ORIGINAL ARTICLE

Journal of Research in Dental and Maxillofacial Sciences

DOI: 10.61186/jrdms.9.3.193

Influence of Polishing Systems on Color Stability of Dental Composite Resins: An In Vitro Study

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Article History
Received: 14 Dec 2023
Accepted: 11 Mar 2024

Abstract

Background and Aim: There is a growing demand for esthetic dental treatments with composite resins like Ceram.x Spectra™ ST® (CS) due to the importance of a beautiful smile; but color change may occur affecting the longevity and quality of composite restorations. The purpose of this study was to evaluate the color stability of a composite resin, subjected to two different polishing systems, after immersion in different coloring solutions (common beverages).

Materials and Methods: Forty specimens were fabricated from CS nanoceramic composite resin and polished with Enhance® and Astropol® finishing and polishing systems. The CIE L*a*b* color parameters were measured before and after immersing the specimens in coffee, red wine, and Coca-Cola. The chromatic difference was assessed by calculating the ΔE. Two-way ANOVA was applied to compare the ΔE values based on the type of polishing system, coloring solution, and their interaction.

Results: Astropol® resulted in better color stability and smoother surfaces than Enhance®. Wine and coffee significantly changed the color stability of tested composite resin ($P<0.05$), while Coca-Cola did not affect the color stability ($P>0.05$).

Conclusion: The choice of dental finishing and polishing system affects the color stability of CS composite resin following exposure to commonly consumed drinks.

Keywords: Composite Resins; Ceramics; Color; Dental Polishing

Cite this article as: Francisco A, Dey T, Mendes JM, Sousa A, Torres O. Influence of Polishing Systems on Color Stability of Dental Composite Resins: An In Vitro Study. **J Res Dent Maxillofac Sci. 2024; 9(3):193-203.**

Introduction

Smile is an important feature of the face, and is crucial for social and psychological well-being. The esthetic component has gained greater preponderance in dental treatments due to the importance of a presentable look [1], and has gained a prominent place in daily clinical practice. Dental composite restorations are minimally invasive [2] and highly common in dental practice [3]. Currently, composite resins are considered the material of choice for anterior and posterior dental restorations, not only because of their excellent optical, mechanical, and physical properties, but also because of their easy handling and application. Composite resins are usually made of methacrylate-based monomers [4], such as bisphenol A-glycidyl methacrylate, urethane dimethacrylate, and ethylene glycol dimethacrylate, reinforced by inorganic filler particles whose content and size affect the color stability of composite resins [5]. However, composite resins also have disadvantages due to intrinsic properties and extrinsic factors. The intrinsic properties depend on the chemical composition of composite resins while the extrinsic factors depend on the environment to which they are exposed, such as diet, oral hygiene, and smoking [6,7].

Ceram.x Spectra™ ST® (CS; Dentsply Sirona) is a light-cure radiopaque composite resin for anterior and posterior restorations of primary and permanent teeth. CS is a nano-hybrid composite resin with pre-polymerized inorganic particles. Its inorganic component is composed of ceramic nanoparticles, mainly barium glass, pre-polymerized non-aggregated inorganic particles, ytterbium fluoride, and other organically modified inorganic particles like glass ceramics. The average particle size varies between 0.1 and 3.0 μm, according to the manufacturer (Table 1). Nanoscale fillers combined with conventional glass fillers are approximately 1 μm in size and are dispersed as a hybrid mixture. The inorganic component of this composite resin is 78-80% by weight or 60-62% by volume, conferring good mechanical, optical, and esthetic properties with excellent handling characteristics. Color stability is the ability of a dental material to preserve its original color. Several factors, such as the composition of composite resin, its surface characteristics [8], curing conditions [9], water sorption capacity, and surface finish influence the color stability of composite restorations [3,10].

Table 1. Characteristics and composition of composite resin and two finishing and polishing systems

Material	Brand (manufacturer)	Composition	Particle size	Filler (wt%)	Classification
Ceram.x Spectra™ ST® composite resin	Dentsply Sirona	Mixture of pre-polymerized SphereTEC® spherical fillers, non-agglomerated barium glass and ytterbium fluoride. The resin matrix contains highly dispersed methacrylic polysiloxane particles.	0.1-3.0 μm (filler)	78-80% (W) / 60-62% (V)	Nanoceramic with pre-polymerized fillers
Enhance® finishing and polishing system	Dentsply Sirona	Finishing system - Dimethacrylate urethane resin Compound impregnated with aluminum oxide. Polishing system - Diamond impregnated dimethacrylate urethane resin compound.	40 μm aluminum oxide (grit)		
Astropol® finishing and polishing system	Ivoclar Vivadent	Astropol F and P are composed of silicone rubber, silicon carbide particles and pigments. Astropol HP contains silicone rubber, diamond particles, aluminum oxide.	12.8 μm aluminum oxide and 3.5 μm titanium dioxide (grit)		

The success of a restoration also depends on its degree of polymerization, which is characterized by the conversion of monomers to polymers, accompanied by a volumetric reduction of the material, a process called polymerization shrinkage [11]. Polymerization of active composite resins by the visible light is a process dependent on the inorganic component (type, amount, and size), organic component, and refractive indices of the materials [12].

The main reason for replacing a composite resin is clinically unacceptable color change, especially in the anterior region of the oral cavity [3]. Dental restorations are exposed to several conditions that cause physical and mechanical changes, such as wear and pigmentation. Thus, over time, the quality of restoration deteriorates, requiring replacement. In the long-term, pigmentation and wear of restorative materials are seen as major problems. The size and content of inorganic particles in composite resins are determining factors for the wear and discoloration of restorative materials [13]. Patients' oral hygiene also plays an important role in color stability, since the presence of plaque and its metabolic end products can degrade the organic matrix of composite resins, further facilitating discoloration [14].

The appearance of esthetic restorations is also influenced by the surface texture, which is directly affected by the inorganic particles in the composition of composite resins. It is essential to maintain the smoothest surface after restoration to keep it free from extrinsic stains and offer a comfortable feel when the patient's tongue touches the restoration. It is universally accepted that a smoother surface has advantages in terms of function, esthetics, and longevity compared to more irregular surfaces that are more susceptible to pigmentation. The surface roughness threshold for bacterial retention is 0.2 µm; below this value, a reduction in plaque accumulation can be expected. Changes of up to 0.3 µm in surface finish can be easily detected by the tongue. The finishing process removes excess material with particles larger than 25 µm, while the polishing process removes particles smaller than 25 µm [15].

The main goals of finishing and polishing are to remove excess material and decrease the surface roughness of restorations, which are useful to improve patient comfort, maintain healthy soft tissues, and ensure good surface resistance to discoloration, reducing the risk of staining [3].

The effect of different finishing and polishing systems on the surface roughness of composite resins has been extensively evaluated in the literature; however, studies on the effect of finishing and polishing systems on color stability are limited in number [13]. Thus, the purpose of the present experimental study was to evaluate and compare the color stability of a dental composite resin subjected to two different polishing systems after immersion in different coloring solutions.

Materials and Methods

Specimen preparation:

In this in vitro experimental study, high viscosity E1 shade CS nanoceramic composite resin (Dentsply Sirona, USA) and two finishing and polishing systems namely Enhance® (Dentsply Sirona, USA) and Astropol® (Ivoclar Vivadent, Liechtenstein) were used.

The sample size was estimated using the sample size calculation formula according to a previous in vitro study on dental materials [16]. Forty samples were fabricated using a conformator to obtain color scales (Porcelain sampler® Item-no. 7015; Smile Line, Switzerland). The samples were prepared in the form of a disc using a stainless-steel mold with 10 mm diameter and 2 mm thickness. First, CS composite resin was placed in the mold; then, the upper part of the sample was covered with a glass coverslip, and composite was pressed against a glass slab to obtain a uniform and smooth surface. Light curing was carried out with SmartLite Focus® curing unit (Dentsply, USA) with a maximum power of 800 mW/cm^2. Each 2 mm-thick increment of enamel composite resin was cured for 20 seconds on each side of the specimen.

Polishing of specimens:

All specimens were abraded with abrasive papers to remove the superficial layer. Twenty specimens were then polished with Enhance® system (Dentsply Sirona), composed of 2 rubber systems, one for finishing and one for flame-shaped polishing, and each one was used for 20 seconds. The remaining 20 specimens were polished with Astropol® system (Ivoclar Vivadent), composed of 3 rubber polishers, one grey finisher, one green polisher and one high gloss pink polisher (all cup-shaped), and polishing was performed for 20 seconds with each instrument.

Next, all specimens were washed with distilled water for 10 seconds and dried with cellulose paper [6]. All specimens were stored in saline at 37°C for 16 hours in an incubator until initial color measurement.

Initial color measurement:

Prior to immersion in different solutions, color measurements were made for each specimen using a spectrophotometer (Vita EasyShade 3D-Master®, VITA Zahnfabrik, Bad Säckingen, Germany). Prior to the measurements, the spectrophotometer was calibrated according to the manufacturer's instructions. Each sample was removed from the saline solution (0.9 g sodium chloride, 100 mL purified water), washed with distilled water and dried with cellulose paper. Three measurements were made at the center of each specimen against a black background [6]. The measured values were recorded in an Excel database (Microsoft 365®, 2022, Seattle WA, USA).

Color measurement system:

The color measurement system used was the Commission Internationale d'Eclairde L*a*b* (CIE L*a*b*) [17]. The CIE L*a*b* system involves measuring three color dimensions; L* represents lightness of an object ranging from 0 (black) to 100 (white), a* represents redness (a>0) and greenness (a<0), and b* represents yellowness (b>0) and blueness (b<0).

Immersion of specimens in coloring solutions:

After the initial measurements, the specimens were immersed in saline solution at 37°C in an incubator and were protected from natural light with aluminum foil. The specimens were randomly assigned to 8 groups and individually immersed in the following solutions: two in coffee (Nescafé Clássico®, Nestlé Suisse, Vevey, Switzerland), two in red wine (Encostas do Bairro, Vinho Regional Tejo 2022, Portugal), two in Coca-Cola® (The Coca-Cola Company, Istanbul, Turkey), and two in distilled water (control groups), for 40 hours at 37°C in an incubator. Storage of composite resin in coffee solution for 40 hours without refreshing simulated the beverage consumption over the period of one month and a few days [18], which was the basis of choosing this specific time period.

Final color measurement:

After 40 hours of incubation, the specimens were washed with distilled water for 10 seconds and dried with cellulose paper [6]. The spectrophotometer was calibrated according to the manufacturer's instructions, and final measurements were performed (Table 2), following the same protocol as the initial measurements. The measure of ΔE was calculated by the formula $\Delta E = \sqrt{(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})}$, where Δ corresponds to the difference between the initial and final values of E, L*, a*, and b*.

Table 2. Samples after immersion in staining solutions

Statistical analysis:

Data analysis was performed using the R program version R 4.1.3 (R Core Team, 2022). The normality of data distribution (ΔE, L*, a*, and b*) was analyzed by the Shapiro-Wilk test, with $P>0.05$ as a criterion to consider the normality of data distribution. The homogeneity of the variances was evaluated by the Levene test, confirming this assumption in all analyses. Two-factor ANOVA was used to compare the chromatic difference (ΔE) values among the groups (effects of polishing system and coloring solution and the interaction between them). The tests of multiple comparisons between coloring solutions used the Bonferroni correction. Two-way ANOVA was also double-checked using LibreOffice Calc, version 7.4. The standardized residuals were calculated to evaluate the assumption of normality of linear models, confirming $P>0.05$ in the Shapiro-Wilk test. To evaluate the form of association between the variables, the effect size was calculated with eta-square (η^2), considering a cut-off point of 0.01 for a slight effect, 0.06 for a moderate effect, and 0.14 for a high effect [19]. The significance level considered for rejecting the null hypothesis was 5% (alpha = 0.05).

Results

The effects of the two polishing systems (Enhance and Astropol) and four coloring solutions (coffee, red wine, Coca-Cola and distilled water as control) on color parameters (L*, a* and b*) were studied before and after immersion in the coloring solution. Each of these parameters were measured five times to obtain the mean (M) and standard deviation (SD). Two-way ANOVA revealed the statistical significance according to the P value and F value as well as substantive significance from η^2 value (effect size). This test was also used to analyze the interaction effect of polishing system and coloring solution.

First, the results of two-way ANOVA are presented for the comparison of ΔE by the polishing system, coloring solution, and their interaction (Table 3). Overall, the Enhance® polishing system (M=4.68, SD=3.65) showed substantial chromatic differences compared to Astropol® polishing system (M=4.08, SD=2.65), with statistically significant results, $F(1,8)=123.48$, $P<0.001$ and large effect size with $\eta^2=0.99$. When evaluating the coloring solution, regardless of the type of polishing system, statistically significant results were obtained with $F(3,16)=3.21$, $P=0.013$, and a high effect size with $\eta^2=0.51$. Multiple comparison tests revealed statistically significant differences between the control and coffee ($P<0.001$), control and red wine ($P<0.001$), coffee and red wine ($P<0.001$), coffee and Coca-Cola ($P<0.001$) and red wine and Coca-Cola ($P<0.001$). Particularly, red wine gave the highest ΔE value (M=10.16, SD=2.15) and coffee gave the second highest (M=7.23, SD=0.55). On the other hand, Coca-Cola and distilled water yielded the lowest ΔE. When the results were compared with respect to the control specimens, red wine and coffee showed a ΔE much greater than the control; whereas, for the Coca-Cola, the ΔE values were similar to the control (Figure 1).

When the polished composite resin specimens were immersed in four coloring solutions, statistically significant changes were observed in L*, a* and b* before and after immersion, with high effect size (Table 3).

Table 3. Two-way ANOVA results to show the effects of polishing system, coloring solution and their interaction on ΔL*, Δa*, Δb* and ΔE values before and after immersion

	ΔL* shown as M(±SD)	Δa* shown as M(±SD)	Δb* shown as M(±SD)	ΔE shown as M(±SD)
Enhance	2.62 (1.37)	-1.24 (0.89)	-3.67 (3.26)	4.68 (3.65)
Astropol	2.06 (1.09)	-0.53 (0.01)	-3.48 (2.41)	4.08 (2.65)
	$F(1,8)=123.48, P<0.001$ $\eta^2=0.99$			
Coffee	3.16 (0.13)	-0.76 (0.16)	-6.46 (0.51)	7.23 (0.55)
Red wine	6.15 (1.37)	-2.23 (1.3)	-7.78 (1.02)	10.16 (2.15)
Coca-Cola	0.01 (0.34)	-0.46 (0.06)	-0.43 (0.07)	0.63 (0.35)
Control (distilled water)	0.06 (0.65)	-0.11 (0.08)	0.38 (0.06)	0.4 (0.66)
	$F(3,16)=3.21, P=0.013$ $\eta^2=0.51$			
Enhance				
Coffee	3.34 (0.01)	-1.01 (0.11)	-6.99 (0.36)	7.81 (0.38)
Red wine	7.46 (0.75)	-3.59 (0.31)	-7.46 (1.19)	11.14 (1.44)
Coca-Cola	0.06 (0.85)	-0.39 (0.02)	-0.58 (0.19)	0.7 (0.87)
Control	-0.37 (0.94)	-0.01 (0.08)	0.33 (0.03)	0.5 (0.94)
Astropol				
Coffee	2.97 (0.13)	-0.52 (0.2)	-5.93 (0.17)	6.65 (0.29)
Red wine	4.84 (0.55)	-0.87 (0.12)	-8.11 (1.13)	9.48 (1.26)
Coca-Cola	-0.07 (0.24)	-0.52 (0.05)	-0.28 (0.12)	0.59 (0.27)
Control	0.5 (0.08)	-0.21 (0.03)	0.42 (0.46)	0.69 (0.47)
	$F(1,34)=2.47, P=0.036$, $\eta^2=0.006$ for polishing system $F(3,34)=125.27, P<0.001$, $\eta^2= 0.99$ for coloring solution			

M = mean, SD = standard deviation, F = F-statistics value, P = probability after Bonferroni correction, η^2 = effect size = SS effect / SS total, SS = sum of squares, df1 = treatment degrees of freedom = number of groups – 1, df2 = error degrees of freedom = sample size of all groups – number of groups.

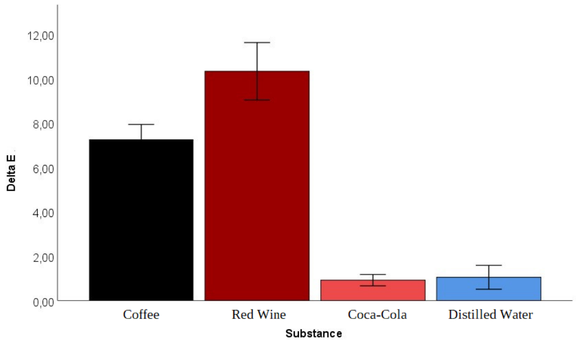

Figure 1. Delta E values of Ceram.x Spectra™ ST® nanoceramic composite resin upon immersion in four coloring solutions (common beverages, distilled water as control).

When the effect of two polishing systems was assessed before and after immersion in coloring solutions, statistically significant results were detected in L* and a* components.

The changes in both L* and a* parameters were higher in the Enhance® polishing system compared to Astropol® after immersion in coloring solutions. Multiple comparisons detected statistically significant differences in L* parameter in comparison of control and red wine (P=0.001), and red wine and Coca-Cola (P<0.001). In a* parameter, significant differences were found only between the control and red wine groups (P=0.006). In b* parameter, statistically significant differences were detected in the comparison of control and coffee (P<0.001), control and red wine (P<0.001), coffee and red wine (P=0.008), coffee and Coca-Cola (P<0.001), and red wine and Coca-Cola (P<0.001). In short, all color parameters changed the most after immersion in red wine. This was the only substance that differed significantly from the control group in all color parameters. Coffee ranked next, but it showed significantly greater changes in b* parameter than the control and Coca-Cola groups. Control and Coca-Cola did not show statistically significant differences in the three parameters, and Coca-Cola was the coloring solution that produced the least changes. Regarding the L* parameter, the change in red wine was the highest, which was higher in the Enhance® polishing system. In a* parameter, red wine caused the highest change, and the observed change occurred mainly in the Enhance® polishing system.

Discussion

The results showed a statistically significant difference between Enhance® and Astropol® polishing systems. Red wine caused the greatest discoloration followed by coffee, with statistically significant differences. Coca-Cola and distilled water caused no statistically significant discoloration.

According to the literature, composite resin would be less stained if it is subjected to polishing; for this reason, in this experimental study, two different polishing systems were compared [2]. Composite resin superficial layers contain more polymers than fillers and although this layer is important for surface roughness, it serves as a drawback when considering its effect on ΔE, due to its high affinity for water and stains [20].

According to the literature, finishing and polishing systems that contain aluminum oxide yield lower surface roughness values, being the best instrument to produce smooth surface restorations compared to discs impregnated with other abrasives. As diamond particles are harder than aluminum oxide and silicon carbide particles, diamond particles create a rougher surface on the restorative material in finishing and polishing procedures. However, these results did not demonstrate significance in the applications of the finishing and polishing systems with aluminum oxide or diamond particles, probably because they contain nanoparticles of equal size to their equivalents [21].

According to Aydin et al. [15], the finishing and polishing system that caused the least color change was impregnated with diamond, while the greatest discoloration was observed in the group that did not undergo finishing and polishing. Alawjali and Lui [22] reported that the finishing and polishing systems that yielded the highest color stability were the systems impregnated with carbide abrasive. Marufu et al. [20] described that the finishing and polishing system that yielded the best color stability was aluminum oxide discs. In the present experimental study, we compared two different finishing and polishing systems namely Enhance® and Astropol, the first with two steps and the second with three steps and we found higher color stability in the groups polished by the Astropol® system.

In the present experimental study, the commonly consumed coloring drinks were selected for evaluation [1,2,6,13-15]. Coffee has proven to be a beverage with a high capacity for discoloration of composite resin and natural teeth [1,2,6,13,14,18,22]. The abundance of yellow pigments with low-polarity coffee dyes have great affinity for the resin matrix [2]. According to Guler et al., the average time of coffee consumption is 15 minutes and among coffee consumers, the average consumption is 3.2 cups per day [18]. Therefore, 40 hours of storage of composite resin in coffee simulates consumption of coffee for more than one month.

Several in vitro studies have shown that there are a variety of food substances that can change the color of a composite resin, the most common being coffee, Coca-Cola, wine, tea, fruit juices, soy sauce, mustard, and ketchup [6,18]. In the present study, the control group immersed in distilled water and also the Coca-Cola group did not experience a significant color change. However, the groups immersed in red wine and coffee showed a significant color change. These results agree with previous studies [1,2,6,13-15].

Our first line of thought was whether the acidity of the drink is causing this significant color change or not. This prompted us to take a look at the pH values of these coloring solutions. Coca-Cola is reported to have a pH of 2.6 to 2.7, mainly due to the phosphoric acid (H_3PO_4) present in its composition. Instant coffee such as Nescafe Classic has a pH of 4.85-5.10, probably due to the acidic Robusta content (52%) mixed with neutral Arabica (48%). Red wine is known to have a pH of 3.3-3.6. The lower the pH, the higher the acidity. This clearly shows that the color change of the polished composite resin does not follow the trend in acidity of the drinks i.e., Coca-Cola > red wine > coffee.

Acids show differences in terms of promoting dissolution and, consequently, erosion of restorative materials. Furthermore, presence of phosphate ions can prevent dissolution, as these ions have been shown to reduce the rate of dissolution of calcium phosphate in tooth [3, 6,14,]. Still, Coca-Cola did not seem to influence the color stability of composite resins.

Red wine was the drink that showed the greatest color change in the present study. According to several studies, ethanol can degrade the polymer matrix, contributing to a more pronounced discoloration caused by red wine [2,6,23]. However, a closer inspection of molecular level chemistry is required in this regard. Red wine used in the present study had an alcohol content of 13%. Alcohols have hydrogen bonding (H-bonding) capability, which can interfere and compete with the intermolecular H-bonding in urethane dimethacrylate (UDMA) present in Enhance® (Figure 2); whereas, silicone rubber present in

Astropol® is not so heavily H-bonded. This explains why red wine caused higher ΔE value in Enhance® polished dental composite resin samples.

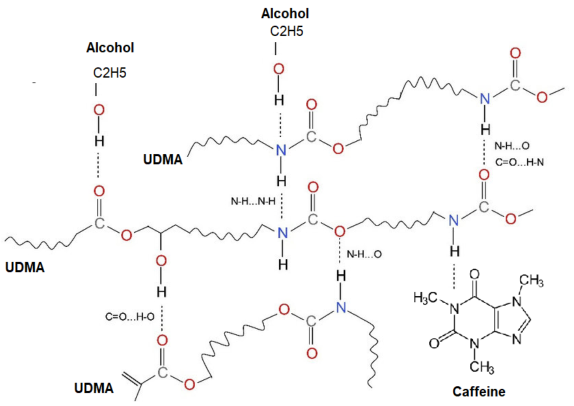

Figure 2. Different sites of hydrogen-bonding in urethane dimethacrylate (UDMA) resin present in Enhance® finishing system; interaction of alcohol and caffeine causing rupture of UDMA intermolecular H-bonds.

On the other hand, Nescafe instant coffee and Coca-Cola have a caffeine content of 3.15% and 0.05%, respectively estimated by high-performance liquid chromatography [24]. Caffeine has two fused rings slightly angled to each other, and has one non-methylated nitrogen which can accept H-bond [25] (Figure 2). Interaction of caffeine with UDMA is supposed to be an entropy-driven surface phenomenon [26], causing cleavage of UDMA hydrogen bonds. This explains the observed trend in ΔE values in the current study i.e., red wine > coffee > Coca-Cola ~ control. The more the alcohol or caffeine content present in the drink, the more the cleavage of H-bonding in Enhance® polishing system, and hence the higher the color change upon polishing would be (Figure 1).

The abrasive particle size present in the finishing and polishing system is directly responsible for the resultant surface roughness of composites. Literature shows that for a nano-filled dental composite resin, Astropol provided a smoother surface (R_a=1.15±0.24) than Enhance PoGo (R_a=1.39±0.39) [27]. This correlates with the aluminum oxide particle size of 12.8 µm vs. 40 µm, respectively (Table 1) and offers further explanation why Astropol® is more color stable. XRD pattern [8], AAS trace metal content [28] and SEM microstructure [29] can also play an important role in analysis of dental nanocomposites.

Quantitative assessment of color change by visual inspection is clinically relevant despite its poor reproducibility and reliability. However, qualitative tools such as electronic devices must assess the color change caused by the tested solutions in the composite resin. The CIE L*a*b* color system used in the present study is recommended for dental purposes. It characterizes color based on human perception and designates according to the three spatial coordinates of L*, a* and b*. Theoretically, if the material is completely color stable with no color difference, it will be detected after its exposure to the tested environment (ΔE=0). Several authors have reported that ΔE values between 1 and 3 are perceptible to the naked eye and ΔE values greater than 3.3 are clinically unacceptable [6,30]. In this regard, the color change of specimens in both of the polisher groups was unacceptable in coffee and red wine. It is also noteworthy that the negative sign associated with change in a* component is due to the negative color scale (green side), whereas the negative sign associated with change in b* component is due to the increase in color from initial to final state in the positive side of the color scale (yellow side).

Conclusion

The present results revealed that red wine and coffee changed the color stability of the tested composite resin; Coca-Cola did not change its color stability. The chemical structure of the finishing and polishing system as well as the chemical components present in coloring solutions play a crucial role in color stability of dental composite resins.

Funding

Not applicable.

Conflict of interests

On behalf of all authors, the corresponding author states that there is no conflict of interests.

Availability of data

All data are included in the manuscript.

Author Contributions

All authors contributed equally to the research and preparation of the manuscript.

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