



BASIC RESEARCH:

Influence of Commercial Toothpastes on Surface Roughness and Color Stability of a 3D-Printed Resin: A Pilot *In Vitro* Study

Influencia de dentífricos comerciales en la rugosidad superficial y estabilidad del color de una resina impresa en 3D: estudio piloto *in vitro*

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ABSTRACT: This pilot *in vitro* study evaluated the effect of different commercial toothpastes containing hydroxyapatite, activated charcoal, or conventional abrasive systems on the surface roughness and color stability of a 3D-printed resin material. Disc-shaped specimens were fabricated and subjected to simulated toothbrushing using toothpaste slurries for a standardized number of cycles. Surface roughness was assessed using a contact profilometer, and color changes were measured spectrophotometrically. Data were analyzed using non-parametric statistical tests with a significance level of 0.05. Toothpaste composition significantly influenced both surface roughness and color stability. The highest roughness values were observed in the activated charcoal group, whereas the lowest color change values were detected in the Be You group. Under the conditions of this pilot study, Be You, a hydroxyapatite-containing toothpaste, showed more favorable optical behavior, while hydroxyapatite-containing products did not show a uniform response across all outcomes. These findings indicate that the abrasivity and composition of commercial toothpastes may influence the surface integrity and optical performance of 3D-printed resin materials. However, these results should be interpreted as preliminary and confirmed in future studies with larger sample sizes.

KEYWORDS: Hydroxyapatite; Toothpastes; Surface properties; Color stability; Dental materials.

RESUMEN: Este estudio piloto *in vitro* evaluó el efecto de diferentes dentífricos comerciales que contienen hidroxiapatita, carbón activado y sistemas abrasivos convencionales sobre la rugosidad superficial y la estabilidad del color de un material de resina impreso en 3D. Se fabricaron especímenes en forma de disco y se sometieron a un cepillado simulado utilizando suspensiones de dentífrico durante un número estandarizado de ciclos. La rugosidad superficial se evaluó mediante un rugosímetro de contacto, y los cambios de color se midieron mediante espectrofotometría. Los datos fueron analizados mediante pruebas estadísticas no paramétricas con un nivel de significancia de 0,05. La composición del dentífrico influyó significativamente tanto en la rugosidad superficial como en la estabilidad del color. Los mayores valores de rugosidad se observaron en el grupo con carbón activado, mientras que los menores cambios de color se registraron en el grupo Be You. Bajo las condiciones de este estudio piloto, Be You, un dentífrico con hidroxiapatita, mostró un comportamiento óptico más favorable; sin embargo, los productos con hidroxiapatita no presentaron una respuesta uniforme en todos los desenlaces evaluados. Estos hallazgos indican que la abrasividad y la composición de los dentífricos comerciales pueden influir en la integridad superficial y el comportamiento óptico de los materiales de resina impresos en 3D. No obstante, estos resultados deben interpretarse como preliminares y confirmarse en futuros estudios con tamaños muestrales mayores.

PALABRAS CLAVE: Hidroxiapatita; Dentífricos; Propiedades de superficie; Estabilidad del color; Materiales dentales.

INTRODUCTION

The increasing demand for esthetic and functional dental restorations has driven the incorporation of additive manufacturing technologies into restorative dentistry, particularly through the use of 3D-printed resin materials for provisional and definitive applications (1,2). These materials offer high precision, customization, and efficient digital workflows, positioning stereolithography (SLA)-based resins as a promising alternative to conventional CAD/CAM and direct restorative materials (3,4). Despite these advantages, concerns remain regarding their long-term behavior when exposed to the mechanical and chemical challenges of the oral environment (5).

The preservation of surface integrity and optical properties is essential for the clinical longevity and esthetic performance of restorative materials. Daily toothbrushing represents a continuous source of mechanical and chemical challenge, as it combines

repetitive abrasion with the action of toothpaste formulations, potentially altering surface roughness and color stability (5-9). Surface roughness is a critical parameter, as increased roughness may promote plaque accumulation, surface staining, and loss of gloss, thereby compromising both esthetics and oral hygiene (6,7). Similarly, color stability plays a key role in maintaining the long-term appearance of restorations, particularly in highly visible areas (8).

Among the factors affecting these properties, toothpaste composition is of particular relevance. The abrasive potential of dentifrices depends on the characteristics of their particles, including size, hardness, morphology, and concentration, as well as the presence of active ingredients aimed at enhancing cleaning or whitening effects (10). Whitening toothpastes, especially those containing activated charcoal, have gained popularity due to their perceived stain-removal capacity; however, several studies have reported that such formula-

tions may increase surface roughness and adversely affect the optical properties of enamel and resin-based materials (11-13).

These effects may be more pronounced in resin materials fabricated using additive manufacturing techniques, as their polymer matrix composition, degree of conversion, and filler distribution differ from those of conventional resin composites (14). Previous studies have shown that 3D-printed resins may exhibit distinct wear patterns and surface responses when subjected to mechanical challenges, raising concerns about their long-term esthetic performance under routine oral hygiene conditions (15,16).

In contrast, hydroxyapatite has been incorporated into dentifrice formulations due to its biomimetic properties and chemical similarity to dental hard tissues (17). Hydroxyapatite-containing toothpastes have demonstrated the ability to reduce abrasive wear and improve surface smoothness in enamel and resin-based materials (18-20). The deposition of hydroxyapatite particles may form a protective layer that mitigates surface degradation during brushing (17). However, evidence regarding their interaction with 3D-printed resin materials remains limited, and their effects on surface roughness and color stability have not been fully elucidated (21,22).

Given the increasing clinical use of 3D-printed resin materials and their routine exposure to different dentifrice formulations, it is important to evaluate how oral hygiene products influence their surface and optical properties. A better understanding of these interactions may contribute to evidence-based recommendations aimed at

preserving the esthetic and functional longevity of restorations fabricated using additive manufacturing technologies (22,23).

Therefore, the aim of this pilot *in vitro* study was to evaluate the influence of different commercial toothpastes, including products containing hydroxyapatite, activated charcoal, or conventional abrasive systems, on the surface roughness and color stability of a 3D-printed resin material after simulated toothbrushing.

MATERIALS AND METHODS

STUDY DESIGN

This pilot *in vitro* experimental and comparative study evaluated the influence of different commercial toothpastes on the surface roughness and color stability of a 3D-printed dental resin material after simulated toothbrushing.

SPECIMEN PREPARATION

A total of fifty standardized disc-shaped specimens were fabricated using a stereolithography (SLA) 3D-printing resin indicated for definitive restorations (VarseoSmile Crown Plus®, Bego, Germany). Specimens were designed with dimensions of 25.0 mm in diameter and 2.0 mm in thickness, according to the manufacturer's recommendations.

After printing, all specimens were cleaned in isopropyl alcohol to remove residual uncured resin and subsequently post-cured under ultraviolet light. Each specimen was inspected to ensure surface uniformity, absence of defects such as cracks or bubbles, and consistency in thickness.

Prior to testing, specimens were stored in physiological saline solution at 37°C for 24 hours to simulate intraoral conditions, as commonly described in studies evaluating 3D-printed dental resins.

EXPERIMENTAL PROCEDURES

The toothpastes evaluated in the present study and their main characteristics are summarized in Table 1. Distilled water was used as the control medium. Specimens were randomly allocated into five experimental groups (n=10 per group) according to the toothpaste used during the brushing simulation: control (distilled water), Colgate Total 12, Colgate Total 12 Charcoal, Ela Mint, and Be You.

Table 1. Characteristics and composition of the toothpastes evaluated in this study.

Toothpaste	Composition	Indication
Distilled water (control)	-	Control
Colgate Total 12 (Colgate-Palmolive)	Sodium fluoride + hydrated silica	Daily oral hygiene
Colgate Total 12 Charcoal (Colgate-Palmolive)	Sodium fluoride + hydrated silica + activated charcoal	Whitening
Ela Mint (Oral Care Co.)	Hydroxyapatite-based particles	Remineralizing oral care
Be You (Curaprox)	Hydroxyapatite-based particles	Whitening and oral care

Given the exploratory nature of this pilot *in vitro* study, a sample size of 10 specimens per group was adopted based on comparable laboratory studies evaluating surface roughness and color stability after simulated toothbrushing. No formal a priori sample size calculation was performed; therefore, the findings should be interpreted

as preliminary and should be confirmed in future studies with larger sample sizes and formal power analysis.

Brushing simulation was performed using a standardized mechanical toothbrushing machine to minimize operator-related variability. A medium-hardness manual toothbrush (Oral-B Indicator Medium) was used for all experimental groups. The brushing device applied a constant vertical load of 200 g and a linear brushing motion at a frequency of 120 strokes per minute, for a total of 40,000 brushing cycles, simulating approximately six months of clinical toothbrushing based on previously validated models.

Toothpaste slurries were prepared by mixing 1 g of toothpaste with 2 mL of distilled water (1:2 ratio), following standardized protocols reported in previous studies (10,12). The slurry was evenly applied to the specimen surface and refreshed periodically during the brushing procedure. After completion of the brushing cycles, all specimens were rinsed with distilled water and air-dried.

OUTCOME ASSESSMENT

Surface roughness was measured before and after brushing using a contact profilometer (Mitutoyo Surftest, Mitutoyo Corp., Japan). Both vertical (ΔRaV) and horizontal (ΔRaH) roughness values were recorded. For each specimen, three measurements were taken in different directions, and the mean value was calculated. The device was calibrated according to the manufacturer's instructions prior to data collection. Changes in surface roughness were calculated as the difference between baseline and post-brushing measurements (Table 2).

Table 2. Surface roughness values (ΔRaV and ΔRaH) of 3D-printed resin specimens after simulated toothbrushing (n=10 per group).

Group	ΔRaV (Mean $\pm$ SD)	ΔRaH (Mean $\pm$ SD)
Control (distilled water)	0.14 $\pm$ 0.02 ^b	0.13 $\pm$ 0.01 ^b
Colgate Total 12	0.20 $\pm$ 0.04 ^b	0.18 $\pm$ 0.03 ^b
Colgate Total 12 Charcoal	0.25 $\pm$ 0.04 ^a	0.23 $\pm$ 0.04 ^a
Ela Mint	0.22 $\pm$ 0.04 ^b	0.20 $\pm$ 0.03 ^b
Be You	0.13 $\pm$ 0.03 ^b	0.12 $\pm$ 0.03 ^b

Different superscript letters within the same column indicate statistically significant differences between groups ($p < 0.05$).

Color measurements were obtained using a digital spectrophotometer (VITA Easyshade, VITA Zahnfabrik, Germany) under the CIE Lab* system. Three readings were recorded per specimen under standardized lighting conditions, and mean values were calculated. Color change was expressed as the total color difference (ΔE).

STATISTICAL ANALYSIS

All data were tabulated and analyzed using SPSS Statistics software (version 26.0; IBM Corp., Armonk, NY, USA). Data normality was assessed using the Shapiro–Wilk test. As the data did not follow a normal distribution, intergroup comparisons were performed using the Kruskal–Wallis test, followed by Mann–Whitney tests for pairwise

comparisons. The level of statistical significance was set at $\alpha = 0.05$.

Although data distribution was non-normal, results are presented as mean $\pm$ standard deviation to facilitate interpretation and comparison with previous studies evaluating similar outcomes.

RESULTS

A total of 50 standardized specimens were fabricated and randomly allocated into five experimental groups (n=10 per group): Control (distilled water), Colgate Total 12, Colgate Total 12 Charcoal, Ela Mint, and Be You. No specimens were excluded, damaged, or lost during the brushing simulation or measurement procedures; therefore, all specimens were included in the final statistical analysis. Data distribution for surface roughness (ΔRaV and ΔRaH) and color change (ΔE) was assessed, showing non-normal distribution for all variables ($p < 0.05$).

Significant differences in surface roughness were observed among the experimental groups ($p < 0.001$). The highest ΔRaV and ΔRaH values were recorded in the Colgate Total 12 Charcoal group, whereas the lowest values were observed in the Be You and control groups. Pairwise comparisons showed that the Colgate Total 12 Charcoal group presented significantly higher roughness values compared with the control ($p < 0.001$),

Colgate Total 12 ($p < 0.001$), Ela Mint ($p < 0.001$), and Be You ($p < 0.001$). In contrast, no significant differences were found among the remaining groups ($p > 0.05$). Figure 1 illustrates the distribution of vertical surface roughness (ΔRaV), while Figure 2 shows the horizontal surface roughness (ΔRaH) among the experimental groups.

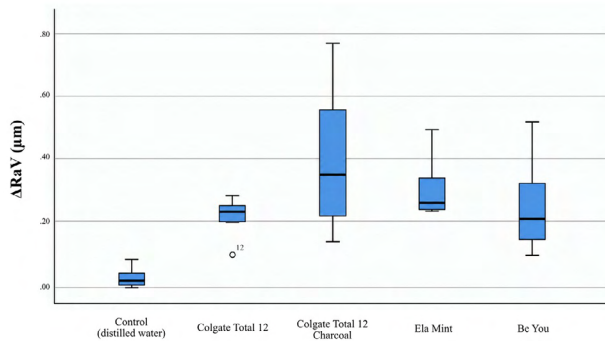


Figure 1. Vertical surface roughness (ΔRaV) distribution among the experimental groups.

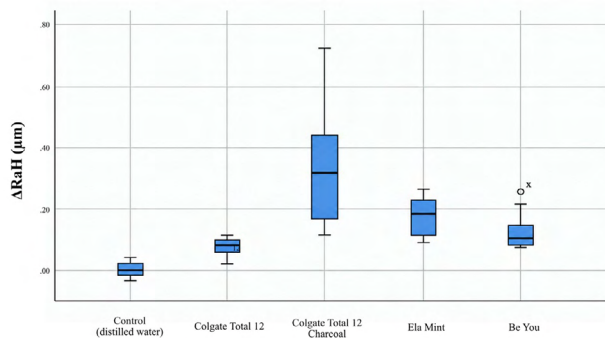


Figure 2. Horizontal surface roughness (ΔRaH) distribution among the experimental groups.

Statistically significant differences in color change were also detected among the experimental groups ($p = 0.007$). The highest mean ΔE value was observed in the Colgate Total 12 group, followed by Ela Mint, Colgate Total 12 Charcoal,

and the control group, whereas the lowest value was recorded in the Be You group. Pairwise comparisons revealed that the Be You group showed significantly lower ΔE values than the control group ($p = 0.003$), Colgate Total 12 ($p = 0.046$), and Ela Mint ($p = 0.028$). No significant differences were observed among the remaining comparisons ($p > 0.05$). Figure 3 presents the distribution of color change (ΔE) among the experimental groups after simulated toothbrushing (Table 3).

Table 3. Color change (ΔE) of 3D-printed resin specimens after simulated toothbrushing ($n = 10$ per group).

Group	ΔE (Mean $\pm$ SD)
Control (distilled water)	2.10 ± 0.27^a
Colgate Total 12	2.74 ± 0.39^a
Colgate Total 12 Charcoal	2.25 ± 0.38^{ab}
Ela Mint	2.45 ± 0.38^a
Be You	1.34 ± 0.30^b

Different superscript letters within the same column indicate statistically significant differences between groups ($p < 0.05$). Kruskal-Wallis test ($p = 0.007$). Post hoc analysis (Mann-Whitney U test) revealed significant differences between Be You and Control ($p = 0.003$), Colgate Total 12 ($p = 0.046$), and Ela Mint ($p = 0.028$).

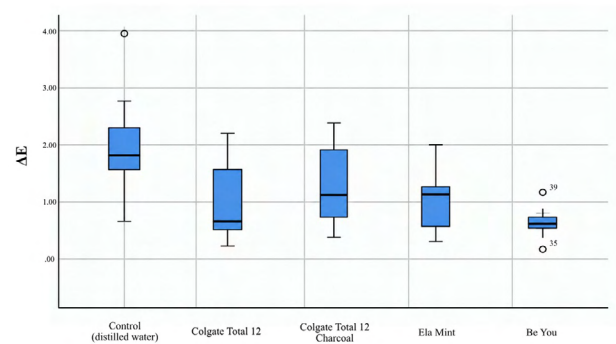


Figure 3. Distribution of color change (ΔE) among the experimental groups after simulated toothbrushing.

DISCUSSION

The present pilot study evaluated the effect of different commercial toothpastes on the surface roughness and color stability of a 3D-printed dental resin after simulated toothbrushing. The results demonstrated that toothpaste composition significantly influenced both surface roughness and color stability of the evaluated material.

Regarding surface roughness, the highest ΔRaV and ΔRaH values were observed in the Colgate Total 12 Charcoal group, whereas the lowest values were recorded in the Be You group. These findings suggest that dentifrices containing abrasive particles, particularly charcoal-based formulations, may produce greater surface alterations on resin-based restorative materials. Mechanical abrasion generated during toothbrushing is known to affect the surface integrity of restorative materials, especially under repeated brushing cycles and in the presence of abrasive particles (11,12,14). This process may increase surface roughness and facilitate plaque accumulation and staining over time (1,2).

These findings are consistent with previous studies evaluating the effect of dentifrices on restorative materials. Bragança *et al.* reported that charcoal-containing toothpastes may significantly increase the surface roughness of resin composites due to their abrasive composition (3). Similarly, Köroğlu *et al.* demonstrated that simulated toothbrushing with whitening dentifrices can lead to measurable surface deterioration (4). Together with previous reports indicating that abrasive components contribute to surface degradation under brushing conditions (9,10), these results reinforce the role of dentifrice composition in determining the surface behavior of resin-based materials (11,12).

With respect to color stability, significant differences were observed among the experimen-

tal groups. The lowest ΔE values were recorded in the Be You group, indicating more favorable color stability under the conditions of this pilot study, whereas higher values were observed in the remaining groups. Interestingly, although the activated charcoal-containing toothpaste produced the highest surface roughness values, it did not produce the highest color change. This suggests that different mechanisms may influence surface degradation and optical behavior. While surface roughness may contribute to light scattering and color perception, other factors such as material composition, resin matrix characteristics, water interaction, and surface chemistry, may also play a relevant role (5).

Previous studies have reported a relationship between surface roughness and color stability in restorative materials. Increased roughness has been associated with greater susceptibility to staining and optical alterations (6,17). Additionally, Campolina *et al.* reported that whitening dentifrices may influence both roughness and color stability after simulated brushing procedures (7). However, the present findings suggest that the relationship between these variables is not always linear, particularly in 3D-printed materials, highlighting the need for further investigation.

From a clinical perspective, these results are relevant for the maintenance of restorative materials, particularly those fabricated using additive manufacturing technologies. The selection of dentifrices with lower abrasivity may contribute to preserving surface integrity and optical properties, thereby improving the longevity and aesthetic stability of restorations (8). This is supported by previous studies indicating that continuous exposure to abrasive agents may compromise the long-term performance of restorative materials (19,20).

In addition, recent evidence has highlighted the potential benefits of hydroxyapatite-containing

dentifrices and the impact of whitening formulations on restorative materials. Hydroxyapatite-based products have been shown to reduce erosion and abrasion under *in vitro* conditions, supporting their potential protective effect on dental surfaces (24). In the present pilot study, Be You showed the lowest color change values; however, the response of hydroxyapatite-containing toothpastes was not uniform across all evaluated outcomes. Similarly, a recent review concluded that whitening dentifrices may adversely affect restorative materials depending on their abrasive system and formulation (25), which is consistent with the differences observed among the groups evaluated in the present study.

It should also be considered that the behavior of 3D-printed resin materials is influenced not only by dentifrice composition but also by manufacturing-related factors. Previous studies have shown that post-printing conditions may affect the mechanical and optical properties of these materials (26), while polishing procedures and aging protocols may alter surface gloss (27). Additionally, build orientation has been associated with variations in roughness, gloss, and color (28). These factors may influence the susceptibility of 3D-printed restorations to toothbrushing abrasion and should be considered when interpreting the present findings. Furthermore, the influence of toothbrushing and dentifrice formulations on the properties of interim prosthodontic materials has been previously demonstrated, reinforcing the clinical importance of selecting dentifrices with controlled abrasive potential (29).

Some limitations of this study should be acknowledged. The present research was

conducted under *in vitro* conditions using simulated toothbrushing, which may not fully reproduce the complexity of the oral environment. Factors such as salivary composition, dietary habits, and variations in brushing technique may influence the long-term behavior of restorative materials. Therefore, further *in vivo* studies are required to confirm these findings. The relatively small sample size and the dispersion observed in some outcomes should be considered when interpreting the results. Therefore, this study should be regarded as a pilot *in vitro* investigation, and the findings should be confirmed in future studies using larger sample sizes and formal a priori power analysis.

Despite these limitations, this pilot study provides preliminary information regarding the influence of different commercial toothpastes on the surface properties and color stability of 3D-printed dental resin materials.

CONCLUSION

Within the limitations of this pilot *in vitro* study, the findings suggest that commercial toothpastes may differently affect the surface roughness and color stability of 3D-printed resin materials. The activated charcoal-containing toothpaste was associated with the greatest increase in surface roughness, whereas Be You showed the lowest color change values. Although hydroxyapatite-containing toothpastes may represent a promising alternative, their behavior was not uniform across all evaluated outcomes. Therefore, these findings should be interpreted as preliminary and confirmed in future studies with larger sample sizes and formal sample size calculations.

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