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RESEARCH AND EDUCATION

Comparison of color stability and wear resistance of different 3D printed definitive restorative resins

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ABSTRACT

Statement of problem. Subtractive manufacturing in computer-aided design and computer-aided manufacturing (CAD-CAM) systems has been extensively studied, but additive manufacturing materials, particularly those used for definitive restorations, are relatively new and data regarding their clinical performance remain limited.

Purpose. This in vitro study aimed to evaluate the color stability of 3 different 3-dimensionally (3D) printed definitive restorative materials under 5 different Commission Internationale de l'Eclairage illuminants and to compare their metameric color differences. In addition, the mechanical wear resistance of these materials was evaluated independently.

Material and methods. A total of 135 specimens with thicknesses of 1.0, 1.5, and 2.0 mm were 3D printed according to the manufacturers' protocols. Color was evaluated before and after thermocycling under 5 illumination conditions (D65, D50, A, F11, F2). ΔE_{00} values were analyzed using mixed-design analysis of variance (α=.05). Wear was evaluated in 2.0-mm specimens using simulated mastication and volumetric analysis, and the wear data were analyzed using the Kruskal–Wallis test (α=.05)

Results. All specimens exposed to illuminant A exhibited clinically unacceptable color changes, regardless of material type or thickness. Under illuminants D50, F11, and F2, color changes were perceptible but remained within clinically acceptable limits. Thermal aging significantly reduced ΔE_{00} values (P=.001). Although wear was observed in all groups, no significant differences were found in volumetric loss (P=.139).

Conclusions. Illuminants significantly influenced color stability across all resin types and thicknesses, whereas increased restoration thickness was associated with reduced color change perceptibility. In addition, no significant differences in wear volume were found among the tested 3D-printed definitive restorative materials. (J Prosthet Dent xxxx;xxx:xxx-xxx)

Traditional dental prosthesis fabrication is labor-intensive, multistep, and prone to human error.[1] Computer-aided design and computer-aided manufacturing (CAD-CAM) technologies allow faster, more accurate, and reproducible prosthesis fabrication.[1,2] CAD-CAM fabrication includes subtractive (milling) and additive (layer-by-layer) techniques.[3] Additive manufacturing via 3-dimensional (3D) printing has gained popularity for its material efficiency, cost-effectiveness, and versatility.[4] The expiration of key patents has increased the availability of dental-specific printing materials for definitive restorations, though most research has still focused on interim restoration applications.[5] The use of 3D-printed materials for definitive prostheses is still underexplored, with limited data on long-term performance. Factors such as restoration thickness, thermal aging, material homogeneity, and particle size have been reported to affect the optical and mechanical properties of restorative materials.[6–10]

This study evaluated the color stability and wear resistance of 3 recently introduced 3D-printed definitive restorative resins at different thicknesses and under various Commission Internationale de l'Eclairage (CIE) illuminants. The null hypotheses were that resin type, restoration thickness, thermal aging, and illuminant would not affect color change and that no significant difference in wear resistance would be observed among the resin types.

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Clinical Implications

The color stability of tested 3D-printed definitive restorative materials may vary depending on the illuminant and material thickness. Therefore, these factors should be considered to maintain long-term esthetic outcomes. In addition, these materials may provide acceptable wear performance over time.

MATERIAL AND METHODS

Three commercially available definitive restorative resins were evaluated: VarseoSmile Crown Plus (BC), Print Crowntec (PC), and P-Crown Resin (SP) (Table 1). These resins are polymer-based hybrid materials incorporating varying proportions of ceramic and composite resin fillers. The specimens were fabricated in 3 different thicknesses (1.0 mm, 1.5 mm, and 2.0 mm). Based on the power analysis, with a statistical power of 95% and an effect size of 0.3, a sample size of 12 specimens per group was initially calculated; however, to increase the reliability of the study, the specimen's size was set at 15 specimens per group, resulting in a total of 135 specimens.

All specimens were 3D printed according to the manufacturers' instructions. Disks (Ø10 mm) were printed using digital light processing (DLP) technology with a layer thickness of 50 µm and a build angle of 90 degrees (Varseo XS; BEGO, ASIGA MAX UV; Cosmodent). Because of its high viscosity, P-Crown Resin was pretreated as per the manufacturer's recommendation by immersing it in hot water (5 to 10 minutes) and shaking it vigorously before use. All specimens were rinsed in 96% ethanol and then post-print polymerization was conducted using a polymerization unit (Otoflash G171–6; NK Optik) under nitrogen atmosphere, applying 1500 flashes to each surface. Surface finishing was completed using a fine brush, pumice, and a universal polishing paste (OptraFine Universal Polishing Paste; Ivoclar AG) according to the manufacturers' guidelines.

Color measurements were performed using a desktop spectrophotometer (CM-3600A; Konica-Minolta Sensing, Inc) under 5 different illuminants: D65 (control), D50, A, F11, and F2 (Table 2). Measurements were made before and after thermocycling to evaluate color stability under different illuminants. Color differences (ΔE_{00}) were calculated using the CIEDE2000 formula between the control illuminant D65 and the other illuminants (Table 3). Before baseline color measurement, all specimens were immersed in distilled water at 37 °C for 24 hours. Baseline color coordinates were measured under D65 illuminant with a 10-degree observer angle in accordance with previous studies[6–8] and CIE standards. To prevent edge loss and ensure measurement validity, the specimens were secured around the Ø4-mm device diaphragm with transparent tape. Color measurements were made 3 times for each specimen, and the mean value was recorded. Measurements were then obtained under the remaining illuminants (D50, F11, F2, and A). The L*, a*, and b* values were recorded using a software program (SpectraMagic NX v2.81; Konica Minolta Sensing). Each measurement was repeated 3 times per specimen, and the mean value was used for analysis.

Thermal aging was performed using a thermocycler (CS-4.8; SD Mechatronik) set to 10 000 cycles between 5 °C and 55 °C (±3.5 °C), with a dwell time of 30 seconds and a transfer time of 10 seconds. Post-aging color measurements were obtained under the same conditions. Color change (ΔE_{00}) was calculated using the CIEDE2000 formula based on L*, a*, and b* values recorded before and after aging and stratified according to illuminant and specimen thickness.

Mechanical wear was quantified by comparing scans before and after testing using a software program (Geomagic Control; Hexagon AB). Each specimen was scanned at 4-mm intervals with a 0.02-mm resolution. The total scanning time per specimen was approximately 15 minutes. Data were processed digitally to calculate the volumetric wear in mm^3 for each specimen's group. Following color evaluation, wear testing was intentionally restricted to specimens with a thickness of 2.0 mm and performed using a Masticator system (SD Mechatronik Masticator system CS-4.2; Willytech) for 240 000 cycles, simulating 1 year of clinical use.[11] In the Masticator system, stainless steel Ø3-mm hemispheres

Table 1. Brand and composition information of definitive restorative resins used

Brands	LOT number	Manufacturer	Color	composition
VarseoSmile Crown Plus	601028	BEGO	A2	4.4′-isopropylidiphenol, ethoxlated and 2-methylpropenoic acid. Silanized dental glass, methyl benzoylformate, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide. İnorganicfillers(particle size 0.7µm) 30-50%wt (ceramicfilled hybrid material).
Print Crowntec	E522	Saremco Dental AG	A2	Bısphenol A Polyethylene Glycol Diether Dimethacrylate, BisEMA 50-75<%, Methyl Benzoylformate 1-5<%, Diphenyl (2,4,6-Trimethylbenzoyl) Phospine Oxide 1-5<%, Dental Glass (Silanized), Pyrogenic, Silica, Catalysts, İnhibitors, silanized dental glass, total content of inorganic fillers (particle size 0.7 µm) is 30 - 50% by mass.
P-Crown	SNR202300030	Senertek	A2	Urethanedimethacrylat%,50-<75, Trimethylbenzonyldiphenylphosphine oxide %0.1-<1

Table 2. Illuminants used

Artificial illuminant environment	Temperature (K)	Lamp type	Application
D65	6504 K	Phosphor 7, Standard daylight (average midday sunlight)	International artificial standard daylight.
D50	5003 K	Phosphor 7, Midday daylight	Represents midday sunlight.
F2 (Fluorescent)	4230 K	Fluorescent lamp (cool white fluorescent	Commonly used in typical office lighting
F11 (TL84)	4000 K	Fluorescent lamp	Often used in warehouse lighting or similar environments
A (Incandescent)	2856 K	Tungsten Halogen	Commonly used in residential lighting

were used as antagonists. Each specimen was scanned using a high-precision laser scanner (LAS-20; SD Mechatronik) both before and after simulated mastication. Wear volume (mm^3) was calculated by superimposing pre- and postwear surface scans using a software program (Geomagic Control; 3D Systems Inc).

Statistical analyses were performed using a software program (IBM SPSS Statistics, v26; IBM Corp). ΔE_{00} values were analyzed with a mixed-design repeated-measures analysis of variance (ANOVA), with restoration brand and thickness as between-subject factors and thermal cycling (before and after) and illuminant as within-subject factors. The sphericity assumption was evaluated using the Mauchly test, and Greenhouse-Geisser corrections were applied when violations were detected for effects involving illuminant. Bonferroni adjustment was used for multiple comparisons (α=.05). As the wear data were not normally distributed, the Kruskal–Wallis test was used to compare wear volume loss among the materials (α=.05).

RESULTS

When the mean ΔE_{00} values of all experimental groups were compared with the control group (D65) before thermal aging, the highest color change was observed in the SC group at 1.0-mm thickness under illuminant A (3.17 ±0.04). In contrast, the lowest ΔE_{00} value was observed in the SP group at 2.0-mm thickness under illuminant F2 (0.67 ±0.04) (Table 4). A review of previous studies indicated that most research using the CIEDE2000 formula interpreted ΔE_{00} values according to the perceptibility and acceptability thresholds proposed by Paravina et al,[12,13] who defined the 50:50% perceptibility threshold (PT) as ΔE_{00}=0.8 units and the 50:50% acceptability threshold (AT) as ΔE_{00}=1.8 units. These thresholds were applied in the present study to evaluate the clinical relevance of color changes. Before thermal aging, the only group exhibiting ΔE_{00} values below the perceptibility threshold under all tested conditions was the SP-F2–2.0-mm group (0.67 ±0.04). Under illuminant A, all material groups (SC, SP, BC), regardless of thickness, exhibited ΔE_{00} values exceeding the clinical acceptability threshold. Under illuminants D50, F11, and F2, color changes were perceptible in all groups but remained within clinically acceptable limits.

In the SC and BC groups, increasing specimen thickness was associated with a statistically significant decrease in ΔE_{00} values under all illuminants (P=.001). In the SP group, the mean ΔE_{00} value at 1.5-mm thickness was significantly higher than those at 1.0-mm and 2.0-mm thicknesses under illuminants D50 and A (P=.001). Under illuminant D50, the 2.0-mm SP specimens showed significantly higher ΔE00 values than the 1.0-mm specimens (P=.001). Under illuminant F11, the 2.0-mm specimens exhibited significantly higher ΔE00 values than the 1.0-mm and 1.5-mm specimens (P=.001). The 1.5-mm thickness also showed significantly higher ΔE_{00} values than the 1.0-mm thickness (P=.001). Under illuminant F2, the 2.0-mm specimens demonstrated significantly lower ΔE_{00} values than the 1.0-mm and 1.5-mm specimens (P=.001), whereas no significant difference was found between the 1.0-mm and 1.5-mm groups (P>.05) (Table 4).

For all restorative materials, ΔE_{00} values under illuminant A were significantly higher than those under illuminants D50, F11, and F2 (P=.001) and exceeded the clinically acceptable limit. ΔE_{00} values under illuminant

Table 3. Study groups for color evaluation

Restorative resin	Thickness	Illumination	Thermal aging (TA)
Bego Varseo Smile CrownPlus (BC)	1 mm	D65/D50, D65/F2, D65/F11, D65/A	Before/After
	1.5 mm	D65/D50, D65/F2, D65/F11, D65/A	Before/After
	2 mm	D65/D50, D65/F2, D65/F11, D65/A	Before/After
Saremco Crowntec (SC)	1 mm	D65/D50, D65/F2, D65/F11, D65/A	Before/After
	1.5 mm	D65/D50, D65/F2, D65/F11, D65/A	Before/After
	2 mm	D65/D50, D65/F2, D65/F11, D65/A	Before/After
Senertek P-Crown (SP)	1 mm	D65/D50, D65/F2, D65/F11, D65/A	Before/After
	1.5 mm	D65/D50, D65/F2, D65/F11, D65/A	Before/After
	2 mm	D65/D50, D65/F2, D65/F11, D65/A	Before/After

Table 4. Evaluation of ΔE_{00} values of different restoration brands and thicknesses under various illuminants

			D50	F11	F2	A	
Brand	**Thickness**	**ΔE**	**M ±SD**	**M ±SD**	**M ±SD**	**M ±SD**	***P***
Asiga	1 mm	Before TA	1.55 ±0.02^{a}	1.24 ±0.03^{b}	1.18 ±0.02^{c}	3.17 ±0.04^{d}	<.001*
		After TA	1.48 ±0.06^{a}	1.16 ±0.05^{b}	1.14 ±0.03^{b}	2.99 ±0.12^{c}	<.001*
	1.5 mm	Before TA	1.57 ±0.02^{a}	1.17 ±0.02^{b}	1.14 ±0.01^{c}	3.10 ±0.04^{d}	<.001*
		After TA	1.51 ±0.08^{a}	1.12 ±0.06^{b}	1.11 ±0.03^{b}	2.96 ±0.16^{c}	<.001*
	2 mm	Before TA	1.53 ±0.02^{a}	1.18 ±0.02^{b}	1.16 ±0.02^{c}	3.01 ±0.04^{d}	<.001*
		After TA	1.48 ±0.04^{a}	1.12 ±0.03^{b}	1.12 ±0.01^{b}	2.90 ±0.09^{c}	<.001*
Bego	1 mm	Before TA	1.56 ±0.05^{a}	1.27 ±0.03^{b}	1.03 ±0.02^{c}	3.06 ±0.10^{d}	<.001*
		After TA	1.47 ±0.06^{a}	1.15 ±0.06^{b}	0.94 ±0.03^{c}	2.81 ±0.13^{d}	<.001*
	1.5 mm	Before TA	1.49 ±0.08^{a}	1.15 ±0.07^{b}	0.97 ±0.03^{c}	2.79 ±0.17^{d}	<.001*
		After TA	1.45 ±0.06^{a}	1.07 ±0.05^{b}	0.94 ±0.02^{c}	2.68 ±0.13^{d}	<.001*
	2 mm	Before TA	1.37 ±0.08^{a}	1.62 ±0.33^{b}	0.93 ±0.04^{c}	2.49 ±0.16^{d}	<.001*
		After TA	1.43 ±0.09^{a}	1.05 ±0.07^{b}	0.93 ±0.04^{c}	2.56 ±0.18^{d}	<.001*
Senertek	1 mm	Before TA	1.23 ±0.05^{a}	0.88 ±0.05^{b}	0.82 ±0.03^{b}	2.64 ±0.11^{c}	<.001*
		After TA	0.72 ±0.06^{a}	0.47 ±0.05^{b}	0.52 ±0.04^{b}	1.47 ±0.13^{c}	<.001*
	1.5 mm	Before TA	1.40 ±0.03^{a}	0.94 ±0.04^{b}	0.82 ±0.05^{c}	2.91 ±0.07^{d}	<.001*
		After TA	1.04 ±0.07^{a}	0.80 ±0.07^{b}	0.53 ±0.06^{c}	2.12 ±0.15^{d}	<.001*
	2 mm	Before TA	1.34 ±0.06^{a}	1.03 ±0.08^{b}	0.67 ±0.04^{c}	2.79 ±0.13^{d}	<.001*
		After TA	1.09 ±0.07^{a}	0.94 ±0.08^{b}	0.46 ±0.04^{c}	2.18 ±0.14^{d}	<.001*

M, mean; SD, standard deviation; TA, thermal aging.
Lowercase letters in same row denote statistically significant differences among illuminants within the group ($P<.05$).

D50 were significantly higher than those under illuminants F11 and F2 ($P=.001$), and illuminant F11 resulted in significantly higher ΔE_{00} values than illuminant F2 ($P=.001$). In the SC and BC groups, both illuminant and restoration thickness had a significant effect on ΔE_{00} after thermal aging ($P=.001$). ΔE_{00} values under illuminant A were significantly higher than those under illuminants D50, F11, and F2 ($P=.001$). However, no significant differences were found among restoration thicknesses in ΔE_{00} values after thermal cycling ($P>.05$) (Table 4).

At 1.0-mm thickness, the mean ΔE_{00} value of the SP group was significantly lower than that of the SC and BC groups under all illuminants ($P=.001$). Similarly, at 1.5-mm thickness, the SP group showed significantly lower ΔE_{00} values than the SC and BC groups under all illuminants ($P=.001$). At 2.0-mm thickness under illuminant D50, the SC group exhibited significantly higher mean ΔE_{00} values than the BC and SP groups ($P=.001$), with no significant difference between the SP and BC groups ($P>.05$). Under illuminant F11, the BC group showed significantly higher ΔE_{00} values than the SC and SP groups ($P=.001$), whereas no significant difference was found between the latter 2 groups ($P>.05$). Under illuminant F2, the SC group exhibited significantly lower ΔE_{00} values than the BC group ($P=.001$). Under illuminant A, the BC group demonstrated significantly lower ΔE_{00} values than the SC and SP groups, and the SP group showed significantly lower values than the SC group ($P=.001$). In the SP group, after thermal aging, ΔE_{00} values under illuminant A were significantly higher than those under illuminants D50, F11, and F2 at 1.0-mm, 1.5-mm, and 2.0-mm thicknesses ($P=.001$).

Additionally, statistically significant differences in ΔE_{00} values were observed among restoration thicknesses within the SP group following thermal aging ($P=.001$) (Table 4). When all definitive restorative resins were evaluated across different thicknesses and illuminants, the SP group exhibited significantly less color change than the SC and BC groups. In the comparison between the SC and BC groups, the BC group demonstrated significantly lower ΔE_{00} values under illuminants F2 and A, whereas no significant differences were observed under the other illuminants. The reduction in ΔE_{00} values following thermal aging was statistically significant ($P=.001$).

The wear data of the crown restoration resin groups were calculated in mm^3. Surface wear was observed in all groups (SC (0.41 ±0.05, SP (0.072 ±0.05 and BC (0.046 ±0.04)). The SP group exhibited greater volumetric wear than the BC and SC groups, and the BC group demonstrated greater volumetric wear than the SC group. However, no statistically significant differences were found among the groups in terms of surface wear ($P=.139$).

DISCUSSION

This study evaluated the effects of resin type, thermal aging, specimen thickness, and illuminant on the color stability of 3D printed definitive restorative specimens. According to the results, the null hypotheses that no significant color differences would exist among different definitive restorative resins, that restoration thickness would not influence color stability, that thermal aging would not affect color change, and that illuminant would not influence color stability were rejected. Conversely, the null hypothesis that resin type would have no effect on mechanical wear was not rejected. Restoration thickness, resin type, illuminant, and thermal aging significantly affected color change ($P<.05$). The manufacturers' instructions for use specify 1.0 mm as the minimum restoration thickness for the evaluated

materials. Therefore, specimen thicknesses were set at 1.0 mm, 1.5 mm, and 2.0 mm.[14] Regardless of thickness or illuminant, the SP resin exhibited the lowest color change both before and after thermal aging. Consistent with the findings of Gawriolek et al[8] stated that the higher ceramic filler content of the SP resin compared with the other resins may explain its superior color stability. However, the compositional details of commercially available definitive restorative resins have not been fully disclosed. Although the BC and SC resins are reported to contain approximately 40% to 50% ceramic filler content (Saremco Print Crowntec; Saremco Dental AG, VarseoSmile Crown Plus; Bego GmbH & Co. KG), the SP resin has been reported to contain more than 50% ceramic particles (P-Crown; Senertek). The increased ceramic filler content substantially increases viscosity, which may influence the material's optical behavior and aging performance.[15]

In this study, both the SC and BC groups exhibited decreased ΔE_{00} values with increasing thickness, regardless of the illuminant. Although the SP group demonstrated less color change than the other groups at all thicknesses, statistically significant differences were still observed among thicknesses. Yılmaz et al[16] produced restorative materials with varying thicknesses using both additive and subtractive manufacturing techniques and evaluated their color stability after thermal aging, indicating that ΔE_{00} values decreased with increasing thickness and after thermal aging. In the SP group, ΔE_{00} values varied according to thickness and illuminant as follows: under illuminants D50 and A, 1.5 mm>2.0 mm>1.0 mm; under illuminant F11, 2.0 mm>1.5 mm>1.0 mm; and under illuminant F2, 2.0 mm<1.0 mm≈1.5 mm. This variability may be attributed to the high viscosity of the material, which could affect the printing process and interlayer fusion. Owing to the influence of the printing process on specimen fabrication, structural homogeneity may not have been fully achieved, and layer polymerization may have been compromised. Considering these factors, no consistent correlation was identified between material thickness and color change in the SP group.

In this study, the decrease in ΔE_{00} values observed after thermal aging, compared with before aging measurements, was statistically significant (P<.05). The ΔE_{00} values after aging may be related to incomplete polymerization of the resin specimens, leading to structural instability and water absorption. The reduced color differences with increasing restoration thickness after thermal aging may be associated with increased opacity caused by changes in the material's physical properties.[13] Yılmaz et al[13] investigating the effect of thermal aging on color, the impact of aging on the relative translucency parameter (RTP) was evaluated, and a reduction in RTP values was reported after aging. Similarly, the reduction in ΔE_{00} values observed in the present study after aging may be attributed to decreased translucency and, consequently, reduced light transmission.[8] Sarafianou et al[17] reported that the conversion of C=C double bonds to C-C single bonds during thermal aging of resin-based composites may contribute to the observed color changes. The presence of unreacted monomers resulting from incomplete polymerization may explain the greater color changes observed in this group. In addition, color alterations in the evaluated materials may be associated with the hydrophobicity of the monomers and their water absorption characteristics.[18]

The printing technology used in 3D printing may influence color stability.[19] Postpolymerization, an essential step in the fabrication of 3D printed materials, enhances material properties by promoting the further conversion of unreacted monomers.[20,21] These factors represent a summary of the general mechanisms that may contribute to reduced color stability in materials used for 3D printing. In the SP group, the presence of perceptible color changes across different thicknesses after thermal aging may also be related to its lower composite resin filler content. Materials used in subtractive manufacturing are polymerized under high temperature and pressure, resulting in a higher degree of conversion and a more compact structure.[22] Although 3D printed restorative resins undergo postpolymerization procedures, their degree of polymerization remains comparatively lower.[23] A low degree of polymerization may compromise mechanical strength, and residual monomers may contribute to surface degradation and reduced surface integrity, ultimately leading to color change.[24] In the present study, the greatest color change was observed under illuminant A (ΔE_{00}: A>D50>F11>F2), regardless of resin type or thickness. Previous studies have demonstrated that the illuminant significantly influenced color perception. Volpato et al[14] reported greater color differences under illuminant A than under illuminant D65 or fluorescent illuminants, attributing this finding to illuminant metamerism.

In the present study, the SC resin exhibited the lowest wear, followed by BC and SP; however, the differences were not statistically significant (P>.05). Despite its higher ceramic filler content, the SP resin demonstrated greater wear, possibly because its higher viscosity adversely affected the printing process and interlayer fusion, as well as the response to thermal treatments applied during fabrication. In addition, layer lines were more pronounced in the SP specimens than in the SC and BC specimens. The SC resin demonstrated the highest wear resistance (SP>BC>SC), possibly because of the presence of bisphenol A–ethoxylated dimethacrylate (Bis-EMA), which exhibits low water sorption and enhances mechanical properties. However, the SC resin showed lower color stability. In contrast, the urethane dimethacrylate

(UDMA)-containing SP resin demonstrated superior color stability despite exhibiting greater wear. Few studies have investigated the wear behavior of 3D printed definitive restorative resins, and most have focused on comparisons between additive and subtractive manufacturing methods. Diken Türksayar et al[25] compared restorations fabricated using CAD-CAM technology and reported that restorations produced with the same manufacturing technique exhibited similar wear behavior. The comparable wear performance observed in the present study may be related to the use of similar production techniques for the evaluated materials. Three-dimensional printed materials are frequently manufactured in large batches and stored for extended periods. In highly viscous resins, filler sedimentation may occur, resulting in nonhomogeneous filler distribution and reduced mechanical stability.[26] Sedimentation increases the filler-matrix distance, thereby decreasing protection of the resin matrix against wear.[10] These factors may have influenced the findings of the present study. The increased wear observed in the SP resin group may therefore be attributed to its higher viscosity.

Limitations of this study included the in vitro design using standardized specimens that did not fully replicate natural tooth anatomy, with thermal aging and mastication simulations performed separately in distilled water. Wear was evaluated on 2.0-mm-thick, aged specimens. Further long-term in vivo and in vitro studies are required to validate these findings.

CONCLUSIONS

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

1. Restorative resin type and thickness did not influence wear behavior; however, illuminant had a statistically significant effect on color change.
2. Viscosity should be carefully controlled during the fabrication of definitive restorative resins to ensure efficient 3D printing, and preheating (thermal or microwave) may be applied if necessary.

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