Comparative Evaluation of Color Stability and Surface Roughness of Novel Nanofiller-Based Bulk Fill Flowable Composites and Conventional Flowable Composites: An In Vitro Study

Shreshtha Muskan[1], Pradeep Solete[2*], S. Delphine Priscilla Antony[3], Vigneshwar Sambandam[4]
[1]Postgraduate Student, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, 162, PH Road, Chennai 600077, Tamil Nadu, India. Email: shreshtha1999@gmail.com | ORCID: 0009-0001-1816-9934
[2*]Professor, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, 162, PH Road, Chennai 600077, Tamil Nadu, India. Email: pandu.pradeep@gmail.com | ORCID: 0000-0002-6670-1171
[3]Associate Professor, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, 162, PH Road, Chennai 600077, Tamil Nadu, India. Email: delphy.priscilla@gmail.com | ORCID: 0000-0001-9509-3665
[4]Senior Lecturer, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai-600077, Tamil Nadu, India. Email: dr.vigneshwart@gmail.com | ORCID: 0000-0002-7796-2190
***Corresponding Author: Pradeep Solete, Professor, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, 162, PH Road, Chennai 600077, Tamil Nadu, India.**
Email: pandu.pradeep@gmail.com

Abstract:

With the increase in utilization of flowable resin composites for anterior restorations, it is vital to note that the long-term performance of these materials in clinical settings relies on the maintenance of a smooth surface as well as their ability to resist color change when exposed to food-staining substances. This study assessed color stability and surface smoothness between a nano-filled bulk-fill flowable composite and traditional flowable composite when immersed in typical foodstains. Samples in disc forms of both materials were fabricated and finished according to a standard procedure. Color change was determined in samples immersed in cola, tea, and turmeric at baseline, 24 hours, 7 days, and 14 days using spectroscopic method in the Lab color space by CIE. Surface roughness was determined using contact profilometer, expressed as Ra value. Independent t-test and analysis of variance (ANOVA) were used for statistical evaluation with $P < 0.05$ as the threshold of significance.Nano-filled bulk-fill flowable composite was found to have a significantly lower Ra value than traditional flowable composite ($P = 0.046$). There was no significant difference in color change between the two groups after immersion for 24 hours ($P = 0.546$). At 7 and 14 days, however, traditional flowable composite underwent significantly greater discoloration compared to nano-filled bulk-fill flowable composite ($P = 0.025$ and 0.016, respectively).Under controlled in vitro conditions, nano-filled bulk-fill flowable composite showed better surface smoothness and increased color stability than the other material.

Keywords: Color Stability, Surface Roughness, Bulk-fill flowable composite
How to cite this article: Muskan S, Solete P, Antony SDP, Sambandam V. Comparative Evaluation of Color Stability and Surface Roughness of Novel Nanofiller-Based Bulk Fill Flowable Composites and Conventional Flowable Composites: An In Vitro Study. Int J Drug Deliv Technol. 2026;16(69s):1253-1260. DOI: 10.25258/ijddt.16.69s.126

Introduction

Resin-based composites are now firmly established as the restorative material of choice for anterior teeth, largely because they allow clinicians to balance esthetics with conservative tooth preparation. Among these materials, flowable composites have undergone notable formulation changes in recent years. Improvements in filler technology and resin chemistry have expanded their indications beyond liners and low-stress applications, making them increasingly attractive for use in the esthetic zone.[1] Nevertheless, the long-term success of anterior composite restorations is determined not only by mechanical integrity, but also by their ability to preserve color and surface quality under everyday oral conditions.[2]

Color stability remains one of the most challenging aspects of resin-based restorations. Discoloration may originate from intrinsic factors related to the material itself, including resin matrix composition, filler content, and the degree of polymerization. Water sorption within the organic matrix can promote pigment penetration and chemical degradation, particularly in materials with higher resin fractions.[3] At the same time, extrinsic factors—most notably the frequent consumption of chromogenic beverages such as coffee and cola—contribute substantially to clinically visible color changes. These effects are of particular concern in flowable composites, which often exhibit greater resin content to achieve enhanced handling and adaptability.[4]

Surface roughness is closely linked to the esthetic performance of composite restorations and cannot be considered independently of color stability. Even minor surface irregularities can disrupt light reflection, reduce gloss, and facilitate plaque and stain accumulation. Although finishing and polishing procedures aim to produce smooth surfaces, exposure to staining media may lead to matrix softening and filler–matrix degradation over time, resulting in increased roughness and subsequent discoloration.[5] In the anterior region, where visual demands are high, such changes may compromise patient satisfaction and lead to premature restoration replacement.

Despite the widespread clinical use of flowable composites in anterior restorations, comparative data regarding their resistance to discoloration and surface degradation remain limited. The aim of this in vitro study was to evaluate and compare the color stability and surface roughness of two resin-based flowable composite materials used for anterior restorations following immersion in different commonly encountered staining media. The null hypothesis was that there would be no statistically significant difference in color stability or surface roughness between the two resin-based flowable composites after exposure to different staining media.

Materials and Methods

Study Design and Ethical Considerations

This in vitro experimental study was conducted to compare the color stability and surface roughness of two resin-based flowable composite materials intended for use in anterior restorations after exposure to commonly consumed staining agents. As the investigation did not involve human participants, patient identifiers, or biological tissues, institutional ethical approval was not required. The present in vitro study was conducted after obtaining approval from the Institutional Review Board (Approval No **SRB/SDC/ENDO-2302/24/TH-74**)

Sample size calculations

The sample size was calculated a priori based on previously reported effect sizes for surface roughness and color stability outcomes in similar in vitro studies, particularly the work of Ebaya et al. (2022).[6] Assuming a two-sided significance level of 5% ($\alpha = 0.05$) and a statistical power of 95%, a medium effect size was considered clinically relevant for between-group comparisons. Under these assumptions, a minimum of 10 specimens per group was required to detect significant differences in color change and surface roughness. Accordingly, 10 specimens per staining medium were allocated for color stability evaluation, and 20 specimens per material were used for surface roughness analysis, ensuring adequate power while accounting for potential specimen loss during preparation.

Materials

Two commercially available resin-based flowable composites were evaluated: a nano-filled bulk-fill flowable composite (NFBF) and a conventional traditional flowable composite (TF). All materials were manipulated, polymerized, and finished strictly following the manufacturers' recommendations. A detailed description of the tested materials, including their composition and manufacturer information, is provided in Table 1.

Table 1. Composition of the nano-filled bulk-fill flowable composite and conventional traditional flowable composite used in the study.

Group	Composition
Nano-filled bulk-fill flowable composite	Methacrylate-based resin matrix, selected dimethacrylate monomers, barium–alumino–silicate glass filler, nano-zirconia filler, nano-bioactive glass filler, organosilane coupling agent, and camphorquinone photoinitiator.
Conventional traditional flowable composite	Bis-GMA, UDMA, TEGDMA, barium glass filler, ytterbium trifluoride, copolymer-based filler, organosilane coupling agent, and camphorquinone photoinitiator.

Specimen Preparation

Standardized disc-shaped specimens were fabricated using cylindrical molds measuring 10 mm in diameter and 2 mm in thickness as shown in Figure 1. Each mold was placed on a Mylar strip (HaweBlue Striproll, Switzerland) over a glass slab to ensure a smooth baseline surface. The composite material was inserted in a single increment, covered with a second Mylar strip and glass slab, and gently pressed to achieve uniform thickness and minimize the oxygen-inhibited layer. Polymerization was carried out using an LED curing unit (Ultradent products Inc., South Jordan, USA) positioned perpendicular to the specimen surface at a distance of approximately 0–1 mm. Light exposure times followed the manufacturers' instructions. After curing, specimens were carefully removed from the molds, excess material was trimmed with a scalpel, and each disc was examined visually. Specimens showing voids, surface defects, or marginal irregularities were excluded and replaced. All acceptable specimens were stored in distilled water at 37 °C for 24 hours prior to baseline testing.

Figure 1. Standardized disc-shaped composite specimens were prepared for surface roughness and color stability evaluation.

Finishing and Polishing

To standardize surface conditions across all specimens, a uniform finishing and polishing protocol was applied. Polishing was performed sequentially using abrasive discs (or silicon carbide papers) with grit sizes of 600, 800, and 1200, followed by final polishing discs under continuous water irrigation. Each polishing step was performed for approximately 20–30 seconds using controlled pressure. All procedures were carried out by the same operator to reduce procedural variability. After polishing, specimens were rinsed thoroughly and ultrasonically cleaned in distilled water for 5 minutes, then air-dried.

Color Stability Assessment

Grouping and Immersion Protocol

Thirty disc specimens were allocated for color stability evaluation and divided into three staining groups (n = 10 per group): cola (Group C), tea (Group T), and turmeric solution (Group Tu). Within each staining group, specimens were further categorized according to composite type (NFBF or TF) based on the predetermined allocation.

Each specimen was immersed individually in a sealed, labeled container containing 10–20 mL of the assigned staining solution and stored at 37 °C to simulate intraoral temperature. To maintain consistent staining conditions, all solutions were freshly prepared and replaced every 24 hours.

Color measurements were obtained at baseline (T0), after 24 hours (T1), 7 days (T2), and 14 days (T3). At each time point, specimens were removed from the solutions, rinsed under distilled water for 30 seconds, gently blotted dry with lint-free tissue, and allowed to equilibrate for 10 minutes before measurement.

Preparation of Staining Solutions

Cola was used directly from a commercially available product at room temperature. The tea solution was prepared by steeping one standardized tea bag (2 g) in 200 mL of boiling distilled water for 5 minutes, followed by cooling to room temperature. The turmeric solution was prepared by dissolving 0.5–1 g of turmeric powder in 200 mL of distilled water, with continuous stirring; the solution was filtered when necessary to remove coarse particles as show in Figure 2.

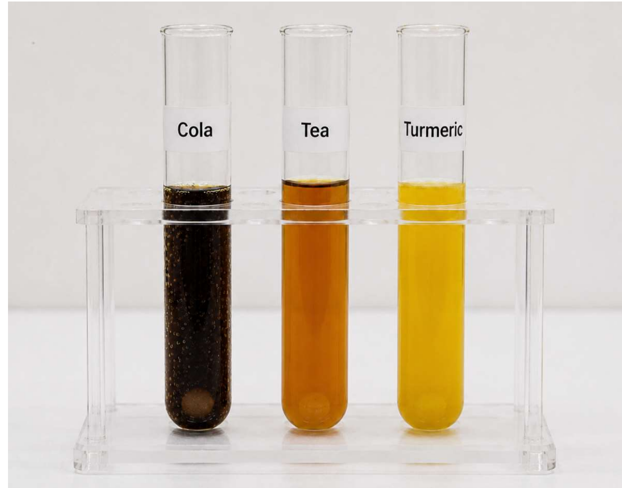


Figure 2. Composite disc specimens immersed in cola, tea, and turmeric staining solutions.

Color Measurement

Color measurements were performed using a reflectance spectrophotometer calibrated before each measurement session according to the manufacturer's instructions. All readings were obtained against a standardized white background, and specimen positioning was kept consistent throughout the study.

Color coordinates were recorded using the CIELAB color space (L*, a*, b*). For each specimen, three readings were obtained from the central region of the disc and averaged. Color change (ΔE) relative to baseline was calculated using the following equation:

$\Delta E^*ab=(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2$

Surface Roughness Evaluation

Sample Allocation

Surface roughness analysis was performed on 40 disc specimens, divided equally according to composite type: 20 specimens of NFBF and 20 specimens of TF. All measurements were carried out after completion of the standardized finishing and polishing procedure.

Roughness Measurement

Surface roughness was measured using a calibrated profilometer. Each specimen was positioned on a stable platform, and measurements were recorded from the polished surface. Instrument parameters were standardized as follows: cut-off length of 0.8 mm, evaluation length of 4.0 mm, and stylus speed of 0.5 mm/s.

Three separate tracings were obtained from different areas of each specimen surface, avoiding the margins. The arithmetic mean roughness value (Ra, µm) was calculated as the average of the three readings. All measurements were performed by a single operator under identical conditions.

Statistical Analysis

Collected data were entered and analyzed using the Statistical Package for the Social Sciences (SPSS version 26.0, IBM Corp., Chicago, USA). Descriptive statistics were calculated in terms of mean and standard deviation. Two-way analysis of variance (ANOVA) was applied to evaluate the effects of composite type and staining media on color stability. One-way ANOVA followed by Tukey's post hoc test was used for intra-media comparisons. Student's t-test, both paired and unpaired as appropriate, was employed for comparisons between groups. Statistical significance was set at $P < 0.05$.

Results

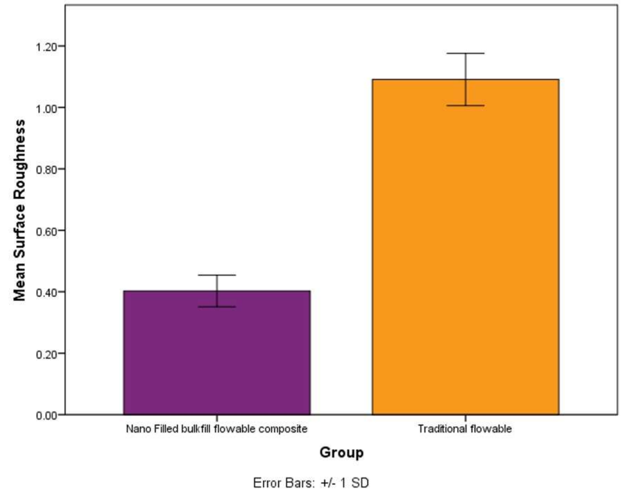
Surface Roughness

A clear difference in surface texture was observed between the two flowable composites. Specimens restored with the nano-filled bulk-fill flowable composite presented noticeably smoother surfaces, with a mean Ra value of 0.4027 ± 0.0515 µm, whereas the traditional flowable composite showed substantially higher roughness values (1.0911 ± 0.0851 µm). Statistical comparison using an independent samples t-test confirmed that this difference was significant ($P = 0.046$). The magnitude of this difference was pronounced, reflected by a large effect size (Cohen's d = 1.47), and the confidence interval for the mean difference remained entirely above zero, reinforcing the clinical relevance of the observed surface disparity (Table 2, Graph 1).

Table 2. Independent Samples t-test Comparing Surface Roughness (Ra, µm) Between the Two Flowable Composites

Composite Material	**Mean (Ra, µm)**	**SD**	**F value**	**P value**
Nano-filled bulk-fill flowable composite	0.4027	0.05154	4.124	0.046*
Traditional flowable composite	1.0911	0.08512		

* Statistically significant at P < 0.05



Graph 1. Comparison of mean surface roughness between the nano-filled bulk-fill flowable composite and the traditional flowable composite.

Color Stability

Color Stability at 24 Hours

After 24 hours of immersion, both materials exhibited measurable color changes, although the extent of discoloration remained broadly similar between groups. The nano-filled bulk-fill flowable composite demonstrated a mean ΔE of 1.4150 ± 0.3422, while the traditional flowable composite recorded a higher, yet comparable, mean ΔE of 1.7967 ± 0.5531. No statistically significant difference was detected at this early stage ($P = 0.546$). While a moderate effect size was noted (Cohen's d = 0.79), the variability within groups suggested that initial staining behavior was inconsistent and material-dependent differences were not yet clearly established (Table 3, Graph 2).

Color Stability at 7 Days

With extended immersion, differences between the materials became more evident. At 7 days, the nano-filled bulk-fill flowable composite maintained lower discoloration values (mean ΔE = 1.8017 ± 0.2444) compared with the traditional flowable composite (mean ΔE = 2.2933 ± 0.6136). This difference reached statistical significance ($P = 0.025$). The associated effect size was large (Cohen's d = 1.01), indicating that the divergence in color stability was not only statistically meaningful but also likely to be perceptible under clinical conditions (Table 3, Graph 2).

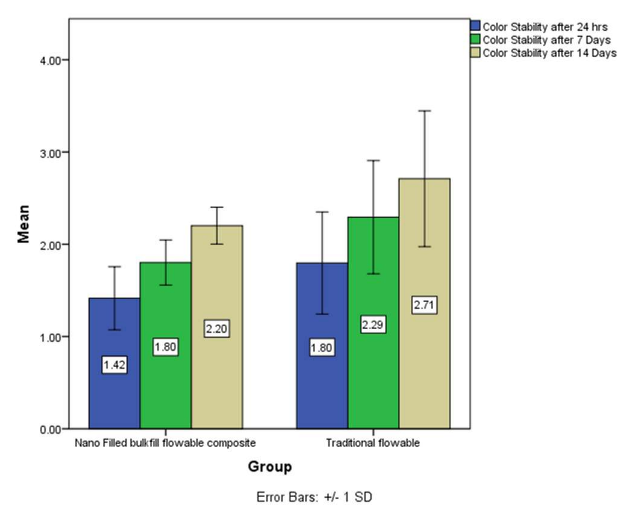
Color Stability at 14 Days

By the end of the 14-day immersion period, the contrast between the two materials had further intensified. The nano-filled bulk-fill flowable composite continued to show better resistance to discoloration, with a mean ΔE of 2.2017 ± 0.1993, whereas the traditional flowable composite demonstrated greater color change (mean ΔE = 2.7100 ± 0.7362). Independent t-test analysis confirmed a statistically significant difference between the groups (P = 0.016). The persistence of a large effect size (Cohen's d = 1.20), together with supportive confidence intervals, suggests that prolonged exposure to staining agents has a more pronounced impact on traditional flowable composites (Table 3, Graph 2)

Table 3. Independent Samples t-test Comparing Color Stability (ΔE) Between the Two Flowable Composites at Different Time Intervals

Time Interval	Composite Material	Mean ΔE	SD	F value	P value
24 hours	Nano-filled bulk-fill flowable	1.4150	0.34215	0.391	0.546
	Traditional flowable	1.7967	0.55312		
7 days	Nano-filled bulk-fill flowable	1.8017 *	0.24441	6.906	0.025 *
	Traditional flowable	2.2933	0.61360		
14 days	Nano-filled bulk-fill flowable	2.2017 *	0.19934	8.333	0.016 *
	Traditional flowable	2.7100	0.73623		

* Statistically significant at $P < 0.05$



Graph 2. Comparison of mean color stability between the nano-filled bulk-fill flowable composite and the traditional flowable composite at 24 hours, 7 days, and 14 days.

Discussion

This in vitro investigation demonstrated that the two resin-based flowable composites exhibited distinct behavior with respect to surface roughness and color stability following exposure to commonly encountered staining media. Overall, the nano-filled bulk-fill flowable composite showed a smoother surface and greater resistance to discoloration when compared with the traditional flowable composite. Although color changes observed after 24 hours were comparable between the two materials, prolonged immersion for 7 and 14 days resulted in progressively higher discoloration values for the traditional flowable composite. On this basis, the null hypothesis was partially rejected. Significant differences were identified for surface roughness and for color stability at extended immersion intervals, whereas no significant difference was detected during the early evaluation period. These findings reinforce the importance of material composition in influencing the long-term esthetic behavior of flowable composites used in anterior restorations.

The experimental approach adopted in this study was designed to focus specifically on factors that are clinically relevant yet amenable to controlled laboratory evaluation. Disc-shaped specimens were selected to ensure uniform geometry and surface area, thereby limiting the influence of anatomical variations that may confound comparisons in tooth-based models. A standardized finishing and polishing protocol was applied across all specimens to reduce operator-related variability and to ensure that observed differences in surface roughness and color stability were predominantly material driven.[7] The use of commonly consumed staining solutions and incubation at body temperature was intended to approximate everyday dietary exposure under simulated intraoral conditions. Additionally, repeated color assessments at multiple time points allowed differentiation between early and progressive discoloration patterns, while independent measurement of surface roughness provided insight into how surface topography may contribute to staining susceptibility.[8]

The smoother surface profile observed for the nano-filled bulk-fill flowable composite is in line with existing literature that highlights the influence of filler characteristics on surface properties. Previous studies have shown that composites containing uniformly distributed nano-sized fillers tend to exhibit improved polishability and reduced surface irregularities when compared with materials incorporating larger or unevenly distributed fillers.[9,10] The lower Ra values recorded in the present study may be attributed to reduced filler protrusion following polishing and greater stability of the resin–filler interface under abrasive forces. In contrast, traditional flowable composites often rely on higher resin content to achieve flowability, which may predispose them to preferential resin wear, subsequent filler exposure, and increased surface roughness.

The association between surface roughness and color stability observed in this study reflects well-established optical and biological concepts. Increased surface irregularities alter light reflection, reduce surface gloss, and promote retention of pigments and plaque. Previous investigations have consistently demonstrated that rougher composite surfaces are more prone to extrinsic staining due to enhanced adsorption of chromogenic substances.[11,12] In the present study, the traditional flowable composite exhibited both higher roughness values and greater color change after extended immersion, suggesting that surface degradation may have contributed to the observed increase in discoloration over time.

The lack of a statistically significant difference in color stability at the 24-hour interval is consistent with reports indicating that early discoloration of resin composites is largely governed by superficial pigment adsorption rather than deeper penetration into the resin matrix.[13] Initial water sorption occurs rapidly following immersion; however, saturation of the polymer network and subsequent diffusion of pigments into subsurface regions typically require longer exposure periods. This may explain why material-dependent differences were not apparent at the earliest time point but became increasingly evident at 7 and 14 days, when cumulative water uptake and matrix softening likely facilitated deeper chromogen penetration.

The greater discoloration observed in the traditional flowable composite at later time points can be attributed to its compositional features. Flowable composites with lower filler loading generally possess increased free volume within the polymer matrix, allowing greater water sorption and solubility. Previous studies have reported that composites with higher resin content are more susceptible to hydrolytic degradation and staining, particularly when hydrophilic monomers such as TEGDMA are present.[14,15] In contrast, nano-filled bulk-fill flowable composites often incorporate optimized filler loading and modified resin formulations that enhance cross-link density and reduce polymerization-related stresses, thereby limiting water diffusion and pigment uptake.

The staining trends observed in this study are also consistent with findings reported by Ebaya (2022) and Meniawi (2026), who emphasized the influence of immersion duration and staining medium composition on composite discoloration.[6,16] Acidic beverages containing tannins or caramel-based colorants have been shown to compromise the resin–filler interface through chemical erosion, increasing surface porosity and facilitating pigment penetration. Although the immersion protocol used in the present study represents a simplified aging model, the progressive increase in ΔE values over time suggests that prolonged exposure to commonly consumed beverages may have a meaningful impact on the esthetic longevity of traditional flowable composites used in anterior regions.

From a clinical perspective, the magnitude of color change recorded in both materials approached or exceeded commonly accepted perceptibility thresholds at extended immersion intervals, supporting previous observations that esthetic degradation remains a concern even with contemporary resin composites.[13,17] Nevertheless, the comparatively lower ΔE values demonstrated by the nano-filled bulk-fill flowable composite indicate a more favorable esthetic profile, particularly in patients with frequent exposure to staining agents. This distinction is clinically relevant, as discoloration remains a common reason for replacement of anterior composite restorations.

The present findings are largely consistent with systematic reviews and meta-analyses identifying surface degradation and discoloration as key contributors to composite restoration failure.[16] While some studies have reported minimal differences between bulk-fill and conventional composites, such variations may reflect differences in filler technology, resin composition, polishing protocols, and aging methods.[18] The standardized specimen preparation and controlled finishing procedures used in this investigation strengthen the likelihood that the observed differences reflect intrinsic material behavior rather than procedural bias.

Clinically, the results suggest that careful material selection can contribute to improved esthetic outcomes in anterior restorations. The nano-filled bulk-fill flowable composite demonstrated better surface smoothness and greater resistance to discoloration under simulated staining conditions, indicating potential advantages in esthetically demanding situations, particularly for patients with dietary habits that predispose restorations to staining.[19]

The strengths of this study include standardized specimen fabrication, controlled finishing and polishing protocols, and objective instrumental evaluation of both surface roughness and color stability at multiple time intervals. These factors enhance internal validity and support meaningful material comparisons. However, certain limitations must be considered. As an in vitro investigation, the study does not fully replicate the complex oral environment, where salivary flow, biofilm formation, mechanical brushing, and intermittent exposure to staining agents may influence material behavior. In addition, the use of flat disc specimens does not entirely reflect the anatomical complexity of clinical restorations.[20]

Future research should build upon these findings by incorporating simulated brushing, longer aging periods, and more complex exposure cycles to better approximate clinical conditions. Well-designed clinical trials would further clarify the relevance of these in vitro observations to long-term restoration performance. Additional studies examining the relationship between surface roughness, gloss retention, and patient-perceived esthetics may also help refine material selection for anterior restorative applications.

Conclusion

Within the limitations of this in vitro study, the nano-filled bulk-fill flowable composite exhibited smoother surface characteristics and greater resistance to discoloration than the traditional flowable composite after prolonged exposure to staining media. Although early color changes were similar, material-dependent differences became evident over time. These findings suggest that composite formulation influences esthetic durability in anterior restorations and should be considered during material selection.

Conflict of interest

The authors have no conflicts of interest to declare.

Author contributions

Shreshtha Muskan; study conception and design. Pradeep Solete; data collection.Delphine Priscella Antony: statistical analysis and interpretation of results. Vigneshwar T; Writing - review & editing; Mohamed Isaqali Karobari- Supervision. All authors reviewed the results and approved the final version of the manuscript to be published.

Acknowledgement and funding

There was no external support for this study.

References

1. Pratap B, Gupta RK, Bhardwaj B, Nag M. Resin based restorative dental materials: characteristics and future perspectives. Jpn Dent Sci Rev. 2019 Nov;55(1):126–38. DOI: 10.1016/j.jdsr.2019.09.004

2. Bansal S, Gupta S, Gupta S, Bogra P, Bansal R, Grover V, et al. Comparative Evaluation of Color Stability and Surface Roughness of Bulk-Fill and Nanohybrid Composites Following Long-Term Mouthrinse Exposure: An In Vitro Study. Cureus. 2025 May;17(5):e84320. DOI: 10.7759/cureus.84320

3. Uctasli MB, Garoushi S, Uctasli M, Vallittu PK, Lassila L. A comparative assessment of color stability among various commercial resin composites. BMC Oral Health. 2023 Oct 24;23(1):789. DOI: 10.1186/s12903-023-03515-9

4. Podgórski F, Musyt W, Bociong K, Nijakowski K. The impact of sports drink exposure on the colour stability of restorative materials: A systematic review. J Compos Sci. 2026 Feb 1;10(2):74. DOI: 10.3390/jcs10020074

5. Ntovas P, Korkut B, Loumprinis N, Rachiotis I, Rahiotis C. Influence of Composite Polishing Pastes on Surface Roughness and Their Stability After Simulated Tooth Brushing. Dent J (Basel). 2025 Nov 10;13(11). DOI: 10.3390/dj13110528

6. Ebaya MM, Ali AI, El-Haliem HA, Mahmoud SH. Color stability and surface roughness of ormocer- versus methacrylate-based single shade composite in anterior restoration. BMC Oral Health. 2022 Sep 27;22(1):430. DOI: 10.1186/s12903-022-02423-8

7. Alex A, Venkatesh V. Comparative Evaluation of Surface Roughness and Color Stability Between Single-Shade Composite and Multi-Shade Composite: An In Vitro Study. Cureus. 2024 Jul;16(7):e65396. DOI: 10.7759/cureus.65396

8. Kareem ASA, Abdel-Fattah WM, El Gayar MIL. Evaluation of color stability and surface roughness of smart monochromatic resin composite in comparison to universal resin composites after immersion in staining solutions. BMC Oral Health. 2025 Jul 19;25(1):1211. DOI: 10.1186/s12903-025-06555-5

9. Cunha LG, Alonso RCB, Santos PHD, Sinhoreti MAC. Comparative study of the surface roughness of Ormocer-based and conventional composites. J Appl Oral Sci. 2003 Dec;11(4):348–53. DOI: 10.1590/s1678-77572003000400014

10. Gurbuz A, Ozkan P, Yilmaz K, Yilmaz B, Durkan R. Effect of at-home whitening strips on the surface roughness and color of a composite and an ormocer restorative material. J Prosthodont. 2013 Jan;22(1):69–73. DOI: 10.1111/j.1532-849X.2012.00918.x

11. Bakti I, Santosa AS, Irawan B, Damiyanti M. Chameleon effect of nano-filled composite resin restorations in artificial acrylic teeth of various shades. J Phys Conf Ser. 2018 Aug;1073:052011. DOI: 10.1088/1742-6596/1073/5/052011

12. Abdelraouf RM, Habib NA. Color-Matching and Blending-Effect of Universal Shade Bulk-Fill-Resin-Composite in Resin-Composite-Models and Natural Teeth. Biomed Res Int. 2016 Oct 23;2016:4183432. DOI: 10.1155/2016/4183432

13. Yenier Yurdagüven G. Assessment of Color Stability of Various Flowable Composite Resins with Different Viscosities. Biomimetics (Basel). 2025 Aug 21;10(8). DOI: 10.3390/biomimetics10080550

14. Korkut B, Haciali C. Color stability of flowable composites in different viscosities. Clin Exp Health Sci. 2020 Dec 30;10(4):454–61. DOI:10.33808/clinexphealthsci.816231

15. Almulhim KS, Shetty AC, Alkathiri H, Alabdulqader D, Al-Yami F. In vitro comparison of color stability and surface roughness of bulk fill flowable composite and universal packable composite. F1000Res. 2023 Sep 25;12:1192. DOI: 10.12688/f1000research.122064.1

16. Meniawi M, Şirinsükan N, Can E. Color stability, surface roughness, and surface morphology of universal composites. Odontology. 2026 Jan;114(1):149–60. DOI: 10.1007/s10266-025-01108-2

17. Paravina RD, Ghinea R, Herrera LJ, Bona AD, Igiel C, Linninger M, et al. Color difference thresholds in dentistry. J Esthet Restor Dent. 2015 Apr 17;27 Suppl 1:S1–9. DOI: 10.1111/jerd.12149

18. Haugen HJ, Marovic D, Par M, Thieu MKL, Reseland JE, Johnsen GF. Bulk Fill Composites Have Similar Performance to Conventional Dental Composites. Int J Mol Sci. 2020 Jul 20;21(14). DOI: 10.3390/ijms21145136

19. Daltoé MO, Soares EJ, Vivanco RG, Segato RAB, Gatón-Hernández P, Nelson-Filho P, et al. Color Stability, Surface Roughness, and Microhardness of Resin-Based Composites After Immersion in Beverages Commonly Consumed by Children or Accelerated Artificial Aging. Pesqui Bras Odontopediatria Clín Integr. 2025;25:e240025. DOI: 10.1590/pboci.2025.064

20. Mira A, Buetas E, Rosier B, Mazurel D, Villanueva-Castellote Á, Llena C, et al. Development of an system to study oral biofilms in real time through impedance technology: validation and potential applications. J Oral Microbiol. 2019 May 6;11(1):1609838. DOI: 10.1080/20002297.2019.1609838