ORIGINAL RESEARCH

Effects of Various Solutions on Color Stability and Surface Hardness of Nanohybrid Dental Composite Under Simulated Oral Conditions

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ABSTRACT

Aim: This study evaluated effects of various solutions on color stability and surface hardness of a nanohybrid dental composite in simulated oral environments.

Materials and methods: Sixty-four composite disks were fabricated and randomly allocated into eight groups ($n = 8$ per group): Artificial saliva (AS), Biotene (B), passion fruit juice (PFJ), orange juice (OJ), Sprite (S), Coca-Cola (CO), apple cider vinegar (ACV), and cranberry juice (CJ). Specimens were immersed in respective solutions at 37°C for 28 days. Surface microhardness was assessed using Vickers microhardness test, and color alterations were quantified using SpectroShade Micro spectrophotometer. Measurements were taken 24 hours after initial polymerization and after 28-day immersion period. Statistical analysis was performed using mixed model ANOVA.

Results: After 28 days, specimens exhibited significant changes in microhardness and color. Polished surfaces showed microhardness decreases of 21.9–35.5%, with ACV and CJ causing largest reductions. Non-polished surfaces unexpectedly showed increased microhardness (11.2–17.4%). Color changes were more pronounced on polished surfaces, with CO and CJ causing maximum alterations. Statistical analysis revealed significant interactions between surface treatment, staining media, and immersion time ($p < 0.05$).

Conclusion: All experimental groups demonstrated significant changes, highlighting composite materials' susceptibility to environmental factors. Even well-polymerized and polished surfaces underwent alterations, emphasizing necessity for periodic follow-up and maintenance polishing in esthetic restorations.

Clinical significance: The present research emphasizes significance of oral environmental factors on composite restoration longevity and esthetics, advocating for patient education on dietary impacts and tailored maintenance strategies to preserve restoration quality.

Keywords: Composites, Microhardness, Shade, Tooth.

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INTRODUCTION

Esthetic dental restorations have become increasingly popular in modern dentistry, with composite resin materials emerging as the primary choice for both patients and clinicians.[1] This preference stems from their enhanced esthetics, superior bonding to tooth structure, and the ability to perform conservative tooth preparation.[2] However, the long-term success of these restorations is often challenged by various factors, including discoloration and changes in mechanical properties, which can significantly impact their clinical performance and patient satisfaction.[3,4] The main objectives of this study are to evaluate two critical aspects of composite resin restorations: Color changes and microhardness alterations upon exposure to common beverages. These factors are paramount in understanding the longevity and esthetic durability of composite restorations in real-world conditions.[5,6]

Composite restorations are susceptible to both intrinsic and extrinsic discoloration.[7] Intrinsic factors involve changes within the resin material itself, such as alterations in the resin matrix and the interface between the matrix and fillers. Extrinsic factors primarily relate to the adsorption and absorption of stains from various sources, including dietary habits and lifestyle factors.[8,9] The susceptibility of dental composites to staining and shade discoloration has been consistently demonstrated *in vitro* studies.[10,11] Alongside color stability, the mechanical integrity of composite restorations is crucial for their longevity. Surface hardness, in particular, is an important property that can be indicative of wear resistance and overall material degradation. Changes in surface hardness can affect the restoration's ability to withstand masticatory forces and maintain its structural integrity overtime.[12,13]

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The present study focuses on a nanohybrid dental composite, a material chosen for its advanced properties that combine the benefits of nanofilled and traditional hybrid composites. Nanohybrid composites have gained significant popularity in recent years due to their excellent esthetics, improved mechanical properties, and enhanced polishability.[14] These composites contain a mixture of nanometer-sized particles (typically 20–75 nm) and larger particles (0.4–1 µm), providing a balance between strength and esthetics.[15] Nanohybrid composites offer several advantages over traditional microhybrid composites. They exhibit higher flexural strength, improved wear resistance, and better color stability due to their unique particle size distribution and composition. The nanoparticles in these composites can fill the spaces between larger particles, resulting in a smoother surface finish and potentially reducing the risk of bacterial adhesion and staining.[16,17]

The method employed for restoration in this study involves the incremental application technique for universal composites. This approach is recommended to maintain an adequate degree of conversion, which is crucial for the longevity of resin restorations. The incremental technique helps address the limited depth of cure associated with conventional resins, a challenge that has long been recognized in the field of restorative dentistry.[3,4] For nanohybrid composites, this technique is particularly important as it ensures optimal polymerization throughout the restoration, maximizing the material's mechanical and esthetic properties.[18]

The study specifically examines the effects of various soft drinks on composite restorations. Soft drinks were selected due to their widespread consumption and potential impact on dental materials. According to recent statistics, the global soft drink market size was valued at USD 417.85 billion in 2023 and is expected to expand at a compound annual growth rate (CAGR) of 5.3% from 2023 to 2030.[19] This prevalence in daily diet makes soft drinks a significant factor in the longevity of dental restorations. The soft drinks used in the study were Biotene (B), passion fruit juice (PFJ), orange juice (OJ), Sprite (S), Coca-Cola (CO), apple cider vinegar (ACV), and cranberry juice (CJ). The selection of these particular beverages represented a diverse range of commonly consumed soft drinks and acidic beverages; Biotene, is an AS substitute, often used by individuals with dry mouth conditions. Its inclusion serves as a comparison point for the other beverages; PFJ and OJ, representing popular fruit juices known for their high vitamin C content but also their acidity. They are frequently consumed for their perceived health benefits and flavor; S and CO, the quintessential carbonated soft drinks, with S being a lemon-lime flavored beverage and C being a cola drink. Both are consumed globally and are staples in the soft drink industry; ACV which while not traditionally considered a soft drink, its inclusion reflects the growing trend of consumption for potential health benefits, despite its high acidity and CJ representing another popular fruit juice, often consumed for its purported health benefits, particularly in urinary tract health. This carefully curated selection encompasses a spectrum of pH levels, sugar content, and chemical compositions, providing a comprehensive representation of acidic beverages that dental restorations routinely encounter. The inclusion of both conventional soft drinks and perceived healthier alternatives allows for a nuanced examination of their effects on dental materials, contributing valuable insights to clinical dentistry and patient education in the realm of oral health maintenance.

Previous studies have shown that beverages such as coffee, tea, and fruit juices can alter the color of composite restorations.[7–10] Interestingly, even beverages not typically associated with staining, such as lemon juice and OJ, have demonstrated the ability to affect composite color.[20–22] However, the effects of these beverages on both color stability and surface hardness of nanohybrid composites, particularly considering the differences between polished and non-polished surfaces, remain to be fully elucidated. The surface characteristics of composite restorations, specifically whether they are polished or non-polished, play a crucial role in their susceptibility to discoloration and degradation. Polished surfaces are generally smoother, potentially reducing plaque accumulation and stain adherence, which could enhance color stability and longevity of the restoration. Conversely, nonpolished or rougher surfaces may be more prone to staining and degradation due to increased surface area and the presence of micro-retentive areas.[23–25] For nanohybrid composites, the polishing process can be particularly effective due to the presence of nanoparticles, potentially leading to a smoother surface compared with conventional composites.[26]

The present study offers a novel approach to evaluating nanohybrid dental composites under simulated real conditions. Its uniqueness stems from the simultaneous examination of color stability and surface hardness changes on both polished and nonpolished surfaces, addressing a critical research gap. Also, the investigation utilizes a diverse array of common beverages, including less studied options like ACV, reflecting contemporary consumption patterns. Understanding the differential effects of various solutions on polished versus nonpolished surfaces of nanohybrid composites is of particular clinical relevance, as not all surfaces of a restoration may be equally accessible for polishing, especially in posterior teeth or in areas near the gingival margin.[27] This knowledge can inform optimal finishing and polishing protocols for nanohybrid composite restorations and guide patient education regarding oral hygiene practices and dietary habits that may affect restoration longevity.[28] By examining both color stability and surface hardness concurrently on polished and nonpolished surfaces of nanohybrid composites, this study aims to provide a comprehensive understanding of the factors influencing composite degradation and discoloration. This multifaceted approach contributes significantly to understanding composite restoration longevity and positions the study as a valuable addition to dental materials science, with implications for future research and clinical practices.

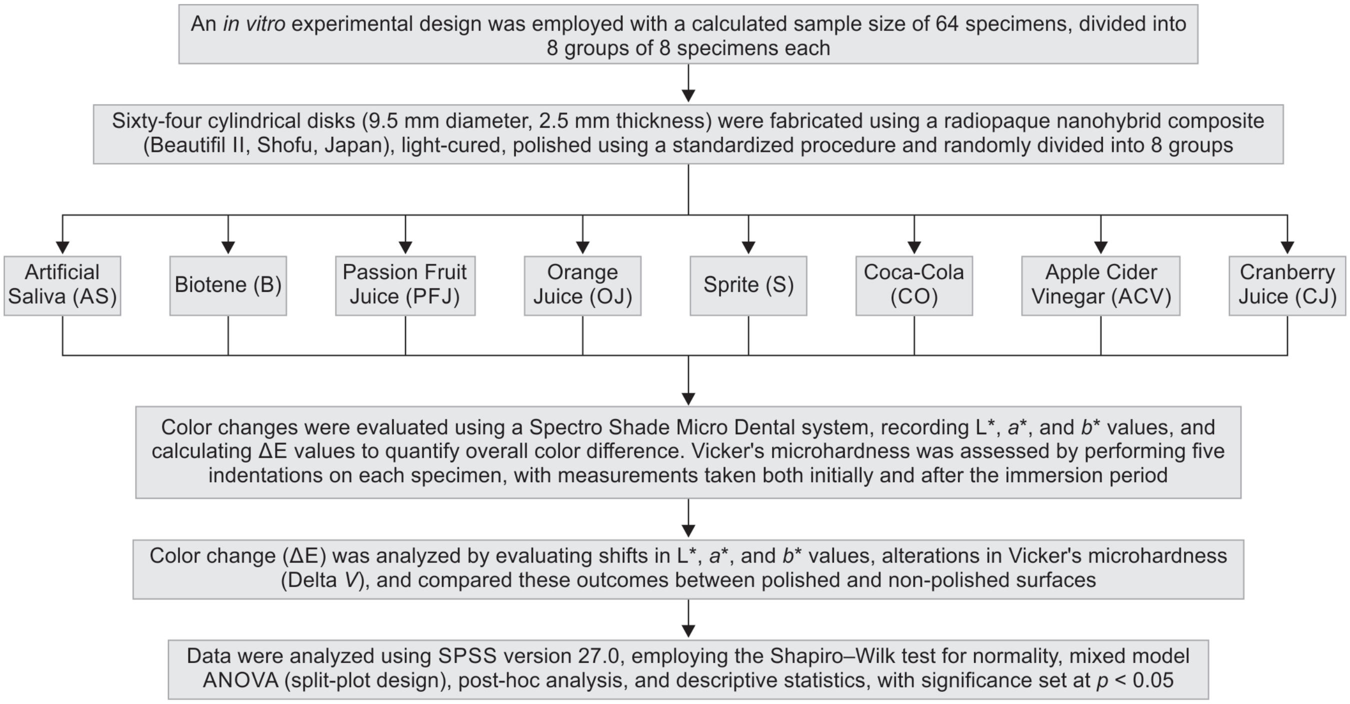
Materials and Methods

Study Design and Sample Size

This study employed an *in vitro* experimental design to evaluate the effects of various common beverages on the color stability and surface microhardness of a nanohybrid composite resin (Fig. 1). The sample size was determined based on previous similar studies in the field of dental materials research. The sample size was calculated to be 64 using the formula:

$$n = \frac{\left(Z^2 1 - \frac{\alpha}{2}\right)(1-p)p}{\xi^2 p}$$

A total of 64 specimens were used, divided into 8 groups of 8 specimens each. This sample size was chosen to provide sufficient statistical power for detecting clinically significant differences between groups while considering practical limitations of specimen preparation and measurement procedures.



An *in vitro* experimental design was employed with a calculated sample size of 64 specimens, divided into 8 groups of 8 specimens each

Sixty-four cylindrical disks (9.5 mm diameter, 2.5 mm thickness) were fabricated using a radiopaque nanohybrid composite (Beautifil II, Shofu, Japan), light-cured, polished using a standardized procedure and randomly divided into 8 groups

Color changes were evaluated using a Spectro Shade Micro Dental system, recording L*, *a**, and *b** values, and calculating ΔE values to quantify overall color difference. Vicker's microhardness was assessed by performing five indentations on each specimen, with measurements taken both initially and after the immersion period

Color change (ΔE) was analyzed by evaluating shifts in L*, *a**, and *b** values, alterations in Vicker's microhardness (Delta *V*), and compared these outcomes between polished and non-polished surfaces

Data were analyzed using SPSS version 27.0, employing the Shapiro–Wilk test for normality, mixed model ANOVA (split-plot design), post-hoc analysis, and descriptive statistics, with significance set at $p < 0.05$

Fig. 1: Experimental workflow for assessing beverage effects on color stability and microhardness of nanohybrid composite resin

Study Duration

The study was conducted over a period of 28 days. This duration was selected to simulate long-term exposure to various beverages, allowing for the observation of cumulative effects on the composite resin properties.

Specimen Preparation

Sixty-four cylindrical disk specimens of a radiopaque nanohybrid composite (Beautifil II, Shofu, Japan) were prepared using a metal mold. Cylindrical specimens were fabricated with dimensions of 9.5 mm in diameter and 2.5 mm in thickness. Inclusion criteria encompassed specimens free from visible defects or air bubbles observed under magnification. Exclusion criteria, conversely, were applied to specimens that exhibited any of the following characteristics upon microscopic inspection: Structural anomalies, heterogeneities, air bubbles, or any other deviations from the established quality benchmarks. By clearly delineating these inclusion and exclusion parameters, the research protocol ensured that only samples meeting rigorous standards of structural integrity were utilized in subsequent analyses, thereby minimizing potential confounding factors and enhancing the reliability of the research outcomes.

The composite resin was applied, shaped, and light-cured following the protocols specified by the manufacturer. Prior to composite placement, transparent glass slides were sanitized using 70% isopropyl alcohol, and the molds were positioned atop these prepared surfaces. The material was packed into the mold, intentionally overfilled, and pressed with a plastic instrument. Another clean glass slide was placed on top to express excess material. The composite was light-cured using a Valo™ LED curing light (Ultradent Products, Inc., UT, United States) with a broadband spectrum wavelength of 395–480 nm. The light tip was positioned 1 mm away from the specimens for 30 s. Excess material was removed with a sharp razor, and the disk was extracted from the mold with light pressure. The side closest to the curing light was marked to distinguish it from the opposite side. The top side of each disk was polished using Sof-Lex series of finishing and polishing disks (coarse, medium, fine, and extra-fine) and polishing rubber wheels (fine and extra-fine) to reduce surface irregularities and improve esthetics.

Experimental Procedures

The 64 cylindrical disk specimens were randomly divided into eight experimental groups ($n = 8$ per group): AS, B, PFJ, OJ, S, CO, ACV, and CJ.

Color Assessment

Color assessment was performed using a Spectro Shade Micro Dental, a comprehensive optic shade communication system. Images of each specimen were taken after the experiment and compared with freshly made specimens of the same dimensions and characteristics. After 28 days, the specimens were collected from the solutions, and their images were taken with SpectroShade Micro. The L^*, a^*, and b^* values were recorded, and ΔE values were calculated using the formula:

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]\,½$$

Delta *E* values were interpreted as follows: 0–2 (excellent match), 2–4 (good match if Delta *L* is below 1), and above 4 (borderline, suggesting adjustments are needed).

Outcome Analysis

The primary outcomes analyzed were color change (ΔE) after 28 days of immersion, changes in L^*, a^*, and b^* values, and changes in Vickers microhardness (Delta *V*). These outcomes were analyzed for both polished and nonpolished surfaces of the specimens, providing a comprehensive assessment of the effects of various solutions on the composite resin properties.

Microhardness Evaluation

Vickers microhardness was determined by performing five indentations on each specimen after initial polymerization and after 28 days of immersion in the solutions. delta Vickers (Delta *V*) represents the difference between the initial microhardness and the measurements made after the experimental period.

Statistical Analysis

Data analysis was conducted using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). The Shapiro–Wilk test was employed to assess the normality of distribution for all measurement data. Mixed model ANOVA (split-plot ANOVA) with one grouping factor (treatment) and one repeated measure (surface within disk) were used to analyze the color and microhardness changes. *Post hoc* analysis was performed to identify significant differences between specific groups. Descriptive statistics including means and standard deviations were calculated for all measurements. The significance level was set at $p < 0.05$ for all statistical tests. This comprehensive statistical approach allowed for the analysis of both between-group differences (effect of different solutions) and within-specimen differences (polished vs nonpolished surfaces), as well as their interactions.

RESULTS

Color Change

The Shapiro–Wilk test was employed to assess the distribution of all measurement data, including L^*, a^*, b^*, and microhardness values for each composite group. The results indicated a normal distribution for all parameters ($p > 0.05$). To evaluate color changes, the average and standard deviation of color differences between the baseline and 28-day measurements for both polished and nonpolished surfaces of the composite samples were computed. These calculations included changes in lightness (ΔL), red–green axis (Δa), and blue–yellow axis (Δb) for all staining solutions used in the study. The polished surfaces exhibited varying degrees of discoloration, with most specimens showing borderline results ($\Delta E > 4$), except for B and S specimens that showed a good match ($2 < \Delta E < 4$). CO and CJ specimens demonstrated the greatest color change among all tested solutions. The nonpolished surfaces generally showed lower ΔE values compared with the polished sides of the same specimens. CO, CJ, and OJ specimens showed borderline results on the nonpolished side. PFJ and ACV specimens exhibited a good match, while AS, B, and S specimens demonstrated an excellent match ($\Delta E < 2$) (Fig. 2).

Shade alterations were observed in all specimens, with the exception of polished surfaces immersed in AS. The extent and nature of these changes varied among different solutions. Biotene induced a shift from A2 to B2 in 50% of polished specimens, while S effected this change in all polished samples. Passion fruit juice consistently altered polished specimens from A2 to A3. Orange juice and ACV caused similar transitions in 75 and 33% of polished specimens, respectively. Cranberry juice uniformly changed polished specimens to C4. Coca-Cola exhibited the most diverse effects, with polished specimens showing variable changes: 50% to D4, 25% to A3.5, and 25% to A3. Non-polished surfaces generally exhibited less pronounced shade alterations compared with their polished counterparts, with notable exceptions. Orange juice, AS (33%), ACV, and PFJ (15%) induced darker shades on nonpolished surfaces. CO, B, and S demonstrated comparable changes on both polished and nonpolished sides. Interestingly, CJ produced a lighter stain (A4) on nonpolished surfaces compared with the darker C4 observed on polished sides.

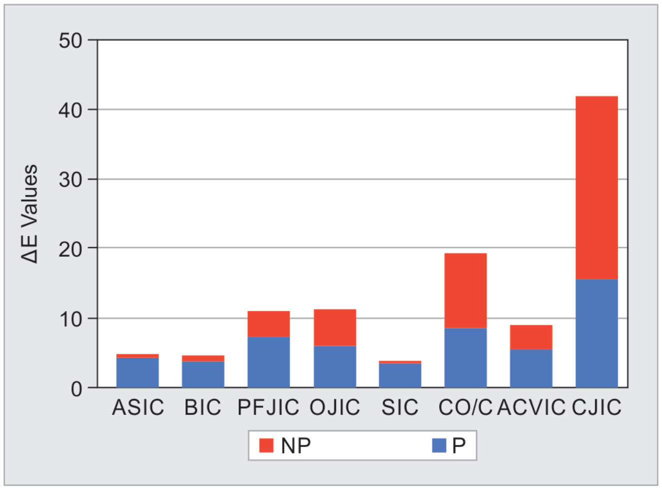


Fig. 2: Color change (ΔE) of polished and non-polished composite surfaces after 28-day immersion in various beverages

Statistical analysis revealed complex interactions among composite surface types (polished and nonpolished), various staining solutions, and duration of immersion ($p < 0.05$). When comparing the magnitude of color change (ΔE) across both surface types, a clear hierarchy emerged. Coca-Cola induced the most significant alterations, followed by CJ, OJ, PFJ, ACV, S, B, and AS, in descending order of impact. The b^* value, representing the blue–yellow spectrum, exhibited the most substantial shifts, contributing heavily to overall discoloration. All test solutions were acidic in nature, with CO demonstrating the lowest pH. A positive correlation was observed between immersion duration and degree of discoloration, though the specific effects of pH varied depending on the pigments present in each solution. After the 28-day immersion period, color changes were evident across all samples, with polished surfaces generally displaying more noticeable alterations compared with their nonpolished counterparts.

Microhardness

The surface hardness of both polished and nonpolished faces of the composite samples was evaluated using the Vickers microhardness test after a 28-day immersion period in diverse solutions. Five separate indentations were conducted on each specimen, and the mean value was calculated to ensure a representative measure of surface hardness. The results showed that the microhardness of the polished side of all experimental disks decreased compared with the control, with reductions ranging from 21.9 to 35.5% . The most significant reduction was observed in specimens immersed in (ACV, 35.5% reduction), followed by cranberry juice (CJ, 31.1% reduction). The least affected were specimens immersed in Coca-Cola (CO, 21.9% reduction) and orange juice (OJ, 23.4% reduction).

For the nonpolished side, all experimental specimens showed an increase in microhardness compared with the control. The increases ranged from 11.2 to 17.4%. Specimens immersed in AS showed the smallest increase (11.2%), while those in CJ exhibited the largest increase (17.4%). Statistical analysis revealed that the microhardness of the nonpolished side was significantly lower than that of the polished side for all disks, including the control, with an average difference of approximately 69%.

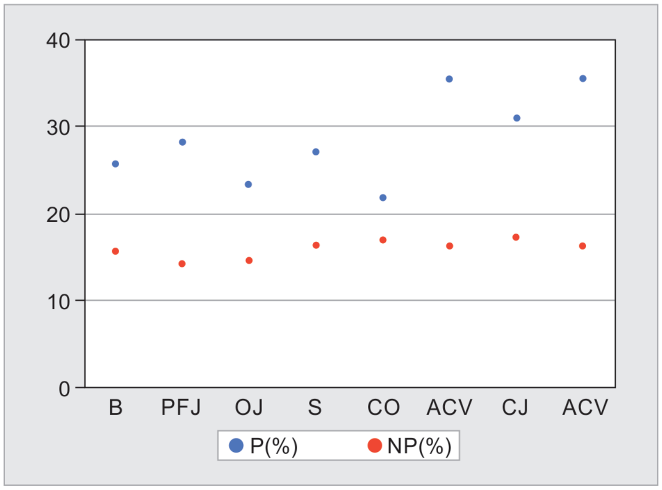


Fig. 3: Percentage change in Vickers microhardness of polished and nonpolished composite surfaces after 28-day immersion in various solutions

The ANOVA for split-plot design was performed to analyze the effects of the different solutions on microhardness. The results showed no significant interaction between the polishing status (polished vs nonpolished) and the staining solution ($p > 0.05$). However, the staining solutions significantly influenced the microhardness values of the composite ($p < 0.05$). *Post hoc* analysis revealed that specimens immersed in ACV and CJ had significantly lower microhardness values on the polished side compared with other solutions ($p < 0.05$). For the nonpolished side, no statistically significant differences were found among the different solutions ($p > 0.05$). Overall, there was a significant reduction in the microhardness values from the baseline (control) to the poststaining condition for the polished side ($p < 0.0001$), while the nonpolished side showed a significant increase in microhardness ($p < 0.0001$) (Fig. 3).

The study on nanofilled dental composite degradation revealed complex interactions between various factors. The Shapiro–Wilk test confirmed a normal distribution for all parameters (L^*, a^*, b^*, and microhardness values) across all composite groups ($p > 0.05$).

Intergroup Comparisons

Intergroup analysis revealed significant variations in color change and microhardness across different staining solutions. Color changes, measured by ΔE values, showed a clear hierarchy of impact among solutions. Coca-Cola induced the most significant alterations, followed by CJ, OJ, PFJ, ACV, S, B, and AS, in descending order. This hierarchy was consistent across both polished and nonpolished surfaces, although the magnitude of change differed. Statistical analysis confirmed complex interactions among composite surface types, staining solutions, and immersion duration ($p < 0.05$). Microhardness changes also varied significantly among groups. For polished surfaces, specimens immersed in ACV showed the highest reduction in microhardness (35.5%), followed by CJ (31.1%). The least affected were specimens immersed in CO (21.9% reduction) and OJ (23.4% reduction). ANOVA results confirmed that staining solutions significantly influenced the microhardness values of the composite ($p < 0.05$). *Post hoc* analysis revealed that specimens immersed in ACV and CJ had significantly lower microhardness values on the polished side compared with other solutions ($p < 0.05$). Interestingly, no direct correlation was found between solution acidity and the degree of degradation. Solutions with the highest pH did not necessarily induce the most significant alterations in microhardness and color. However, darker-pigmented solutions, such as CO and CJ, consistently caused more pronounced color changes across all specimens.

Intragroup Comparisons

Intragroup analysis focused on comparisons between polished and nonpolished surfaces within each solution group. Consistently across all groups, polished surfaces exhibited more pronounced color changes compared with nonpolished surfaces. For instance, while polished specimens showed borderline results ($\Delta E > 4$) in most solutions, their nonpolished counterparts generally showed lower ΔE values. This trend was particularly evident in CO, CJ, and OJ groups. Shade alterations also showed intragroup variations. In the CO group, polished specimens displayed diverse changes (50% to D4, 25% to A3.5, 25% to A3), while nonpolished surfaces showed less pronounced alterations. Similarly, CJ produced a darker stain (C4) on polished surfaces compared with a lighter stain (A4) on nonpolished surfaces. Microhardness changes revealed a striking intragroup pattern. Across all solution groups, polished surfaces consistently showed a decrease in microhardness, while nonpolished surfaces exhibited an increase. The microhardness of nonpolished surfaces was significantly lower than that of polished surfaces for all disks, including the control, with an average difference of approximately 69%. This pattern holds true regardless of the staining solution, indicating a strong influence of surface treatment on microhardness changes. Color parameter changes also showed intragroup trends. Generally, L^* and b^* values decreased across specimens within each group, indicating a shift toward darker and less yellow shades. The a^* value tended to move closer to zero on the green–red scale for most specimens within groups, with exceptions noted for the nonpolished side of CO disks and the polished side of CJ disks. These intragroup comparisons highlight the significant impact of surface treatment on composite degradation, with polished and nonpolished surfaces responding differently to the same staining solution. This underscores the importance of considering surface characteristics in predicting the long-term performance of dental composites in various oral environments.

The present study on nanohybrid dental composites provides crucial insights into their performance when exposed to common beverages, revealing complex interactions between surface treatment, staining solutions, and immersion duration. All specimens exhibited some degree of discoloration, with polished surfaces, generally showing more pronounced changes than nonpolished surfaces. Coca-Cola and CJ induced the most significant color alterations across both surface types. Microhardness tests yielded intriguing results; polished surfaces experienced a decrease in hardness for all solutions, with ACV and CJ causing the most significant reductions, while nonpolished surfaces unexpectedly showed an increase in microhardness. This divergent response between polished and nonpolished surfaces to identical staining solutions underscores the critical role of surface characteristics in composite performance. Interestingly, the impact of staining solutions did not directly correlate with their acidity; however, darker pigmented solutions consistently caused more pronounced color changes. Artificial saliva (AS) demonstrated the least detrimental effects on the composite, suggesting that a neutral oral environment best preserves the material's properties. These findings highlight the intricate balance between various factors affecting the longevity and esthetic durability of dental restorations, emphasizing the need for careful consideration in clinical practice and patient education regarding oral hygiene and dietary habits. The study's comprehensive approach, examining both color stability and microhardness changes on different surface treatments, contributes valuable knowledge to the field of dental materials science and has significant implications for improving the long-term success of composite restorations.

DISCUSSION

The present study elucidates the multifaceted interactions governing the discoloration and degradation of dental composites under diverse oral conditions. The proliferation of esthetic dental restorations in contemporary dentistry necessitates a comprehensive understanding of the impact of varying oral environments on the durability and esthetic integrity of composite materials.[1,2] This investigation sought to delineate the effects of common beverages on both the chromatic stability and surface microhardness of nanohybrid composites, with particular emphasis on the influence of surface treatment. The selection of a nanohybrid composite (Beautifil II) for this research was predicated on its advanced physicochemical properties, which synergistically incorporate the advantages of nanofilled and traditional hybrid composites. Nanohybrid composites exhibit enhanced esthetic qualities, superior mechanical properties, and improved polishability, rendering them appropriate for both anterior and posterior restorative applications.[14,15] The methodological approach employed in this study adhered to established protocols in dental materials research. The research employed appropriate materials and techniques to evaluate the degradation of nanofilled dental composites. The Shapiro–Wilk test ensured the validity of statistical analyses by confirming normal data distribution.[29] The average, standard deviation, and ΔE provided comprehensive measures of color change.[30,31] The Vickers microhardness test accurately assessed the material's hardness.[32] ANOVA for split-plot design allowed for a thorough analysis of the effects of polishing status and staining solutions.[33] These methodologies ensure the generation of reliable, reproducible, and comparable results, thereby contributing to the robustness of the study's findings and their potential for integration into the existing body of knowledge in restorative dentistry.

The findings reveal intricate interactions between composite surfaces and various staining solutions, with no direct link observed between solution acidity and degradation severity. This observation aligns with Soares-Geraldo et al.'s research, which found that PFJ caused the most significant microhardness changes among eight common beverages tested.[7] Their hypothesis that hydrophobic solutions preferentially stain hydrophobic materials, while hydrophilic solutions affect hydrophilic components of dental composites, offers a potential explanation for our results. The findings of the present study are also consistent with Wasilewski et al.'s demonstration that the combination of whiskey and cigarette smoke induced greater color changes in composite specimens compared with cigarette smoke alone.[8]

The variability in color change, particularly on nonpolished surfaces, can be attributed to differences in the degree of polymerization and surface topography, as suggested by previous studies.[26] However, our observation of greater color change on polished surfaces in the CJ group diverges from this trend. This exception suggests that certain colorants may preferentially incorporate into surfaces roughened and smoothed by polishing disks, highlighting the complex nature of stain adherence and penetration in composite materials.[17] The microhardness results revealed interesting patterns, with polished surfaces generally showing a decrease and nonpolished surfaces an increase overtime. These findings are in line with Geurtsen's research on the extraction of organic substances from composites by organic solvents.[19] The decrease in microhardness on polished surfaces can be explained by the leaching of substances, consistent with previous studies. However, the increase on nonpolished surfaces suggests a different type of interaction, which has not been widely reported in the literature. The hypothesis that characteristic molecules from each solution's stain were incorporated into the crosslinking network of the nonpolished side, explains both the increase in microhardness and the greater discoloration compared with the polished side.[16,17] This hypothesis offers a novel perspective on the interaction between staining solutions and composite surfaces, potentially opening new avenues for research in this field.

The present investigation, while yielding valuable insights, is subject to certain methodological constraints that warrant consideration in subsequent research endeavors. Primarily, the *in vitro* experimental design, although facilitating controlled conditions, may not fully encapsulate the intricate oral milieu, including such factors as salivary enzymatic activity, thermal fluctuations, and mechanical stresses. Future investigations should aim to incorporate these variables to provide a more comprehensive elucidation of composite degradation mechanisms. Furthermore, while the current study's 28-day duration offered significant observations, there remains a need for longitudinal studies that can elucidate effects manifesting over extended periods of clinical service, spanning months to years. Such protracted investigations could potentially reveal long-term degradation patterns that may not be apparent in short-term studies. Additionally, subsequent research should explore the potential role of oxidative processes in both chromatic alterations and microhardness modifications of dental composites. This avenue of inquiry, as suggested by previous literature, could provide deeper insights into the underlying mechanisms of composite material degradation overtime.[9–11] In addressing these limitations, future studies will contribute to a more nuanced and comprehensive understanding of dental composite behavior in clinical settings, ultimately informing improved material design and clinical protocols.

The message to clinicians based on this study's outcomes is multifaceted. First, the findings underscore the critical role of surface treatment in the long-term performance of composite restorations. While polished surfaces may initially confer superior esthetic properties and enhanced surface hardness, our results suggest that these surfaces may exhibit increased susceptibility to certain types of staining and degradation over extended periods. This observation necessitates a re-evaluation of current clinical practices regarding surface finishing protocols. Second, the selection of composite material should be informed not only by the classification of the restoration, but also by patient-specific factors, including dietary habits and oral hygiene practices. The current findings indicate that dark-pigmented beverages, particularly those characterized by low pH, may accelerate composite degradation. This emphasizes the need for a more personalized approach to material selection in clinical practice, taking into account the patient's lifestyle and dietary preferences. Furthermore, patient education emerges as a crucial component of clinical care. While complete avoidance of staining agents is impractical in most cases, patients should be thoroughly informed about the potential impacts of dietary choices on their restorations. Clinicians should emphasize the importance of moderation in consumption of potentially staining beverages and reinforce proper oral hygiene practices as essential measures for maintaining restoration esthetics and longevity. The observed increase in microhardness on nonpolished surfaces overtime challenges the conventional wisdom that initial hardness is a reliable indicator of long-term performance. This finding suggests that clinicians should consider the potential for material property changes when planning and placing restorations, and perhaps re-evaluate the emphasis placed on initial surface hardness as a predictor of clinical success. Last, the complex interactions between composite materials and various oral solutions, as demonstrated in this study, underscore the importance of regular follow-ups and maintenance protocols for composite restorations. These interactions, which can lead to changes in color and microhardness overtime, necessitate ongoing monitoring to ensure optimal long-term performance of restorations. The outcomes of this study emphasize the need for a comprehensive, patient-centered approach to composite restoration placement and maintenance. Clinicians should consider material properties, surface treatments, patient-specific factors, and long-term follow-up care in their treatment planning and execution. This holistic approach may contribute to improved longevity and patient satisfaction with composite restorations.

CONCLUSION

The present investigation elucidates the intricate interplay between dental composite materials and diverse oral environment solutions. The findings reveal substantial alterations in composite properties in scenarios where polymerization or polishing is incomplete, emphasizing the critical nature of meticulous clinical technique. Notably, even in instances where composite surfaces are adequately polymerized and polished, significant modifications occur when exposed to aqueous environments at physiological temperatures (37°C) over extended periods. The results of this study demonstrate a hierarchical impact of various staining solutions on color change and microhardness, with CO and CJ inducing the most pronounced effects. Intriguingly, polished surfaces exhibited greater susceptibility to discoloration compared with their nonpolished counterparts, while paradoxically showing decreased microhardness overtime. This dichotomy in surface behavior illuminates the complex nature of composite degradation processes. Furthermore, the absence of a direct correlation between solution acidity and the degree of degradation suggests that other factors, such as pigment composition and molecular interactions, play crucial roles in the long-term stability of composite restorations. These findings accentuate the necessity for a nuanced approach to composite material selection and clinical application, taking into account patient-specific factors and anticipated oral environment conditions. The authors conclude that while proper clinical technique remains paramount, the inevitable aging of composite materials in the oral cavity warrants further investigation. Future research endeavors should focus on elucidating the precise mechanisms underlying composite aging and its implications for susceptibility to extrinsic and intrinsic discolorations, as well as microhardness alterations. Such insights will be instrumental in advancing the development of more durable and stable composite materials for dental applications.

Clinical Significance

This study investigated the effects of various common beverages on the color stability and microhardness of nanohybrid composite resins, revealing complex interactions between composite surfaces and staining solutions. No direct correlation was found between solution acidity and the degree of composite degradation. Dark-pigmented beverages, such as CO and CJ, caused the most pronounced color changes, regardless of their pH levels. Polished surfaces generally exhibited greater color changes but decreased microhardness overtime, while nonpolished surfaces showed less color change but increased microhardness. The behavior of composites varied depending on the specific staining solution, with hydrophobic and hydrophilic components of the composite reacting differently to various beverages. Surface treatment (polished vs nonpolished) significantly influenced both color stability and microhardness changes, highlighting its importance in restoration longevity.

The authors conclude that composite degradation in the oral environment is a complex process influenced by multiple factors beyond simply pH or pigmentation. The study emphasizes the need for a comprehensive approach to material selection, restoration technique, and patient care to optimize the longevity and esthetics of composite restorations. The findings suggest that clinicians should consider not only the initial properties of composite materials, but also their potential long-term behavior in various oral conditions when planning restorations.

Furthermore, the authors recommend future research directions focusing on long-term *in vivo* studies, investigating the role of oxidation processes in composite degradation, and developing composite materials with enhanced resistance to the diverse challenges presented by the oral cavity. This research underscores the importance of ongoing advancements in dental materials to meet the complex demands of the oral environment and ensure optimal patient outcomes.

Ethical Approval

Ethical clearance was obtained from the Institutional Ethical Committee (ABSM/EC10/2018).

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