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BASIC RESEARCH:

Color Stability of Dental Composites Under Accelerated Aging in Staining Solutions

Estabilidad del color de resinas compuestas dentales tras envejecimiento acelerado en soluciones pigmentantes

Alireza Ranjbar DDS[1] https://orcid.org/0000-0002-6422-6629
Yasaman Sherafatmand DDS[1] https://orcid.org/0000-0001-6956-1621
Ahmadreza Mirzaei DDS[1] https://orcid.org/0000-0003-4524-6752
Sajjad Omidian PhD[2] https://orcid.org/0000-0003-4734-4751
Sara Abtahi DDS[1-3] https://orcid.org/0000-0001-8373-797X

[1]Ph.D. Candidate, Department of Dental Biomaterials, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran.
[2]Researcher, Faculty of Biomedical Engineering (Center of Excellence), Amirkabir University of Technology (Tehran Polytechnic) Tehran Iran.
[3]NanoTech Laboratory, School of Engineering, Faculty of Science and Engineering, Macquarie University, Sydney 2109, Australia
Department of Dental Biomaterials, School of Dentistry, Tehran University of Medical Sciences, Tehran 1416753955, Iran.

Correspondence to: Sara Abtahi - sarushka76@gmail.com

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ABSTRACT: This study aimed to evaluate and compare the effects of three commonly consumed beverages coffee, tea, and cola on the color stability of two commercially available resin composites, Geanial Anterior and Edge Com. Disk-shaped specimens (n=20) from each composite were prepared and subjected to staining by immersion in coffee, tea, cola, or distilled water (control). The specimens underwent thermocycling (10,000 cycles between 5°C and 55°C) to simulate one year of clinical aging. Color assessments were performed using a spectrophotometer, and color differences were calculated using both the CIE76 (ΔE^*) and CIEDE2000 (ΔE_{00}) formulas. Analysis revealed that both composites experienced color changes after immersion in the staining solutions, with coffee causing the most significant discoloration, followed by tea, while cola had minimal effects. No statistically significant difference was observed between the two composites regarding their susceptibility to staining, but the staining agents themselves had a significant effect on color stability ($p<0.001$). The results indicate that both coffee and tea cause noticeable discoloration in resin composites, with coffee being the most potent staining agent. These findings suggest that clinicians should consider the effects of patient dietary habits when selecting composite materials and educating patients on beverage consumption to maintain the aesthetic quality of restorations.

KEYWORDS: Composite resins; Dental materials; Color stability; Accelerated aging; Spectrophotometry; Beverages.

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RESUMEN: El objetivo de este estudio fue evaluar y comparar los efectos de tres bebidas de consumo habitual café, té y cola sobre la estabilidad del color de dos resinas compuestas comerciales: Geanial Anterior y Edge Com. Se prepararon discos (n=20) de cada resina compuesta, los cuales fueron sometidos a tinción mediante inmersión en café, té, cola o agua destilada (control). Posteriormente, los especímenes se sometieron a termociclado (10,000 ciclos entre 5 °C y 55 °C) para simular un año de envejecimiento clínico. La evaluación del color se realizó mediante espectrofotometría, calculando las diferencias de color con las fórmulas CIE76 (ΔE*) y CIEDE2000 (ΔE_{00}). El análisis reveló que ambas resinas experimentaron cambios de color tras la inmersión en las soluciones pigmentantes, siendo el café el agente con mayor capacidad de tinción, seguido del té; la cola tuvo un efecto mínimo. No se observaron diferencias estadísticamente significativas entre los dos materiales en cuanto a su susceptibilidad a la tinción, pero los agentes pigmentantes sí mostraron un efecto significativo sobre la estabilidad del color ($p<0.001$). Los resultados demuestran que tanto el café como el té inducen una decoloración clínicamente perceptible en las resinas compuestas, siendo el café el agente más potente. Estos hallazgos sugieren que los clínicos deben considerar los hábitos dietéticos del paciente al seleccionar materiales compuestos y al educarlos sobre el consumo de bebidas para mantener la calidad estética de las restauraciones.

KEYWORDS: Resinas compuestas; Materiales dentales; Estabilidad del color; Envejecimiento acelerado; Espectrofotometría; Bebidas.

INTRODUCTION

Resin-based dental composites are widely used in restorative dentistry due to their aesthetic properties, ease of use, and ability to bond to the tooth structure. However, one of the persistent challenges in the use of composite materials is their susceptibility to discoloration over time, particularly when exposed to common staining agents. Color stability is particularly important for anterior restorations, where any visible change in shade can affect patient satisfaction and may lead to additional treatments or early replacement of the restoration. Among the most common reasons for failure, fracture of the tooth or restoration remains prevalent, while aesthetic concerns-such as color mismatch, anatomical form, and surface staining-are frequently observed in restorations placed for aesthetic purposes (1).

Composite restorations can discolor due to extrinsic factors like surface staining, plaque buildup, and superficial degradation, or intrinsic factors such as chemical changes within the material, including unreacted monomers and incomplete polymerization. The resin's composition, filler properties, polymerization degree, and water absorption impact color stability (2, 3). External factors, including diet, smoking, oral hygiene, and surface finishing, also influence discoloration. Together, these factors affect the long-term aesthetic outcomes of composite restorations (4, 5). Beverages such as coffee, tea, and cola are well-known for their high staining potential due to their acidic nature and pigmented compounds (3, 6). Coffee, with its melanoidins, and tea, rich in tannins, can penetrate the composite resin matrix, leading to noticeable discoloration (7). Cola, while less pigmented, can degrade the composite structure over time due to its low pH, enhancing its vulnerability to staining (8).

Although research has been conducted on the staining effects of individual beverages on resin composites, few studies have directly compared the effects of multiple staining agents on different types of resin composites. Moreover, the use of advanced color difference formulas, such as

CIEDE2000 (ΔE_{00}), which better reflects human visual perception of color changes, is not consistently applied across comparative studies, with many relying solely on the CIE76 (ΔE^*) formula (9).

The aim of this study is to compare the effects of three commonly consumed beverages -coffee, tea, and cola- on the color stability of two commercially available resin composites, Geanial Anterior and Edge Com. Using thermocycling to simulate aging and employing both ΔE^* and ΔE_{00} color difference formulas, this study seeks to evaluate the extent of discoloration and provide a better understanding of how different staining agents affect composite materials over time.

METHOD AND MATERIALS

A detailed summary of the materials used in this study is presented in Table 1.

Table 1. Specifications of the composites used in this study.

Material	Type	Shade	Lot	Resin Content	Filler Composition	Particle Size	Filler Load	Photoinitiator	Manufacturer
G-ænial ANTERIOR	Micro-Hybrid	A2	230725A	UDMA, dimethacrylate comonomers	Prepolymerised silica, strontium fluoride and lanthanoid fluoride containing fillers, fluoroaluminosilicate, fumed silica	0.1 µm-17 µm, 16 nm	77 wt.%	Camphorquinone	GC Europe N.V., Leuven, Belgium
EdgeCom	Nano-Hybrid	A2	202070101	Bis-GMA, BDDMA, DUDMA	Silica, Glass-Ceramic	93 nm-4 µm	78 wt.%	Camphorquinone and 2,4,6-Trimethylbenzoyl diphenyl phosphine oxide	Hamerz Medical Co., Tehran, Iran

UDMA: Urethane dimethacrylate; Bis-GMA: Bisphenol A-glycidyl methacrylate; BDDMA: 1,4-Butanediol dimethacrylate; DUDMA: Diurethane dimethacrylate.

SPECIMEN PREPARATION

Disk-shaped composite specimens were prepared using a custom-made rubber mold, producing specimens with a thickness of 3.5 mm and a diameter of 10 mm. One-millimeter-thick glass slides were placed beneath and above the mold to ensure an identical surface finish for each specimen. An LED light-curing unit (CuringPen, Eighteeth, Changzhou, China; 385-515 nm, dual peaks at 410 nm and 470 nm) was positioned on the glass slide to cure the composites according to the manufacturer’s instructions. The light intensity of the curing unit was evaluated using a digital radiometer (DigiRate, Monitex, New Taipei City, Taiwan), revealing an intensity of approximately 1000 mW/cm². The specimens were cured on both sides, with the upper side (cured first) marked for color evaluation.

A total of 20 disk-shaped specimens were prepared from each composite. Once prepared, the specimens from each composite were randomly assigned to four subgroups (n=5) for immersion. Prior to baseline color measurement and immersion, the specimens were stored in distilled water at 37 °C for 24.

IMMERSION MEDIA PREPARATION AND STAINING PROCEDURE

Following baseline color assessment, the specimens were immersed in four different solutions according to their subgroup allocation: distilled water, coffee, tea, or cola soft drink (The Coca-Cola Company, Atlanta, GA, USA). Coffee solution was prepared by mixing a single 1.8-gram packet of instant coffee (Nescafé Gold, Nestlé S.A., Vevey, Switzerland) with 180 mL of hot water. Tea solution was prepared by steeping two teabags (English Tea, Ahmad Tea Ltd, London, UK) in 240 mL of boiling water.

Each specimen was placed in a separate 15 mL centrifuge tube filled with the respective immersion medium. The tubes were then placed in a thermocycling device (Delta Co., Mashhad, Iran) and subjected to 10,000 cycles between 5 °C and 55 °C, simulating approximately one year of clinical aging. The dwell time at each temperature was set to 30 seconds, with a 10-second drain time between cycles. Considering the protocol, the total immersion time for each specimen was approximately 8 days in total. After every 2,000 cycles, the immersion media was replaced with fresh solution, and the specimens were rinsed and cleaned with gauze.

COLOR ASSESSMENT

A portable spectrophotometer (i1 Pro, X-rite, Michigan, USA) was used to perform the baseline and final color assessment after the staining procedure. At the beginning and after each group measurements, calibration was performed as indicated by manufacturer. All measurements were performed by a single trained operator with standardized D65 light room illumination, under a white background. Three readings were performed for each specimen, and the mean values of color coordinates were obtained.

To evaluate the color differences between time intervals, both the CIE76 (ΔE*) and CIEDE2000 (ΔE_{00}) color difference formulas were used.

The ΔE* formula is based on the Euclidean distance between two color points in the CIELAB color space, using three parameters: lightness (L*), chroma on the red-green axis (a*), and chroma on the yellow-blue axis (b*) (10). The formula calculates the color difference as follows:

$$\Delta E^* = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

For a more refined assessment, the CIEDE2000 (ΔE_{00}) formula was also used (11). This formula accounts for perceptual non-uniformities in the CIELAB color space by introducing corrections for lightness, chroma, and hue. The formula is as follows:

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

ΔL′, ΔC′, and ΔH′ are the differences in lightness, chroma, and hue for a pair of specimens. SL, SC, and SH are weighting functions that adjust the total color difference for perceptual variations. KL, KC, and KH are parametric factors, each set to 1 for this study. RT is a rotation term that accounts for the interaction between chroma and hue differences.

For ΔE*, the 50:50% perceptibility threshold (PT) was set at 1.2, and the acceptability threshold (AT) was set at 2.7 (12). For ΔE_{00}, the 50:50% PT was set at 0.8, and the AT was set at 1.8 (12). These thresholds were applied to evaluate whether the color changes observed in the specimens were within clinically acceptable ranges.

STATISTICAL ANALYSIS

ΔE* and ΔE_{00} data were statistically analyzed using SPSS software (v 27, IBM, Armonk, USA). A two-way analysis of variance (ANOVA) was conducted to evaluate the main effects of composite type and staining solution on color stability, with significance set at $p < 0.05$. Post-hoc comparisons using Tukey's and Scheffé's tests were then performed to identify specific differences between staining solutions (coffee, tea, cola, and water) and to assess the relative performance of the two composite materials under these conditions.

RESULTS

Color difference values, expressed as ΔE* and ΔE_{00}, are presented in Table 2 and Table 3, respectively, with visual differences among subgroups illustrated in Figure 1.

ANOVA results indicated no statistically significant differences in color stability between the two composites, Geanial Anterior and Edge Com, across the various staining solutions. However, the staining solution itself had a highly significant effect ($p<0.001$). The interaction between composite type and staining solution was not significant ($p=0.17$), allowing for independent analysis of the effects of the staining solutions.

Post-hoc analysis using Tukey's test revealed significant differences between the staining solutions. Water and cola formed a homogeneous subset with the least color changes, tea formed a distinct second group, and coffee demonstrated the greatest color change, standing out as a separate third group.

It is important to note that both ΔE* and ΔE_{00} analyses yielded consistent results in this regard.

Table 2. Mean Color Difference Values (ΔE*) of Composites Subjected to Aging in Different Staining Media.

	Water	Cola	Tea	Coffee
G-ænial ANTERIOR	0.64 ± 0.23[a]	0.86 ± 0.24[a]	4.48 ± 0.94[b]	11.3 ± 2.92[c]
EdgeCom	0.64 ± 0.24[a]	1.22 ± 0.72[a]	2.77 ± 0.48[ab]	10 ± 0.96[b]

Table 3. Mean Color Difference Values (ΔE*) of Composites Subjected to Aging in Different Staining Media.

	Water	Cola	Tea	Coffee
G-ænial ANTERIOR	0.61 ± 0.23[a]	0.78 ± 0.23[a]	4.33 ± 0.75[b]	9.59 ± 3.2[b]
EdgeCom	0.64 ± 0.37[a]	1.16 ± 0.67[a]	2.63 ± 0.71[ab]	8.48 ± 0.71[b]

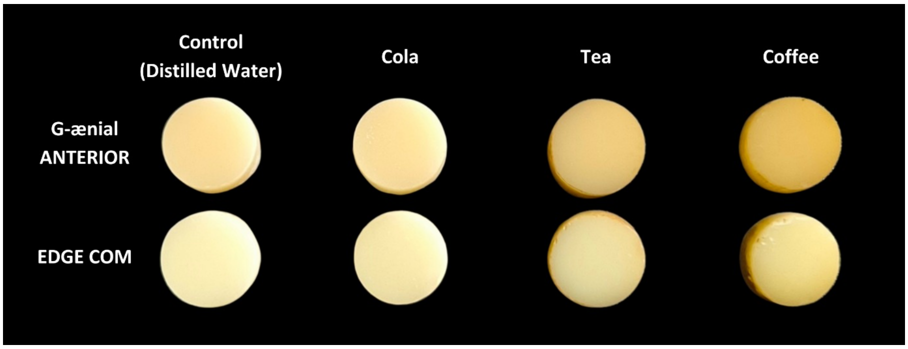

Figure 1. Photographs of Specimens from Each Subgroup After the Staining Procedure.

DISCUSSION

The present study demonstrated that the different staining solutions had a significant impact on the color stability of the tested dental composites, with coffee causing the most discoloration, followed by tea, while water and cola showed the least. No statistically significant difference was observed between Geanial Anterior and Edge Com composites.

This aligns with previous research, which indicates that different composite types may well reveal different degrees of discoloration, as the respective composition of these materials may vary (13). However, despite the differences in the composition of the tested composites (presented in Table 1), filler loading percentages were very close, and this may partly explain the results. Furthermore, it should be noted that material composition, while important, is not the only determining factor in color stability. Evidence shows that factors such as polymerization condition, surface roughness, and polishing methods may well be critical (14-16). Therefore, in the present study we aimed to produce an identical surface finish, pressing glass slides onto uncured composite. To preserve such a finish, no polishing procedures were taken to avoid any possible dissimilarities arising from operator error. Such close matching of the surface finish may be another reason for the obtained results.

Another potential factor contributing to the lack of significant differences between the two composites could be the aging protocol employed in this study. Previous research has consistently shown that, after artificial aging or thermocycling, many composite materials tend to exhibit similar levels of color stability (17-20). This may be attributed to similar degradation mechanisms affecting the polymer matrix and filler particles of the composites, leading to a similar impact on their color stability over time.

When examining the specific staining solutions, coffee and tea were found to cause the highest levels of discoloration, in agreement with numerous previous studies (21). The pronounced staining of these beverages is largely due to their chemical compositions and their interactions with the resin matrix of dental composites. Both coffee and tea contain pigments and other compounds that are capable of causing significant aesthetic alterations in dental materials.

Coffee, in particular, has a pronounced staining potential due to the presence of high-molecular-weight nitrogenous compounds known as melanoidins, which are formed during the roasting process (22). These compounds exhibit a strong affinity for the polymer matrix of dental composites, leading to substantial discoloration. In addition to melanoidins, other colorants within coffee also penetrate the composite structure, causing clinically unacceptable changes in appearance (23). In contrast, tea stains the composite through a different mechanism. While it contains tannins and polar colorants, the primary staining process involves the adsorption of these colorants onto the material's surface (24). Tea-induced stains can sometimes be resolved through brushing, whereas coffee's colorants tend to cause deeper, more persistent discoloration by both adsorption and absorption into the composite matrix (25). This was evident in our study, as a loosely attached dark layer was easily wiped off the tea-submerged specimens during the cleaning process with gauze prior to replacing the immersion solutions.

The hydrophilic nature of the filler particles and certain components of the silane coupling agents in composites can increase their susceptibility to staining. Composites can absorb water, which in turn facilitates the penetration of colorants from beverages like coffee and tea (26). This effect is intensified by the acidic nature of these drinks, which can degrade the composite matrix, increase porosity, and thereby allow more extensive infiltration of colorants (27, 28). Temperature also plays a critical role in the extent of discoloration. Studies have demonstrated that higher temperatures intensify the staining effects of coffee on dental composites (29). This is likely due to increased mobility of the colorants and their enhanced ability to penetrate the composite material at elevated temperatures. As thermocycling was employed in this study, the increased temperature fluctuations may further account for the larger ΔE values observed in the coffee-stained specimens compared to other groups.

Another notable finding was the relatively low level of discoloration caused by cola, which was not statistically different from the control group aged in distilled water. Despite cola's low pH, which could theoretically contribute to the degradation of dental materials, our findings-consistent with previous studies-demonstrated that its staining effect is relatively mild. This effect can be attributed to cola's lack of yellow pigments. Although cola has a low pH (around 2.5), it does not contain the yellow colorants found in beverages such as coffee, which are known to significantly contribute to staining (30). Therefore, cola may cause less discoloration than coffee and tea, attributing this difference to the absence of these pigments (24). While the caramel colorant in cola does contribute to some level of discoloration, its effect is less severe than that of the natural pigments found in coffee and tea (31).

In clinical dentistry, evaluating color differences in restorative materials requires a clear understanding of both perceptibility and acceptability thresholds. Perceptibility thresholds (PT) represent the smallest color differences that can be detected by 50% of observers, while acceptability thresholds (AT) indicate the point at which 50% of observers find the color differences acceptable for clinical use. These thresholds serve as critical benchmarks for assessing whether a color discrepancy in dental restorations is visually noticeable or within acceptable aesthetic limits. In this study, we applied a 50:50% PT of 1.2 for ΔE* and 0.8 for ΔE_{00}, while the AT values were set at 2.7 and 1.8, respectively, to determine whether the observed color changes fell within clinically acceptable ranges (12). Figure 2 and Figure 3 illustrate the projection of PT and AT onto the color difference chart, providing a clear visual representation of which staining media resulted in clinically significant discoloration.

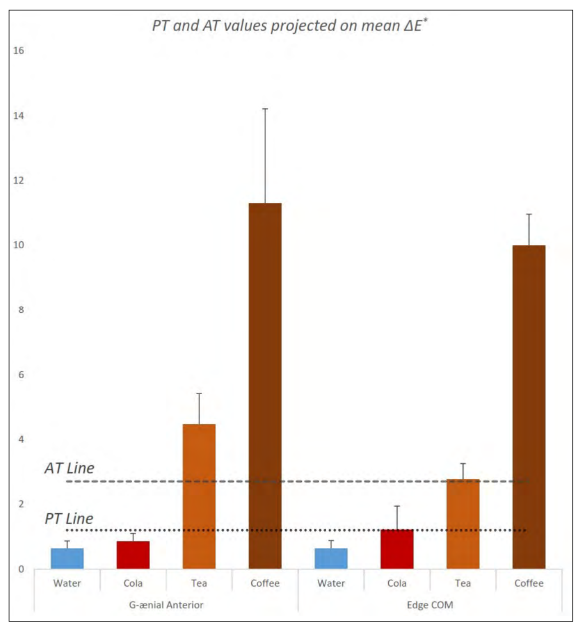

Figure 2. Bar chart depicting ΔE* values of resin composites after staining for each group, with perceptibility threshold (PT) and acceptability threshold (AT) projected onto the chart.

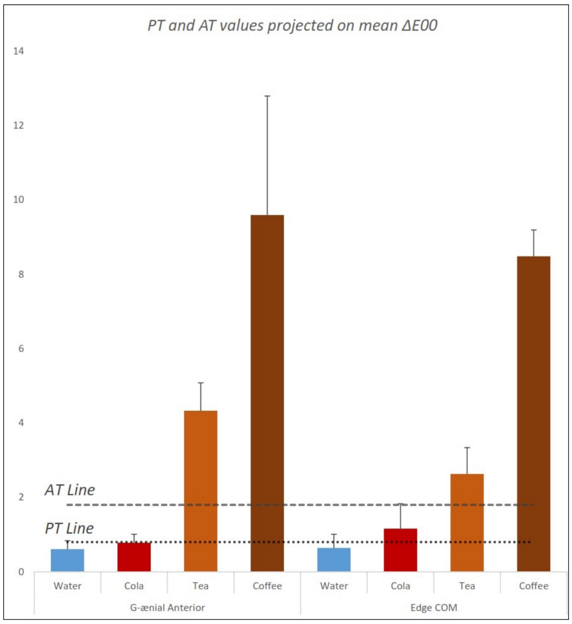

Figure 3. Bar chart depicting ΔE00 values of resin composites after staining for each group, with perceptibility threshold (PT) and acceptability threshold (AT) projected onto the chart.

In this study, we evaluated both ΔE* and ΔE_{00} to assess color changes. While ΔE* is widely used, ΔE_{00} is often preferred in dental aesthetics due to its greater sensitivity to small color differences. ΔE_{00} better accounts for perceptual differences, aligning more closely with how the human eye perceives color, making it more suitable for applications where precise color matching is essential (32). This distinction is evident in our results, as the mean ΔE_{00} for tea-stained Edge COM was significantly above the AT, a differentiation that was not as clear in the ΔE* chart. Similarly, the mean ΔE_{00} for cola-stained Edge COM was clearly above the perceptibility threshold PT, further demonstrating ΔE_{00}'s enhanced sensitivity. In any case, it can be concluded that the discoloration caused by coffee and tea exceeds the clinically acceptable threshold in all measurements and samples. This underscores the importance of advising patients on the potential staining effects of these beverages, particularly for those with aesthetic dental restorations. Regular consumption of coffee and tea may compromise the long-term appearance of composite restorations, and patients should be made aware of the potential need for more frequent maintenance or alternative dietary choices to preserve their dental aesthetics.

Several approaches help to reduce the discoloration on the composites. Repolishing is an effective method for managing the discoloration of dental composites, particularly when staining is confined to the superficial layers. Studies have shown that repolishing can significantly reduce discoloration caused by extrinsic factors, such as pigments from beverages like coffee and tea, by removing stains that typically reside within the first 20-40 micrometers of the composite surface (33). However, the success of repolishing depends on the depth of the discoloration and may not fully restore the original color in cases of deep, intrinsic staining (34, 35). In clinical settings, repolishing may be recommended every 6 to 12 months for patients with high consumption of coffee or tea, especially for restorations located in the aesthetic zone (36, 37). Furthermore, evidence suggests that multi-step polishing protocols, particularly those employing sequential abrasives, produce smoother composite surfaces that exhibit enhanced resistance to discoloration (37-39). In addition to repolishing, the application of surface sealants provides an added layer of protection against discoloration. These low-viscosity resins penetrate microstructural defects in the composite, forming a smoother, hydrophobic surface that minimizes water absorption and reduces the infiltration of staining agents (40, 41). Sealants can be applied at the time of restoration placement or during follow-up visits, particularly for patients with high staining risk or limited access for optimal oral hygiene (42). While surface sealants can improve color stability, their effectiveness varies based on the composition of the sealant and the conditions the restoration is exposed to, with some sealants even contributing to discoloration under certain circumstances (43).

The results of this study suggest that patients receiving composite restorations in the esthetic zone should be particularly mindful of colored beverages, such as coffee and tea, which have a significant impact on discoloration. While this study focused on two composites, further research is needed to assess a wider variety of materials under more extensive and long-term aging protocols. However, these findings indicate that the choice of composite may not be the primary determinant of color stability. Clinicians should consider these results and incorporate best practices to preserve the color and aesthetics of restorations, including patient education and regular maintenance, to ensure the longevity of esthetic outcomes.

This study has several limitations that should be acknowledged. First, the relatively small sample size may limit the statistical power and generalizability of the findings, even though the results exhibited consistent trends across groups. Second, while the decision to forego polishing was made to ensure a uniform surface finish and minimize operator variability, this approach does not fully replicate clinical procedures, where polishing is routinely performed and significantly affects surface properties and staining susceptibility. Third, although thermocycling was employed to simulate one year of clinical aging, the immersion duration and experimental conditions may not entirely reflect the complex oral environment, which includes dynamic mechanical forces, microbial activity, salivary enzymes, and varying dietary habits over longer periods. Future studies should include larger sample sizes, incorporate clinically relevant finishing protocols, and consider long-term *in vivo* assessments to better evaluate the color stability of dental composites under realistic conditions.

CONCLUSION

This study demonstrated that different staining solutions significantly influence the color stability of dental composites, with coffee and tea causing the most pronounced discoloration, while cola and water had minimal effects. The absence of significant differences between the two composites suggests that composite type may not be the primary determinant of color stability. Instead, external factors such as beverage composition, acid content, and temperature play a more critical role. Given these findings, clinicians should educate patients on the potential staining effects of beverages and recommend appropriate maintenance strategies to preserve the aesthetics of composite restorations.

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AUTHOR CONTRIBUTION STATEMENT

Conception-design of study: A.R., Y.S., A.M., S.O. and S.A.
Data acquisition: A.R. and S.A.
Data analysis-interpretation: A.R.
Drafting manuscript: A.R., S.A., Y.S. and A.M.
Critical revision of manuscript: S.O.
Final approval and accountability: A.R., S.A., S.O., Y.S. and A.M.
Technical or material support: A.R., S.A. and S.O.
Supervision: A.R., S.A. and S.O.

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