glass filler, and ytterbium fluoride), spherical mixed oxide matrix Bis-GMA, UDMA, Bis-EMA

To test the staining effect of the different solutions, statistical analysis was performed by means of ANOVA on the log-transformed Δ*E*00 values to guarantee the required normality assumptions as tested by the Kolmogorov–Smirnov test. To test the staining susceptibility of the different composite resins, all staining values were pooled together per composite and the Δ*E*00 values were submitted to Fisher's LSD post hoc test.

Results

The results are summarized in Tables 2 and 3. All tested materials showed significant ($p < 0.01$) color changes after 28 days of immersion in the staining solutions. When analyzed over a black background, mean Δ*E*00 values varied

Table 2 Average Δ*E*00 differences and standard deviations (in parentheses) before and after the staining process per group analyzed over a black background

Code	Cpr	Coffee	Coke	Orange juice	Salive	Tea	Red wine	Total
1	Estelite posterior	7.5^{A}	0.8^{A}	1.7^{A}	1.1^{A}	11.0^{A}	29.7^{B}	8.6^{B}
		(1.0)	(0.2)	(0.7)	(0.2)	(0.9)	(1.9)	(10.3)
2	ELS	12.8^{C}	1.5^{A}	2.5^{A}	0.8^{A}	12.2^{A}	22.2^{A}	8.7^{B}
		(1.2)	(0.8)	(0.4)	(0.2)	(0.6)	(2.1)	(8.0)
3	Saremco microhybrid	10.7^{B}	0.8^{A}	1.9^{A}	0.8^{A}	10.2^{A}	21.5^{A}	7.7^{A}
		(1.2)	(0.3)	(0.2)	(0.3)	(0.7)	(1.3)	(7.6)
4	Filtek Supreme	17.9^{E}	1.4^{A}	2.8^{A}	1.9^{A}	18.0^{C}	37.6^{E}	13.3^{F}
		(1.5)	(0.3)	(0.4)	(0.3)	(1.0)	(1.9)	(13.2)
5	Inspiro SN	18.8^{E}	3.6^{B}	5.5^{C}	1.5^{A}	16.4^{B}	28.9^{B}	12.5^{E}
		(1.8)	(1.0)	(0.8)	(0.3)	(0.6)	(0.9)	(9.9)
6	Venus diamond	12.1^{C}	1.2^{A}	2.3^{A}	0.8^{A}	11.2^{A}	30.8^{C}	9.7^{C}
		(1.0)	(0.5)	(0.6)	(0.1)	(0.5)	(1.5)	(10.6)
7	Miris 2 NR	15.6^{D}	1.5^{A}	3.6^{B}	1.5^{A}	15.1^{B}	27.1^{B}	10.7^{D}
		(1.0)	(0.4)	(0.5)	(0.6)	(0.4)	(0.6)	(9.6)
8	Tetric bulk fill	19.0^{E}	1.0^{A}	7.5^{D}	1.5^{A}	19.7^{D}	33.8^{D}	13.8^{G}
		(1.3)	(0.3)	(0.3)	(1.0)	(1.2)	(0.9)	(11.9)
Total		14.3	1.5	3.5	1.2	14.2	29.0	10.6
		(4.1)	(1.0)	(2.0)	(0.6)	(3.5)	(5.3)	(10.4)

Results with same capital letter are not significantly different according to Fisher's LSD test; p value < 0.01

Table 3 Average Δ*E*00 differences and standard deviations (in parentheses) before and after the staining process per group analyzed over a white background

Code	Cpr	Coffee	Coke	Orange juice	Salive	Tea	Red wine	Total
1	Estelite posterior	10.4^{A}	0.6^{A}	1.2^{A}	1.0^{A}	21.4^{D}	35.0^{D}	11.6^{C}
		(1.0)	(0.3)	(0.3)	(2.2)	(0.2)	(0.7)	(13.0)
2	ELS	16.2^{C}	1.3^{B}	2.5^{B}	1.0^{A}	14.7^{B}	27.8^{B}	10.6^{B}
		(1.2)	(0.8)	(0.4)	(2.7)	(0.2)	(0.7)	(10.1)
3	Saremco microhybrid	14.6^{B}	1.1^{B}	2.2^{B}	0.5^{A}	12.7^{A}	24.7^{A}	9.3^{A}
		(1.3)	(0.3)	(0.4)	(1.2)	(0.2)	(0.8)	(9.0)
4	Filtek supreme	23.0^{D}	1.6^{B}	3.5^{B}	2.3^{A}	21.3^{D}	51.1^{G}	17.1^{G}
		(1.2)	(0.4)	(0.6)	(2.8)	(0.5)	(1.3)	(17.9)
5	Inspiro SN	24.4^{D}	3.5^{C}	4.7^{C}	1.9^{A}	19.5^{C}	35.5^{D}	14.9^{E}
		(1.5)	(0.4)	(0.5)	(0.8)	(0.2)	(0.4)	(12.7)
6	Venus diamond	17.2^{C}	1.5^{B}	2.9^{B}	1.2^{A}	14.8^{B}	39.1^{E}	12.8^{D}
		(0.9)	(0.3)	(0.7)	(1.5)	(0.1)	(0.4)	(13.6)
7	Miris 2 NR	16.5^{C}	1.8^{B}	3.3^{B}	0.8^{A}	15.4^{B}	31.8^{C}	11.6^{C}
		(1.2)	(0.3)	(0.6)	(1.1)	(0.1)	(0.7)	(11.2)
8	Tetric bulk fill	23.0^{D}	1.3^{B}	8.2^{D}	1.0^{A}	22.1^{D}	44.8^{F}	16.7^{F}
		(2.1)	(0.3)	(0.3)	(1.2)	(0.2)	(1.0)	(15.6)
Total		18.2	1.6	3.6	1.2	17.7	36.2	13.1
		(4.8)	(0.9)	(2.1)	(8.4)	(0.6)	(3.6)	(13.3)

Results with same capital letter are not significantly different according to Fisher's LSD test; p value < 0.01

from 0.8 for Venus Diamond, Saremco Microhybrid and ELS in saliva and Estelite Posterior in coke, to 37.6 for Filtek Supreme in red wine. When analyzed over a white background mean $\Delta E00$ values varied from 0.5 for Saremco Microhybrid in saliva to 51.1 for Filtek Supreme in red wine. When the $\Delta E00$ means of all staining solutions were pooled together per composite material and analyzed over a black background, values varied from 8.6 for Estelite Posterior to 13.8 for Tetric Bulk Fill. When the $\Delta E00$ means of all staining solutions were pooled together and analyzed over a white background, values varied from 9.3 for Saremco Microhybrid to 17.1 for Filtek Supreme. Red wine was the most staining solution followed by coffee, tea, orange juice, coke and saliva independent of the background.

Discussion

In the oral environment, composite resins are subjected to a continuously repeated contact with different staining substances. According to numerous studies [17–30], multiple factors can influence the discoloration process of composite resin materials by these substances, such as incomplete polymerization, water sorption, staining foods and beverages, oral hygiene and surface roughness. In this study, focus was put on the possible influence of diet by analyzing the staining potential of several common drinks such as red wine, coffee, tea, orange juice and coke. The choice of these food colorants was based on the fact that they have already been used in various studies [31–37]. The control storage medium was represented by artificial saliva (Glandosan®, Helvepharm AG).

The detailed testing protocol was adopted by the one proposed by Ardu et al. [38] where all details of the procedure were extensively discussed. However, two main differences were present in this study in comparison to the previous one: Polishing of the surface of the samples and substitution of Filtek Silorane by Tetric Bulk Fill. Polishing of the surface was introduced due to the fact that literature is not univocal concerning its influence on staining of composite resin materials [39–42]. Substitution of Filtek Silorane by Tetric Bulk Fill was done because Filtek Silorane is fading out of the market. Moreover, manufacturers are proposing more and more bulk fill materials in order to save time so the inclusion of a representative of this type of composite material was considered interesting by the authors. The immersion duration of 28 days in the staining solutions was consistent with the most recent literature reviews representing around 2.5 years of clinical service [43–46].

The spectrophotometric measurements with a black and a white background were done in order to simulate different clinical conditions such as class IV restorations, class I, II, III and composite veneers as well [6, 47–49]. The choice of using $\Delta E00$ instead of ΔE as an investigation method was made because it has been claimed, in the literature, to provide a better fit in the evaluation of color difference thresholds having a better discrimination capacity on small color differences [50]. The $\Delta E00$ disturbance level (the color difference which is perceived as disturbing by patients) is reported [51] to be 2.2 while the same level for ΔE is 3.3 [24]. Another important aspect is to investigate the perceivable level of the perceptibility threshold which for ΔE00 is set to 1.2 [51]. Therefore, all the values under this threshold are not perceived by human eyes, but only detectable by measuring instruments such as colorimeter or spectrophotometer.

In this study, red wine had the highest staining potential followed by coffee and tea. The low pH of 4.5 of the red wine used in this study and its relatively high level of tannins may serve as an explanation for its high staining capacity, especially if compared to the coffee brewed in "lungo mode" or the aromatic and mild tea (Twinings Earl Gray tea) employed in this study. These results are in line with the precedent study done on unpolished samples [38].

Saremco Microhybrid showed the best results in the study, followed by ELS, independent of the background. The only chemical difference between these two materials is the substitution of TEG-DMA in Saremco Microhybrid by Bis-EMA in ELS. This is in contrast to the results of the previous study by Ardu et al. [38] where no significant difference was found between Saremco Microhybrid and ELS. A possible explanation is that surface polishing could have lowered the surface reactivity of TEG-DMA. TEG-DMA may enhance surface hardness, elastic modulus and degree of polymerization in comparison to Bis-EMA, all factors which contribute to better behavior against staining agents. Estelite Posterior performed quite well. The high inorganic load of the material (70% by volume) together with the presence of a relatively hydrophobic monomer such as Bis-MPEPP may have contributed to this result. Venus Diamond showed an important affinity to high polarity molecules such as the ones present in tea, as well as to low polarity colorants of coffee. This might be associated with the TCD-DI-HEA monomer specific to Venus Diamond. Inspiro NR, in accordance with a previous study [38] revealed to be susceptible to coloration when in contact with acidic beverages such as orange juice or coke. A speculative explanation may be a weak silanization of the filler and/or its even distribution which may allow for a large exposition of the fillers in contact with the etching solutions on the surface of the material.

Tetric Bulk fill and Filtek Supreme performed the worst. The results of Tetric Bulk Fill might be the consequence of its relatively high translucency which may accentuate the perceptibility of staining. The behavior of Filtek Supreme is in line with the results of other studies and seems to be related to the matrix composition and probably to the special filler used [16, 38, 43].

Concerning the possible influence of filler charge percentage by weight and by volume on the staining susceptibility of composite resins, the results of this study did not provide enough evidence to show the correlation between these two factors. A possible cause for staining susceptibility difference between the materials could be the chemical composition and different monomer quantities of the resins used in the composite, which is unfortunately never disclosed in details by the manufacturers.

In general, the influence of the background on the ranking of the materials tested was low. When small differences were present, they were explainable by the different degree of transparence of the material as seen in Estelite Posterior in tea and red wine.

The obtained mean values of color change are comparable to previous studies [38, 52]. More specifically, the results of this study with polished surfaces of the samples showed the same trend as the ones of a pervious study where the surfaces were not polished [38]. However, the values recorded in the previous study were around 30% higher, showing a higher discoloration potential of samples without polishing in comparison to samples with polishing.

Conclusions

The two null hypotheses of the study were rejected: different staining solutions had different staining effects and all composite resin materials showed significant changes in color after 4 weeks of immersion in staining solutions.

Under the conditions of this in vitro experiment, each tested composite resin presented a specific affinity to the multiple staining solutions. Nevertheless, when all the results were pooled together, general trends were observed, such as Saremco Microhybrid presenting the best results and Filtek Supreme presenting the highest staining susceptibility. Clinical studies are needed in order to confirm these observations in vivo.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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