Original Article

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Dentistry Section

Effect of Ageing, Staining and Polishing on the Colour Stability of a Single, a Group Shade and Nano Fill Dental Composite: An In-vitro Study

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ABSTRACT

Introduction: With the increase in aesthetic requirements, more people are requesting tooth coloured fillings. An anterior restoration is deemed unacceptable if its colour changes significantly.

Aim: To assess the colour stability of a single shade, a group shade and a nano fill dental resin composite which comes in multiple shades.

Materials and Methods: This in-vitro study was conducted in the month of August 2021 at the Advanced Technology Dental Research Laboratory at the King Abdul Aziz University, Jeddah, Western region, Saudi Arabia. Three composites were tested; a single shade (Omnichroma), a group shade (Optishade Light (OL) and Optishade Medium (OM)) and a conventional nano fill (Z350) 40 cylindrical discs (10 mm in diameter and 2 mm in depth) were fabricated in total. Each material and shade to be tested had 10 samples per group (n=10). The materials were aged in a thermocycler for 5000 cycles then stained with either green tea or coffee for six days. Upon completion of the staining protocol, they were then polished with soflex diamond polishing system. Colour measurements were taken at each stage, calculated and compared. Mixed model repeated Analysis Of Variance (ANOVA) was performed to determine significance of the colour change (ΔE_{00}) between materials and treatments and Bonferroni test was used for multiple comparison between groups.

Results: The effect of ageing varied according to individual material; Z350 had lower ΔE_{00} when compared to other materials. After staining with tea, it was found that Z350 and Omnichroma exhibited a significant change ($p<0.05$) in ΔE_{00} when compared to OL. Polishing improved the ΔE_{00} in all the materials. All green tea-stained materials with the exception of Omnichroma returned to a clinically acceptable E_{00} after polishing. After polishing coffee stained samples, OL and OM remained above the clinically acceptable threshold while Z350 and omnichroma were returned to a clinically acceptable level.

Conclusion: All the materials showed a change in ΔE_{00} after ageing, with OM and Z350 being the only materials to exhibit a clinically acceptable change. While polishing decreased ΔE_{00} in all the materials, it did not return them all to a clinically acceptable level. Thus, polishing helps improve the appearance of stained restorations but may not be enough to completely remove stains, even in newly introduced direct aesthetic dental materials.

Keywords: Aesthetic dental filling, Discolouration, Omnichroma, Optishade

INTRODUCTION

Currently the material of choice for direct restorations among most dental practitioners is dental resin composites [1,2]. This is due to their excellent aesthetics and material properties [3]. Providing the patient with a functional, yet imperceptible aesthetic restoration is the ultimate goal of a dental practitioner. As a means to that end, dental resin composite systems were created with a myriad of shades to enable the clinician to match the surrounding tooth structure seamlessly. Unfortunately, the placement of perfectly camouflagued restorations remains an unattained goal in many clinical cases [4]. Recently, in an attempt to make the process of shade selection easier while improving the final result, manufacturers created dental resin composite materials which have one or very few shades to replace the multiple shades used previously [5]. These materials are called 'single shade' or 'group shade' dental resin composites and have been found to blend into the surrounding tooth structure very well [6,7].

Among the requirements for a successful aesthetic restoration is that it maintain its colour and shade [8,9]. Colour change is among the main reasons for the replacement of anterior dental resin composite restorations [9]. Some of the most common reasons for such discolouration include the consumption of dietary substances such as tea and coffee [10-13]. These drinks stain teeth as well as dental resin composite restorations and can change the perceived shade of the filling [10,14]. Although the most recent formulations of dental resin composites often maintain colour over extended periods of time, they are still prone to staining and discolouration. Chairside polishing is a method frequently used to decrease the appearance of stains in mildly discoloured teeth and restorations [15-18]. While other studies have recorded the effect of polishing pastes or chairside polishing on stains in dental resin composites, they did so in the absence of ageing and for varying periods of time [16-18]. This study aimed to mimic the clinical scenario by ageing the materials as well as simulate a typical biannual dental visit prior to testing if polishing would improve the discolouration in a single and group shade dental resin composite. The colour stability was tested after ageing, staining with green tea or coffee and subsequently polishing. The null hypothesis was that none of the treatments would affect the colour stability of the materials, irrespective of the material used.

MATERIALS AND METHODS

This in-vitro study was conducted in the month of August 2021 at the Advanced Technology Dental Research Laboratory at the King Abdul Aziz University, Jeddah, Western region, Saudi Arabia with Ethical approval number 071-03-19. Three commercially available, widely used dental resin composite systems were chosen. The details of each system as given by their respective manufacturers are shown in [Table/Fig-1]. Two of the systems used in this study, Omnichroma and Optishade, possess colour adjustment potential

according to their manufacturers. The Omnichroma is supplied in one shade only, while Optishade has three available shades, of which OL and OM were chosen to simulate the filling of anterior teeth. The third composite system tested, Z350, is among the most commonly used in dental practices. Z350 does not have a chameleon effect. A2 is one of the most popular shades so it was chosen to be included in the study.

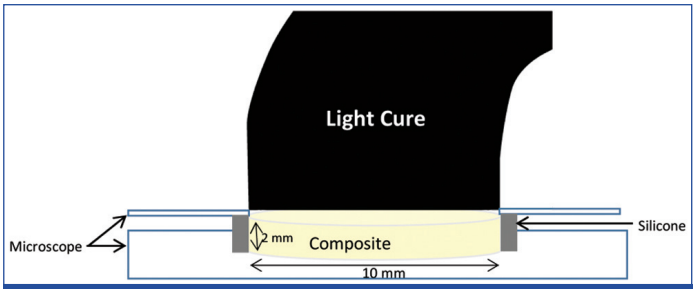
Material (Manufacturer)	Organic matrix	Inorganic filler	Shade(s)	Abbreviation
Omnichroma (Tokuyama Dental)	UDMA TEGDMA	- Uniform sized supra-nano spherical filler (260 nm spherical SiO_2-ZrO_2) - Composite filler (include 260 nm spherical SiO_2-ZrO_2) - Filler loading 79% by wt (68% by vol)	Universal	Omni
Optishade (Kerr)	BisGMA BisDMA TEGDMA	- Spherical silica and zirconia particles formed from a molecular suspension (effective particle size 5-400 nm) and 400 nm barium glass particles - Adaptive Response Technology (ART) with zirconia/silica nanoparticles and rheological modifiers - Filler loading 81% by wt (64% by vol)	Light and Medium	OL and OM
Z350 (3M ESPE)	BisGMA UDMA TEGDMA PEGDMA bis-EMA(6) resins	- Non-agglomorated/ non-aggregated silica fillers (20 nm), non-agglomorated/ non-aggregated zirconia fillers (4-11 nm) and aggregated zirconia/ silica cluster fillers (20 nm silica and 4-11 nm zirconia). The average cluster particle size is 0.6-10 microns. - Filler loading 78.5% by wt (63.3% by vol)	A2	Z350

[Table/Fig-1]: Composition of tested composite resins.

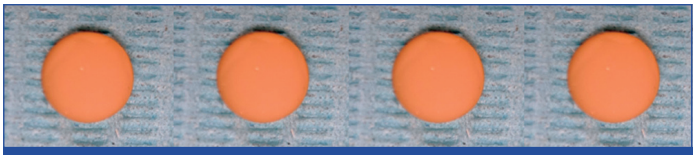
Study Procedure

In total 40 cylindrical discs (10 mm in diameter and 2 mm in depth) were fabricated. Each material and shade to be tested had 10 samples per group (n=10). The specimens were made using a custom-made silicon mould. The mould was placed on a glass microscope slide which rested on a glass slab. The composite was then adapted into the mould and covered with another glass slide to remove the excess. The specimen was immediately light cured for 20 seconds on the top and bottom using a LED Light Curing Unit (LCU) (3M ESPE Elipar, St Paul, MN, USA). The power density was measured with digital radiometer (Bluephase Meter II, Ivoclar, Amherst, NY, USA) at 1100 mW/cm^2 immediately before specimen preparation.The specimen preparation setup is illustrated while showing a completed specimen [Table/Fig-2,3]. The methodology for the study is illustrated in [Table/Fig-4].

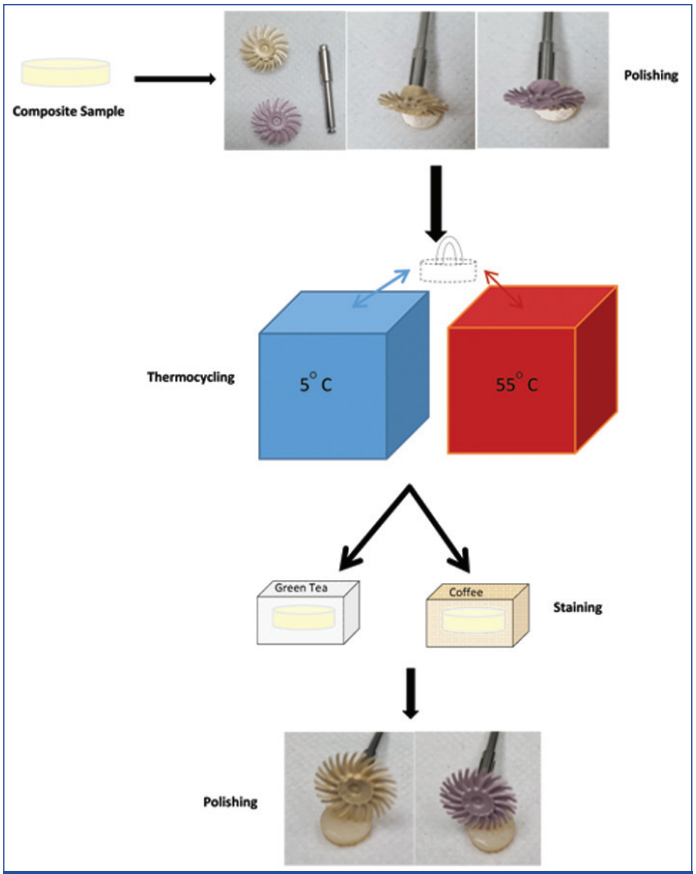
Specimens were then polished using the sof-lex diamond polishing system. The colour parameters of each sample were then determined using a clinical spectrophotometer (Vita Easyshade Advance 5, Vita Zahnfabrik, Germany). As per the manufacturer's instructions, the spectrophotometer was calibrated prior to use using the white calibration plate provided. To determine a specimen's colour parameters, the measurement tip was placed in direct contact and perpendicular to the sample surface. A positioning jig was used to place the measuring tip on each specimen in a reproducible manner. Each sample was measured three times and the mean values were used for analysis. Recalibration was done after 10 samples were analysed.



[Table/Fig-2]: Schematic representation of sample preparation.



[Table/Fig-3]: Finished composite samples.



[Table/Fig-4]: Illustration of study methodology.

Ageing procedure: All the samples were artificially aged in a custom made thermocycling unit. The thermocycling chambers had a temperature of 5°C and 55°C (15 seconds dwell time in each temperature chamber) for 5000 cycles [19].

Staining and polishing samples: Each material group was divided into two (n=5) and immersed in one of two staining solutions; coffee (1 teaspoon coffee in 180 mL of just boiled water, Nescafe Classic, USA) or green tea (one teabag brewed in just boiled water for two minutes, (Twinings Green Tea, Twinings, UK). It has been reported that the average coffee drinker consumes 3.2 cups per day and spends 15 minutes drinking a single cup [13]. Thus, storage in coffee for 24 hours simulates about one month of coffee consumption [13]. The specimens were stored in their respective staining solutions in an incubator (Memmert, Schwabach, Germany) at 37°C for six days, which represents approximately six months of tea or coffee drinking. After the immersion time was completed, the samples were removed from their respective containers, rinsed for 10 seconds, air dried and then their colour parameters were recorded. Samples were then polished using sof-lex diamond

polishing system (3 M ESPE) and their colour parameters measured once again. The samples were placed in separate containers to ensure that the same sample was measured each time.

Measurement of colour change: Baseline shades for all samples were taken immediately after sample preparation was completed. The colour parameters of each sample was measured at four different time points; immediately after preparation (T0), after ageing (T1), after staining (T2) and finally after polishing (T3). Samples were measured in the same location in the laboratory each time and a positioning jig was used to standardise the placement of the probe on the specimen during measurement of the colour parameters.

Each specimen's colour change was calculated according to the CIEDE2000 formula (ΔE_{00}) [20].

$$[(\frac{\Delta L}{K_L S_L})^2 + (\frac{\Delta C}{K_c S_c})^2 + (\frac{\Delta H}{K_H S_H})^2 + R_T (\frac{\Delta C}{K_C S_C}) (\frac{\Delta H}{K_H S_H})]^{0.5}$$

The CIEDE2000 colour-difference formula in Microsoft Excel was used for this analysis as proposed by Sharma G et al., [21].

To determine the Threshold of Perceptability (PT) and Threshold of Acceptability (AT), the parameters described by Paravina RD et al., were used [22]. The CIEDE2000 (ΔE_{00}) values in dentistry were 50:50 PT was found to be 0.8 and 50:50% AT was found to be 1.8 [22]. Thus, the colour change was considered undetectable when $\Delta E_{00} \leq 0.8$ and considered clinically unacceptable when $\Delta E_{00} \geq 1.8$ [22].

STATISTICAL ANALYSIS

Mixed model repeated ANOVA was performed to determine ΔE_{00} between materials and treatments and Bonferroni test was used for multiple comparison between groups. Statistical software, Statistical Package for the Social Sciences (SPSS) Ver. 17 (IBM Inc., Armonk, NY, USA) was utilised at 0.05 significance level.

RESULTS

The mean ΔE_{00} and standard deviations of all the materials after ageing, staining and polishing are shown in [Table/Fig-5]. The mixed model repeated ANOVA showed that the staining solution, material and polishing all had a statistically significant effect on ΔE_{00} ($p<0.001$) as shown in [Table/Fig-6]. Furthermore, the statistical difference is material dependant in all the processes which the samples were subjected to. Pairwise comparisons are shown in [Table/Fig-7]. It shows that there is a significant difference between Z350 and Omni. Z350 showed significantly less of a change in ΔE_{00} values after ageing. Z350 and Omni both had significantly higher ΔE_{00} values ($p<0.001$) when stained with green tea, while coffee did not have a significant effect on the value of ΔE_{00}. On comparison with Z350, OL showed significantly higher ΔE_{00} values when stained with coffee ($p<0.05$). Polishing coffee stained samples showed no significant differences during pairwise comparisons as shown in [Table/Fig-7].

In spite of the significant differences or lack of it, OL, Omni and Z350 all showed a clinically unacceptable change in ΔE_{00} when stained with either green tea or coffee. When aged, OM had a ΔE_{00} of 1.5, and 1.6 when stained with tea, which was reduced to 1.4 after polishing. Staining OM with coffee increased ΔE_{00} to 3.1 which decreased to 2.1 after polishing. Regardless of the staining solution,

Material	Aged (SD)	Staining solution	Stained (SD)	Polished (SD)
OL	1.89 (0.48)	Tea	1.92 (0.78)	1.40 (0.86)
	1.88 (0.49)	Coffee	4.40 (1.1)	2.90 (0.52)
OM	1.50 (0.72)	Tea	1.60 (0.24)	1.40 (0.64)
	1.60 (0.69)	Coffee	3.10 (0.98)	2.10 (1.08)
Omni	1.99 (0.64)	Tea	3.90 (0.4)	2.15 (0.48)
	1.90 (0.59)	Coffee	2.67 (0.5)	1.60 (0.58)
Z350	1.13 (0.31)	Tea	4.93 (0.99)	0.64 (0.26)
	1.12 (0.41)	Coffee	2.12 (0.62)	1.18 (0.47)

[Table/Fig-5]: Mean ΔE00 with standard deviation (SD) of aged, stained and polished materials.

Source	Type III sum of squares	df	Mean square	F	p-value
Ageing	8.581	1	8.581	27.533	0.00001*
Ageing x material	11.181	3	3.727	11.959	0.00001*
Staining	37.698	1	37.698	64.194	0.00001*
Staining x material	8.482	3	2.827	4.815	0.00705*
Staining x solution	0.020	1	.020	0.034	0.85525*
Staining x material* solution	24.615	3	8.205	13.972	0.00001*
Polishing	275.104	2	137.552	428.901	0.00001*
Polishing x material	20.395	6	3.399	10.599	0.00001*
Polishing x solution	1.460	2	.730	2.275	0.11101
Polishing x material x solution	31.697	6	5.283	16.472	0.00000*

[Table/Fig-6]: Mixed model repeated ANOVA results (*signifies significant difference and "x" is the interaction between the factors mentioned).

polishing in Z350 reduced the ΔE_{00} to below 1.8. With the exception of Omni, all the materials had ΔE_{00} of less than 1.8 after polishing green tea-stained samples. In the coffee-stained samples, polishing Omni and Z350 resulted in a clinically acceptable ΔE_{00}. Both OL and OM had ΔE_{00} of above 1.8.

DISCUSSION

Aesthetic restorations are frequently requested and placed in dental practices [3]. Optishade and Omni are both aesthetic restorative materials that have recently been introduced into the dental marketplace. Z350 is a nano composite commonly used in dental practices with a long track record, thus it was chosen for this work. A vital marker of the success of an aesthetic restoration is its colour stability [23]. Colour stability has been frequently evaluated by immersion of the test materials in staining solutions [12,14,18,23-25]. The choice of staining solutions was derived from commonly consumed beverages. Coffee is among the most commonly consumed beverages and green tea is becoming more popular among health conscious individuals [23,26]. The Commission Internationale de l'Eclairage (CIELAB) colour difference formula has been used by several studies to evaluate colour stability [11,14,23]. However, the CIEDE2000's formula corrects for small colour variations and is a recommended formula which improves the perception of the visual colour difference [7,27]. Thus, CIEDE2000 was used in this work [22].

Mat pair		Aged		Green tea stained		Polished		Coffee stained		Polished	
		Mean Diff (SE)	p-value	Mean Diff (SE)	p-value	Mean Diff (SE)	p-value	Mean Diff (SE)	p-value	Mean Diff (SE)	p-value
OL	OM	0.1858	1.00000	0.2499 (0.423)	1.00000	0.0159 (0.38)	1.00000	1.2620 (0..26)	0.63222	-0.7602 (0.48)	0.80171
OL	Omni	-0.1001	1.00000	-2.2612 (0.423)	0.00040*	-0.2112 (0.38)	1.00000	1.7361 (0.26)	0.01873*	0.4629 (0.48)	1.00000
OL	Z350	0.7680	0.05800	-3.2171 (0.423)	0.00001*	1.0451 (0.38)	0.08599	2.2918 (0.26)	0.03981*	-0.2339 (0.48)	1.00000
OM	Omni	-0.2859	1.00000	-2.5112 (0.423)	0.00013*	-0.2271 (0.38)	1.00000	0.4741 (0.26)	1.00000	1.2231 (0.48)	0.13043
OM	Z350	0.5821	0.27308	-3.4670 (0.423)	0.00001*	1.0292 (0.38)	0.09370	1.0299 (0.26)	1.00000	0.5264 (0.48)	1.00000
Omni	Z350	0.8681	0.02312*	-0.9558 (0.423)	0.22950	1.25626 (0.38)	0.02702*	0.5558 (0.26)	1.00000	-0.6967 (0.48)	1.00000

[Table/Fig-7]: Pairwise comparisons of ΔE00 after ageing, staining and polishing.
*indicates significant difference, SE is standard error and Mean Diff is the abbreviation for mean difference

As soon as a material is placed in a patient's mouth, it begins to age. In an effort to better simulate the clinical situation in the laboratory, all the materials tested were aged prior to staining. It has been reported that 10,000 cycles in a thermocycling machine are equivalent to one year of clinical function, thus the samples were aged for 5,000 cycles to simulate approximately six months of clinical service [28]. The samples were placed in the staining solution for six days which simulated six months of the consumption of the chosen beverage [13]. This study simulated the scenario of biannual dental check-ups, as recommended by dentists.

In this study, the null hypothesis was rejected because there was a significant difference in ΔE_{00} in between the materials tested and the procedures that they were subjected to. Z350 and OM had a clinically imperceptible change in ΔE_{00} after ageing, with Z350 being significantly different from OM. OL and Omni had ΔE_{00} of just over 1.8, making their colour change clinically apparent and just over the acceptable threshold. Pairwise comparisons with OL showed that staining with green tea significantly increased ΔE_{00} in Z350 and Omni while there was no significant difference in OM. This is in agreement with researchers who found that tea stained dental resin composites more than coffee did [13]. The reason given for the staining potential of tea is the presence of tannins. This is an interesing finding as green tea has been found to have a lower percentage of tannins (3.1%) when compared with black tea (13.36%) [29]. Despite the lower tannin content, both Z350 and Omni showed a significant difference after being stained with green tea. The lower tannin content may explain the positive effect polishing had on the green tea stained samples. The results of this study showed that staining with coffee caused a greater increase in ΔE_{00} in OL, when compared to Omni or Z350. This is in agreement with a previous work by AlHamdan EM et al., which found the colour stability of Omni to be comparable to Z350 when staining with coffee [24]. The OL and OM findings are in agreement with studies which found that coffee stained more than tea [11,30]. These findings are most likely due to the differences in the chemistry of the staining solutions themselves and their interactions with the individual material. Both Z350 and Omni have a similar filler loading and Urethane Dimethacrylate (UDMA) in their resin composition [31,32], while OL and OM are two shades of the same material, with identical filler loading and no UDMA in the composition of their resin matrix [33]. Even though the difference was not significant, OL appeared more stained when compared to OM. OL is the lighter shade and thus it is expected to stain more than a darker shade as has been reported previously [34].

As mentioned in the results section, all the materials exhibited clinically unacceptable changes in ΔE_{00} after staining regardless of whether a significant difference was found or not. Polishing the samples decreased the ΔE_{00} in all the materials to varying levels. After polishing, Z350 had a ΔE_{00} of less than 1.8 regardless of the staining solution. Polishing coffee stained Omni also exhibited a clinically acceptable ΔE_{00}. OL and OM also showed a decrease to below 1.8 after polishing the green tea stained samples. These results are in agreement with researchers who found that extrinsic stains decreased after polishing [18,25].

The absorption of colourants found in the different foods and beverages is a cause of staining in the oral environment. Water is the carrier for the staining pigments to travel into the resin matrix. Thus, water sorption has a major impact on colour stability and it is affected by the hydrophilicity of the resin matrix as well as the resin matrix to filler ratio. The higher the ratio of resin matrix to fillers within the restorative material, the more the water sorption and subsequent colour change [14,35]. It has been found that UDMA resin composites tend to have better colour stability when compared with Bisphenol-A-Glycidyl-Methacrylate Bis-GMA as UDMA has lower water sorption [14]. Resin based materials which contain Bis-GMA or Triethyleneglycol Dimethacrylate (TEGDMA) are hydrophilic and thus may show higher rates of absorption [36-38]. In this study, the material without Bis-GMA, Omni, did not show more colour stability than all the other materials.

As with most processes in the oral cavity, multiple factors affect the final outcome. The results of this work may be better explained by looking at both the filler loading and resin composition. The material with the lowest filler loading in this study was Z350 at 78.5% by weight. The next highest filler loading was Omni at 79% by weight. OL and OM were both 81% [31-33]. Thus, Z350 showed the most change when stained with tea, while OL and OM showed a smaller change.

The author has suggested that it is possible to remove stains on dental composite resin restorations through polishing [38]. In this work, that was true for Z350 regardless of which solution stained it, OL and OM after tea staining, and Omni after coffee staining. Polishing did not fully remove the stains for OL and OM after coffee staining or Omni after green tea stained it. It did, however, markedly decrease ΔE_{00} in all the materials tested. This is in agreement with a previous study which showed that even though the staining decreased, it was not completely removed [15].

Limitation(s)

As with all in-vitro studies, the limitation of this work is that it is not a complete simulation of the clinical situation, as in the mouth several factors are involved, such as toothbrushing and mastication along with ingestion of other types of food and drink. The staining solutions were also placed for an approximation of six months, which is a relatively short amount of time to judge the staining potential of a restoration. Further research involving the addition of toothbrushing to the processes which the samples are subjected to and a longer period of immersion would yield more information regarding the behaviour of the materials.

CONCLUSION(S)

Within the limitations of this study, several conclusions may be drawn regarding the colour stability of the materials tested. Among the most important for the clinician is that all the materials showed a change ΔE_{00} after ageing, with OM and Z350 being the only materials to exhibit a clinically acceptable change. Then, when the materials were stained for an approximation of six months, nearly all the materials showed clinically unacceptable staining. Only OM showed a clinically imperceptible change when stained with green tea. While polishing decreased ΔE_{00} the regardless of the staining medium, not all the materials went back to a clinically acceptable level of ΔE_{00}. Thus, it is important that a clinician is aware that aesthetic dental filling materials are susceptible to a visually apparent colour change after clinical service and that such a colour change does not automatically necessitate replacement of the restoration. Chairside polishing should improve the stained appearance but it may not completely remove the stain to return the material to the original perceived shade.

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