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RESEARCH AND EDUCATION

Erosive-abrasive effects on optical and surface properties of 3D printed resins with different surface finishing: An in vitro study

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ABSTRACT

Statement of problem. The optical stability and surface roughness of 3-dimensionally (3D) printed dental resins under erosive-abrasive challenge remain critical to their clinical application, especially for esthetic restorations.

Purpose. The purpose of this in vitro study was to evaluate the effect of an erosive-abrasive challenge on the optical properties, gloss, and surface roughness of 3D printed resins subjected to different surface finishing.

Material and methods. Three 3D-printed resins: PriZma (PR), Vitality (VT), and Nanolab (NN) were subjected to 3 surface treatments (n=10): control - no treatment (CO), polishing (PO), or glaze application (G). Color change (ΔE_{00}), translucency parameter, contrast ratio, gloss, surface roughness, and surface morphology were assessed before and after erosive-abrasive challenge (citric acid exposure followed by 100 000 cycles of simulated toothbrushing). ΔE_{00} was analyzed using 1-way ANOVA and Tukey post hoc tests, and other data were analyzed using 2-way repeated-measures ANOVA and Bonferroni post hoc tests (α=.05).

Results. A significant variation in ΔE_{00} was found among the different groups (P<.001). VT-PO group showed an imperceptible change (ΔE_{00}<0.8). Translucency increased in the CO groups (P<.001) but remained stable in the PO and G groups, except for PR-PO. In contrast, significant reductions were observed in the CO groups (P=.001). Gloss was maintained or increased after the challenge in PR resin, except for PR-G, which preserved its initial values (P<.001). G and VT-PO groups exhibited ideal roughness values (Ra approximately 0.2 μm).

Conclusions. Erosive-abrasive challenge significantly affected the optical and surface properties of 3D-printed resins. Polishing and glazing improved property stability compared with untreated surfaces. Glazing was most effective for PriZma and Nanolab, while its effectiveness was reduced for Vitality. (J Prosthet Dent xxxx;xxx:xxx-xxx)

Three-dimensional (3D) printing has significantly advanced restorative dentistry by facilitating the rapid and exact fabrication of restorations and prostheses with complex morphologies.[1,2] These systems provide enhanced workflow flexibility and personalization, facilitating the production of both interim and definitive restorations.[3,4] However, the durability of these restorations in clinical settings depends fundamentally on maintaining their optical and surface stability within the challenging oral environment.[5,6]

Dental restorative materials are constantly exposed to chemical, thermal, and mechanical stressors, such as acidic foods, colored drinks, and abrasion from toothbrushing, all of which may compromise the surface integrity and optical properties of the materials.[7,8] Three-dimensionally printed resins can exhibit greater susceptibility to increased surface roughness and loss of gloss following simulated toothbrushing and thermocycling when compared with milled computer-aided design and computer-aided manufacturing (CAD-CAM) resin materials.[4,6,9]

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Clinical Implications

Degradation observed on untreated surfaces, in contrast with the enhanced integrity exhibited by glazed surfaces, highlights the critical role of surface finishing in preserving the surface and optical properties of 3D-printed resins.

CAD-CAM technology enables the production of restorative material blocks with fewer internal defects and better mechanical properties because of their homogeneous composition and controlled polymerization.[10] Three-dimensionally printed resins offer greater precision and reduced material waste, since the additive process is not limited by bur size or tool path as in subtractive milling,[11] minimizing machining-induced surface defects that compromise flexural strength.[12]

Evidence regarding the long-term performance of 3D printed resin as definitive restorative materials remains limited.[13,14] For these resins to be considered suitable for definitive restorations (as Nanolab and Vitality), a filler content above 50 wt% has been recommended to enhance mechanical stability and wear resistance.[15] Current formulations include lower filler contents to ensure printability and dimensional accuracy, which may compromise their resistance to fatigue and wear when compared with CAD-CAM composite resins with 70 wt% filler loading.[16]

The interaction with staining agents accelerates discoloration and surface degradation, and the variability is material dependent.[5,8,17] Previous studies have demonstrated that 3D printed resins exhibit satisfactory color stainability under specific conditions, particularly when subjected to appropriate surface finishing protocols[3,18,19] which are essential in counteracting the degradation of the restorative materials. Mechanical polishing and glazing improve surface refinement and ensure long-term esthetics.[20–22] Sequential polishing protocols have been reported to be more efficacious in minimizing surface roughness.[23] Glazing functions as a protective layer that mitigates extrinsic discoloration and material degradation.[19,21,24] However, divergent findings have been reported regarding the effectiveness of these methods.[17,25] The efficacy of these protocols may also be influenced by the chemical composition of the resin, the thickness of the print layers, and the techniques used during postpolymerization.[26,27]

Nonetheless, research that has assessed the synergistic impact of erosive-abrasive challenge and various surface treatments on the optical and surface properties of 3D printed dental resins is sparse. The present study sought to analyze the effects of erosive-abrasive challenges on the color stainability, translucency, contrast ratio, gloss, surface roughness, and surface morphology of 3D printed restorative resins subjected to different surface treatments. The null hypotheses were that the erosive-abrasive challenge would not alter the optical characteristics of the tested resins irrespective of surface finishing and that no statistically significant variation in surface roughness would occur after the challenge.

MATERIAL AND METHODS

This in vitro study evaluated three 3D printed nanohybrid resins: PriZma Bio Crown (Makertech Labs) (PR), Smart Print Bio Vitality (Smart Dent) (VT), and Nanolab 3D (Wilcos) (NN), each containing nanometric filler particles suitable for additive manufacturing (Table 1). Ninety circular specimens (Ø15×1.5 mm) were designed using a software program (Meshmixer; Autodesk) and printed at a 90-degree orientation using a digital light processing (DLP) 3D printer (Moonray; SprintRay Inc). The sample size (n=10 per group) followed previous studies[3,6,19] with similar designs evaluating 3D-printed and CAD-CAM resin-based materials, which demonstrated adequate sensitivity for ANOVA-based analyses.

A calibration procedure was performed to establish the appropriate ultraviolet (UV) exposure parameters for each resin, setting the bottom layer exposure to 70 seconds (8 mm lift distance, 6 seconds light-off delay, 3 mm/second lift speed) and adjusting subsequent layers accordingly. Before printing, all resins were preheated and homogenized at 31 °C for 40 minutes. Printing was conducted under controlled temperature, humidity, and lighting conditions, with equal resin volumes dispensed into the tank and temperature monitored throughout. After printing, the specimens were cleaned with isopropyl alcohol using a soft-bristle brush, dried with warm air, and postpolymerized in a UV chamber (Phrozen Cure; Odontomega) for 40 minutes. Specimens were then stored in 100% relative humidity at 37 °C for 24 hours, ultrasonically cleaned for 15 minutes, and air dried; their final thickness was verified with digital calipers (500–17X-30; Mitutoyo Corp).

Table 1. 3D printed resins used: commercial name, chemical composition, and batch

Resin	Manufacturer	Chemical Composition	Batch No.
PriZma Bio Crown	Makertech	Oligomers, monomers, photoinitiators, stabilizers, pigments, and silanized zirconia filler particles (14% wt.)	202422
Smart Print Bio Vitality	Smart Dent	Oligomers, monomers, photoinitiators, stabilizers, pigments, and nanosilicates (<120 nm), (58% wt.)	PVL 046/24
Nanolab 3D	Wilcos	Composition containing oligomers, monomers, photoinitiators, stabilizers, pigments, and nanoparticle fillers.	2209035

Table 2. Glaze materials used, including manufacturer information, batch number, chemical composition, and viscosity

Glaze	Manufacturer	Chemical Composition	Viscosity	Batch No.
PriZma Seal	Makertech	Bisphenol A epoxylate dimethacrylate; 2,4,6-trimethyl-benzoyl-diphenylphosphine oxide; urethane dimethacrylate; Tetrahydrofurfuryl Methacrylate; amine	128 mPa·s	110924
SmartSeal	Smart Dent	Acrylic monomers; photoinitiator	127 mPa·s	SS02
MasterSeal	Wilcos	Bisphenol A Glycidyl Methacrylate; ethoxylated Bisphenol-A dimethacrylate; Methyl Methacrylate; Urethane Dimethacrylate; phosphinic oxide photoinitiator; Tinuvin/P; Butylated Hydroxytoluene; Lumilux Blue Z	100-150 mPa·s	072023

Before surface finishing, the specimens were randomly allocated to the experimental groups using a computer-generated randomization list to minimize bias related to optical and surface finishing factors. Each resin was divided into 3 groups (n=10): control (CO) - no surface treatment, polishing (PO), and glaze (G). Polishing was performed with disks (Sof-Lex; 3M Oral Care) for 20 seconds per grit under water cooling. For glazing, the specimens were first airborne-particle abraded with 110-µm aluminum oxide (Mega-Ox; Lukadent GmbH) at 0.2 MPa and a 5-cm distance, rinsed, and air dried. A thin glaze layer (PriZma Seal; Makertech Labs, SmartSeal; Smart Dent, and MasterSeal; Wilcos) was applied with a micro-applicator and light polymerized for 10 minutes in a UV chamber (Creality UV Curing Chamber; Creality 3D Technology Co). Detailed glaze composition and viscosity are reported in Table 2. All glazed specimens were visually inspected to ensure complete polymerization and surface uniformity.

For the erosive-abrasive challenge, specimens were immersed in a 0.3% citric acid solution (pH 2.6) under orbital agitation (Kline NT151; Novatecnica) for 96 hours.[28] They were then placed in a brushing simulator (MEV2; Odeme) for 100 000 brushing cycles[9,14] with soft-bristled brushes (Condor Classic Macia; Condor SA) and toothpaste (Colgate Tripla Ação; Colgate - RDA 70) diluted in distilled water (1:2)[29] with an axial load of 1.96 N. The brushes were replaced every 5000 cycles.

Tests were conducted before and after the challenge. Color measurements were made with a portable reflection spectrophotometer (Color Guide 45°/0° BYK-Gardner) in triplicate over standardized white (L^*=96.15; a^*=–1.18; b^*=0.29) and black (L^*=0.64; a^*=0.94; b^*=–2.16) backgrounds. Color coordinates (L^*, a^*, b^*) were recorded based on the CIELab system, with values obtained over the black background. Color differences (ΔE_{00}) were calculated using the CIEDE2000 formula[30]: $\Delta E_{00}=[(\Delta L^*/K_LS_L)^2 + (\Delta C^*/K_CS_C)^2 + (\Delta H^*/K_HS_H)^2 + RT(\Delta C^*/K_CS_C) \times (\Delta H^*/K_HS_H)]^{1/2}$ where ΔL^*, ΔC^*, and, ΔH^* represent the differences in lightness, chroma, and hue, respectively. S_L, S_C, S_H, and the rotation term (RT) adjust for perceptual uniformity, and K_L, K_C, and K_H were set to 1.[31] Perceptibility and acceptability thresholds were defined as ΔE_{00}=0.8 and ΔE_{00}=1.8, respectively.[32] Translucency was assessed using the CIEDE2000 color difference (1:1:1 weighting) between measurements obtained over white and black backgrounds. The translucency parameter (ΔTP_{00}) was calculated using the following formula[33]: $\Delta TP_{00}=[(L'_B-L'_W/K_LS_L)^2 + (C'_B-C'_W/K_CS_C)^2 + (H'_B-H'_W/K_HS_H)^2 + RT(C'_B-C'_W/K_CS_C) \times (H'_B-H'_W/K_HS_H)]^{1/2}$, where subscripts "B" and "W" denote values recorded over black and white backgrounds, respectively. Perceptibility (PT) and acceptability (AT) thresholds for translucency were set at ≤0.62 and ≤2.62, respectively.[33] Contrast ratio (CR) was calculated using spectral reflectance (Y) derived from the L^* coordinate, as follows: $Y=[(L^* + 16)/116]^3 \times Yn$, where Yn=100 represents the perfect diffuse white reference. CR was determined by the ratio of reflectance over black (Y_B) and white (Y_W) backgrounds: $CR=Y_B/Y_W$. Values range from 0 (fully transparent) to 1 (completely opaque).[33]

Gloss was evaluated in gloss units (GU) using a precision gloss meter (ZGM 1120; Zehntner) set at a 60-degree angle,[5,34] following the International Organization for Standardization (ISO) 2813 standard.[35] Three measurements per specimen were performed near the center, rotating the specimen by 90 degrees each time. According to da Costa et al,[36] gloss values between 40 and 50 GU are considered clinically acceptable and were used as a reference for interpretation. Surface roughness (Ra) (µm) was measured using a contact profilometer (Surfcorder SE 1700; Kosakalab).[10] Three equidistant readings were made on each specimen to obtain the mean Ra value. Qualitative surface morphology was evaluated by SEM (JSM-5600LV; JEOL) at ×400 magnification.

Data were tested for normality using the Shapiro-Wilk test. For color change, 1-way ANOVA followed by Tukey post hoc tests was used to compare surface treatments within each material. Two-way repeated measures ANOVA followed by Bonferroni post hoc tests was performed on the analyzed parameters. All statistical tests were performed using a statistical software program (IBM SPSS Statistics, v25.0; IBM Corp) (α=.05).

RESULTS

Figure 1 shows the data for color change (ΔE_{00}). A significant effect of surface treatment on color change was identified within each 3D printed resin (PR ($F(2,27)$=12.7, P<.001), VT ($F(2,27)$=30.1, P<.001), and NN ($F(2,27)$=12.8, P<.001). All CO groups presented values above the clinical acceptability threshold (AT>1.8), as did the NN-G group. The VT-PO group was the only

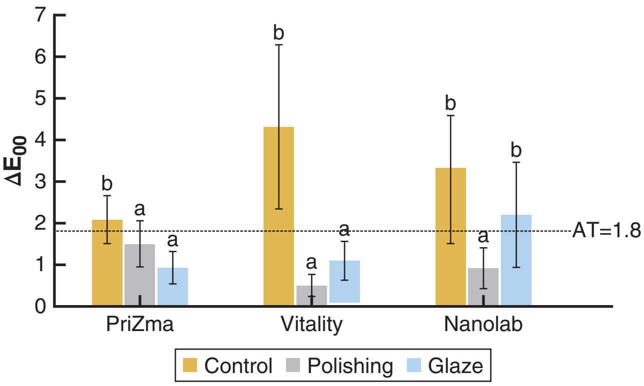

Figure 1. Mean and standard deviations (±SD) of color changes (ΔE_{00}) for 3D printed resins with different surface finishing after erosive-abrasive challenge. Different letter indicates significant differences within the same resin; AT, Acceptability threshold. Clinical thresholds for color differences set at ΔE_{00}=0.8 (perceptibility) and ΔE_{00}=1.8 (acceptability).

one that did not have a perceptible color change after the erosive-abrasive challenge (PT<0.8).

TP values are shown in Table 3. Within each resin, a significant increase in TP was observed in the CO groups after the erosive-abrasive challenge (PR: $F(2,18)=8.47$, P=.003, η^2_p=.49; VT: $F(2,18)=8.81$, P=.002, η^2_p=.50; NN: $F(2,18)=38.36$, P<.001, η^2_p=.81). PO and G groups maintained stable TP values after the erosive-abrasive challenge, except for the PR-PO group. The NN-G group showed greater translucency after the challenge compared with its CO and PO groups. All groups showed clinically acceptable translucency parameter changes (ΔTP_{00}<2.62).

Significant reductions in CR values were observed in the CO groups after challenge for all materials (PR: $F(2,18)=7.63$, P=.004, η^2_p=.46; VT: $F(2,18)=12.24$, P=.007, η^2_p=.64; NN: $F(2,18)=27.69$, P=.001, η^2_p=.75) (Table 4). In contrast, the PO groups maintained stable CR values. The NN-G group showed an increase in CR value after the challenge (P=.001).

Table 4. Mean ±standard deviation of contrast ratio (CR) values of different 3D printed resins with various surface treatments before and after the erosive-abrasive challenge

Material	Surface Treatment	Erosive-Abrasive Challenge	
		Before	After
PriZma Bio Crown	Control	0.75 ±0.07^{Bb}	0.67 ±0.03^{Aa}
	Polishing	0.68 ±0.03^{ABa}	0.66 ±0.02^{Aa}
	Glaze	0.68 ±0.02^{Aa}	0.68 ±0.03^{Aa}
Smart Print Bio Vitality	Control	0.98 ±0.06^{Bb}	0.88 ±0.03^{Aa}
	Polishing	0.84 ±0.04^{Aa}	0.86 ±0.04^{Aa}
	Glaze	0.84 ±0.04^{Aa}	0.87 ±0.04^{Aa}
Nanolab 3D	Control	0.85 ±0.07^{Cb}	0.77 ±0.05^{Aa}
	Polishing	0.74 ±0.03^{Ba}	0.74 ±0.04^{Aa}
	Glaze	0.69 ±0.02^{Aa}	0.73 ±0.02^{Ab}

Within the same material, different uppercase letters in the same column (P≤.027) and different lowercase letters in the same row (P≤.009) indicate significant difference between surface treatments or evaluation times, respectively.

Mean gloss values are shown in Table 5. The PR-G group exhibited a maintenance of gloss value after the erosive-abrasive challenge, while the PR-CO and PR-PO groups showed increased gloss values ($F(2,18)=21.10$, P<.001, η^2_p=.70). The VT-CO group presented lower gloss values before and after the challenge compared with the other groups ($F(2,18)=9.21$, P=.014, η^2_p=.51). The NN-G group showed a reduction in gloss after the challenge ($F(2,18)=62.83$, P<.001, η^2_p=.87), although it remained higher than the other surface treatments (P<.002).

Surface roughness results are shown in Table 6. For the PR and NN resins, the CO groups exhibited reduced roughness after the challenge, whereas the PO groups showed a slight increase (PR: $F(2,18)=14.37$, P=.004, η^2_p=.82; NN: $F(2,18)=26.35$, P=.001, η^2_p=.74). Glazed specimens of PR and NN resins, as well as the VT-PO group, achieved ideal roughness values after the challenge (Ra approximately 0.2 µm) (VT: $F(2,18)=11.57$, P<.001, η^2_p=.82).

SEM images (Figs. 2-4) confirmed that untreated surfaces (CO group) exhibited prominent microcracks, filler exposure, and surface degradation after aging. Glazed specimens showed more uniform textures with

Table 3. Mean ±standard deviation of translucency parameter (TP) values of different 3D printed resins with different surface treatments before and after erosive-abrasive challenge

Material	Surface Treatment	Erosive-Abrasive Challenge		
		Before	After	ΔTP
PriZma Bio Crown	Control	8.58 ±0.86^{Aa}	10.24 ±0.43^{Ab}	1.66
	Polishing	9.86 ±1.02^{ABa}	10.65 ±0.45^{Ab}	0.79
	Glaze	10.08 ±0.72^{Ba}	9.91 ±0.78^{Aa}	−0.17
Smart Print Bio Vitality	Control	3.01 ±0.46^{Aa}	4.18 ±0.51^{Ab}	1.18
	Polishing	5.42 ±1.27^{Ba}	4.98 ±0.97^{Aa}	−0.44
	Glaze	4.75 ±0.60^{Ba}	4.83 ±0.85^{Aa}	0.08
Nanolab 3D	Control	6.31 ±1.57^{Aa}	8.50 ±1.34^{Ab}	2.19
	Polishing	9.34 ±0.97^{Ba}	9.10 ±0.94^{Aa}	−0.24
	Glaze	10.53 ±0.61^{Ca}	10.72 ±0.55^{Ba}	0.18

Within same material, different uppercase letters in same column (P≤.001) and different lowercase letters in same row (P≤.001) indicate significant difference between surface treatments or evaluation time, respectively. Clinical thresholds for translucency differences set at ≤0.62 (perceptibility) and ≤2.62 (acceptability).

Table 5. Mean ±standard deviation of gloss values (GU) of different 3D printed resins with various surface treatments before and after erosive-abrasive challenge

Material	Surface Treatment	Erosive-Abrasive Challenge	
		Before	After
PriZma Bio Crown	Control	3.08 ±0.40^{Aa}	39.37 ±18.18^{Ab}
	Polishing	20.55 ±8.93^{Ba}	59.03 ±19.63^{Ab}
	Glaze	60.22 ±15.23^{Ca}	54.28 ±18.45^{Aa}
Smart Print Bio Vitality	Control	2.69 ±0.32^{Aa}	6.98 ±3.30^{Ab}
	Polishing	39.73 ±13.08^{Bb}	26.65 ±11.73^{Ba}
	Glaze	33.55 ±12.42^{Ba}	30.82 ±14.35^{Ba}
Nanolab 3D	Control	2.23 ±1.17^{Aa}	6.85 ±3.71^{Aa}
	Polishing	16.79 ±6.92^{Bb}	10.68 ±4.28^{Aa}
	Glaze	69.81 ±5.88^{Cb}	53.41 ±13.08^{Ba}

Within the same material, different uppercase letters in the same column (*P*≤.002) and different lowercase letters in the same row (*P*≤.008) indicate significant difference between surface treatments or evaluation time, respectively.

Table 6. Mean ±standard deviation of surface roughness (µm) of different 3D printed resins with various surface treatments before and after erosive-abrasive challenge

Material	Surface Treatment	Erosive-Abrasive Challenge	
		Before	After
PriZma Bio Crown	Control	0.96 ±0.38^{Aa}	0.35 ±0.21^{Ab}
	Polishing	0.18 ±0.08^{Ba}	0.17 ±0.05^{Aa}
	Glaze	0.21 ±0.14^{Ba}	0.11 ±0.04^{Ba}
Smart Print Bio Vitality	Control	1.59 ±0.35^{Aa}	1.21 ±0.59^{Aa}
	Polishing	0.08 ±0.02^{Cb}	0.16 ±0.06^{Ba}
	Glaze	0.73 ±0.42^{Ba}	0.70 ±0.52^{Aa}
Nanolab 3D	Control	0.64 ±0.19^{Aa}	0.39 ±0.12^{Ab}
	Polishing	0.19 ±0.08^{Bb}	0.32 ±0.08^{Aa}
	Glaze	0.34 ±0.19^{Ba}	0.24 ±0.08^{Ba}

Within the same material, different uppercase letters in the same column (*P*≤.042) and different lowercase letters in the same row (*P*≤.036) indicate significant difference between surface treatments or evaluation times, respectively.

fewer defects, especially in PR and NN resins. In Vitality resin, some localized surface wear and partial exposure of the resin matrix were noted even in the glazed group, indicating that treatment effectiveness may be material dependent.

DISCUSSION

The stability of the optical and surface properties of 3D printed dental resins subjected to erosive-abrasive challenges is a crucial factor for the clinical success of esthetic restorations. In this study, color change, gloss, translucency, contrast ratio, and surface roughness were investigated considering different surface treatments, including polishing and glaze application. The results demonstrated significant effects of surface treatment and material type on the evaluated properties after a simulated erosive-abrasive challenge; thus, the null hypotheses that erosive-abrasive challenge would not alter the optical characteristics of the tested resins irrespective of surface finishing and that no statistically significant variation in surface roughness would occur after the challenge were rejected.

The color stainability of dental restorations is a critical esthetic property, as significant visual changes can compromise patient satisfaction and the clinical longevity of the restoration.[17,32] In the PR and VT resins, ΔE_{00} values did not differ significantly between the PO and G groups, indicating that both surface finishing methods were similarly effective in maintaining the original color stainability of these materials. In contrast, for the NN resin, a statistically significant difference was observed (*P*<.001), with the PO group exhibiting lower ΔE_{00} values than the G group. A surface finishing protocol for 3D printed resins has not yet been defined. Aluminum oxide polishers have been shown to be effective,[19] but others have reported that glaze application

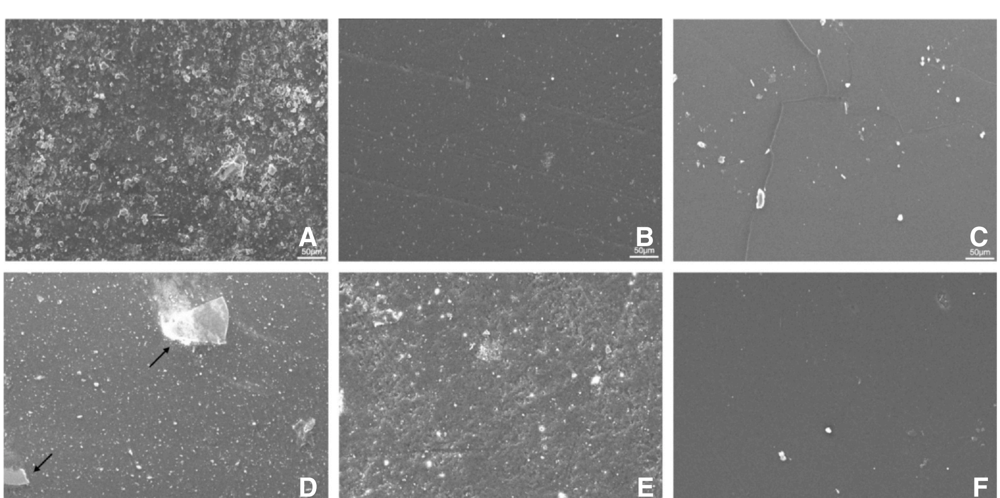

Figure 2. Scanning electron microscopy (SEM) images of PriZma before and after erosive-abrasive challenge. A-C, Surface morphology before challenge: A, Control group; B, Polishing group; C, Glaze group. D-F, Surface morphology after challenge: D, Control group; E, Polishing group; F, Glaze group. *Black arrows* indicates the presence of exposed filler particles. Original magnification ×400. Scale bar 50 µm.

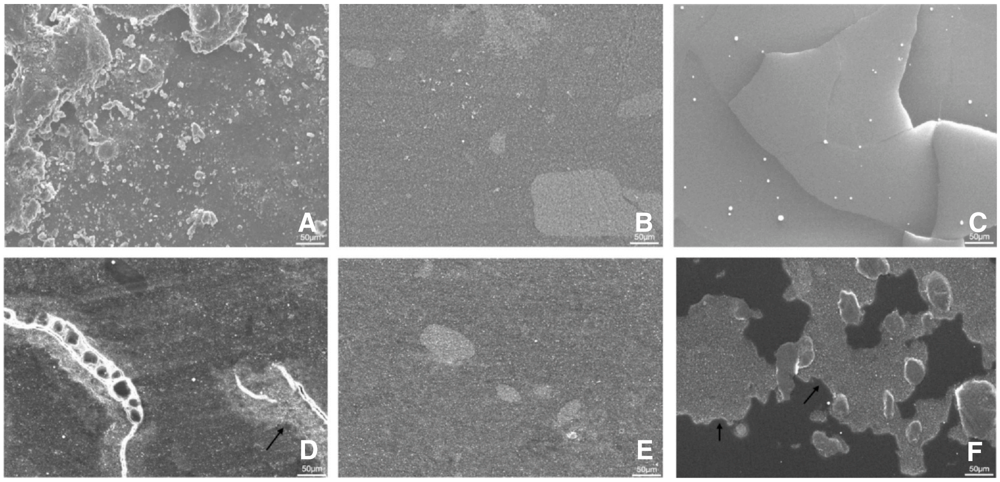

Figure 3. Scanning electron microscopy (SEM) images of Vitality before and after erosive-abrasive challenge. A-C, Surface morphology before challenge: A, Control group; B, Polishing group; C, Glaze group. D-F, Surface morphology after challenge: D, Control group; E, Polishing group; F, Glaze group. *Black arrow* indicates the presence of exposed filler particles. Original magnification ×400. Scale bar 50 µm.

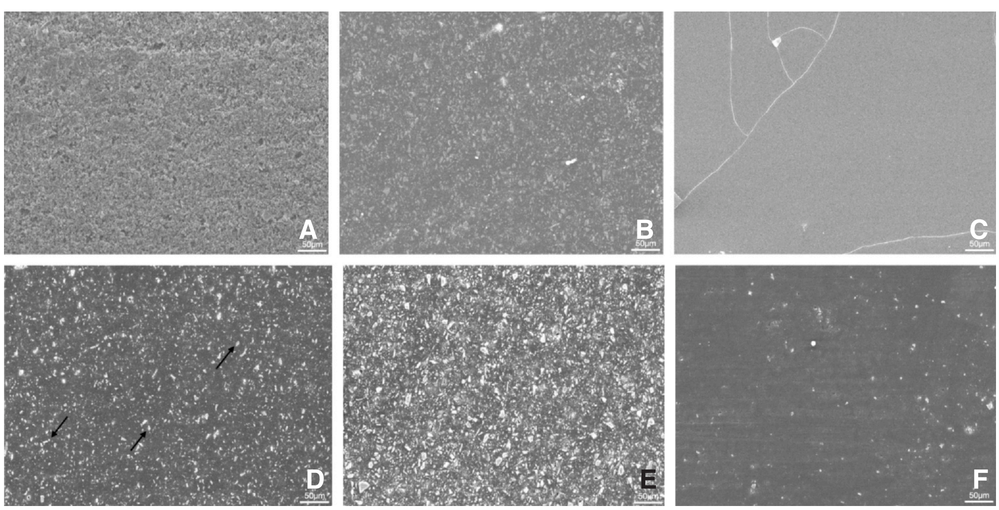

Figure 4. Scanning electron microscopy (SEM) images of Nanolab before and after erosive-abrasive challenge. A-C, Surface morphology before challenge: A, Control group; B, Polishing group; C, Glaze group. D-F, Surface morphology after challenge: D, Control group; E, Polishing group; F, Glaze group. *Black arrows* indicates the presence of exposed filler particles. Original magnification ×400. Scale bar 50 µm.

was more effective[21] and similar outcomes have also been reported for the finishing method used.[25] Glaze may fill microporosities, create a protective barrier, and reduce pigment absorption, ensuring greater optical stability and lower surface roughness.[24] The behavior of 3D printed resins varies with the finishing protocol, as color stainability has been reported to be influenced by material composition, polymerization, and finishing-material interaction.[17,19] All CO groups exhibited ΔE_{00} values above the clinical acceptability threshold (ΔE_{00}>1.8), indicating greater susceptibility of untreated surfaces to water sorption, degradation, and staining,[19,21] emphasizing the need for the adequate surface finishing of 3D-printed restorations.

Translucency is crucial for reproducing natural tooth appearance. In this study, VT and NN resins, as well as the PR-G group, showed no translucency change after the challenge. All CO groups exhibited increased translucency. This behavior was consistent with smoother surfaces allowing greater light transmission[26] and with the presence of silica or zirconia nanoparticles in PR and NN resins, which reduced light scattering.[33] According to the perceptibility and acceptability thresholds, only PR-CO, PR-PO, VT-CO, and NN-CO showed perceptible (ΔPT_{00}>0.62) but clinically acceptable (ΔPT_{00}<2.62) changes in translucency after the challenge.

In addition to the translucency parameter, CR helps assess the masking ability and opacity of dental materials over underlying substrates. CR values differed among materials, reflecting variations in resin matrix composition and surface treatments. The CO group showed reduced CR after the challenge, suggesting matrix degradation and increased translucency. Most treated groups maintained stable CR values after the challenge, except the NN-G group, which showed an increase. Among the evaluated resins, only VT was opaque (CR≥0.8), while PR and NN demonstrated intermediate opacity (0.60<CR<0.80).[33]

Surface gloss and roughness have been reported to be important surface properties of dental restorative materials.[27,36] Gloss is responsible for the mirror-like surface appearance.[19] It depends on light reflection and is influenced by the refractive index and particle characteristics of the material.[20] Glaze application was the most effective method of maintaining gloss in PR and VT resins after the challenge, supporting evidence[27] that glaze forms a uniform wear-resistant surface layer. Although NN-G showed a reduction in gloss, values remained within the clinically acceptable range (40 to 50 GU).[36] Only PR-PO, PR-G, and NN-G groups maintained acceptable gloss after the challenge, while other groups, particularly VT, showed consistently low gloss. This behavior in VT resin may relate to its hybrid polymer matrix and clustered small filler particles, which can reduce glaze wetting and interfacial bonding,[7,10] compromising gloss retention.

In addition to the stability of optical parameters, low surface roughness is essential for the clinical longevity of restorative materials, since Ra values above 0.2 µm favor bacterial plaque accumulation and may affect optical outcomes.[18] All G groups showed stability in roughness after the challenge; however, only PR-G and NN-G maintained Ra<0.2 µm compared with the PO groups. For VT resin, polishing produced the lowest roughness before and after the challenge. Previous studies[18,22] indicated that glaze effectiveness depended on the material's chemical composition and structural density, which influenced the interaction between the protective layer and the resin surface.

Consistent with the findings of the present study, all CO groups showed the greatest Ra variations after the challenge. The absence of a surface finishing increases susceptibility to changes caused by acidic immersion[1] and toothbrushing.[27] These results emphasize the role of protective treatments, such as glaze, in maintaining restoration functionality and esthetics. SEM images confirmed the superiority of glaze in maintaining surface uniformity under erosive-abrasive conditions, although material characteristics may influence its performance (Figs. 2-4). In VT resin, glaze did not properly adhere, and its protective effect diminished after the challenge, partially exposing the matrix. This finding reinforced the need for customized strategies to preserve the esthetic and functional characteristics of 3D printed resin restorations.

Limitations of the present study included that laboratory conditions do not fully replicate the complexity of the oral environment. Variables such as mastication forces, biofilm activity, long-term staining, and fatigue cycles may significantly influence clinical outcomes. In addition, the spectrophotometer aperture could have caused some edge loss, potentially affecting the accuracy of color and translucency measurements, particularly for more translucent materials. Therefore, future in vivo studies or extended aging protocols are warranted to assess these factors, along with the potential effects of printing angle and post-polymerization procedures. Additionally, analyzing new materials and finishing techniques may provide further insights into optimizing 3D restorations.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The erosive-abrasive challenge induced significant changes in the optical and surface properties of 3D printed resins, with effects dependent on surface finishing and material type.
2. Polished and glazed finishes were effective in maintaining color stainability, translucency, and gloss while reducing surface roughness and degradation compared with untreated surfaces.
3. Glaze efficacy was particularly pronounced in PR and NN resins, whereas VT resin exhibited greater surface degradation despite surface treatment.

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