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Effect of Gastric Acid on Surface Roughness and Color Stability of 3D-Printed Permanent Resins

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Abstract

Background: In dentistry, 3-dimensional (3D) printed permanent resin materials are widely used due to their durability and aesthetic versatility. However, their response to acidic environments, such as exposure to gastric acid in conditions like gastroesophageal reflux, is not yet fully understood. This study investigates the impact of simulated gastric acid on the color stability and surface roughness of 3D-printed permanent resin materials.

Methods: A total of 60 specimens (n = 15 in each group) were prepared as disc-shaped specimens using 4 different 3D-printed permanent resins: VarseoSmile TriniQ (VST), Crowntec (CR), C&B Ceramic Resin (CB), and Permanent Crown (PB). The specimens were exposed to a simulated gastric acid solution (pH 1.2) at 37°C for 18 hours, and color change (ΔE) was measured by a spectrophotometer, and surface roughness (Ra) was measured by a contact profilometer.

Results: After gastric acid exposure, color change (ΔE) in all groups remained within clinically acceptable limits (ΔE <3.3). However, significant differences in surface roughness were observed depending on the material type. The CB group showed higher surface roughness compared to the other groups ($P < .05$).

Conclusion: The 3D-printed permanent resins maintained color stability under gastric acid exposure, while surface roughness varied depending on the material composition. These findings highlight the importance of material selection, especially for patients with acidic oral environments.

Keywords: 3D printing, color change, gastric acid, permanent resin, surface roughness

INTRODUCTION

Additive manufacturing (AM) technology has revolutionized several industries by allowing for the rapid fabrication of personalized products with complicated geometry.[1] Among the various three-dimensional (3D) printing materials used in dentistry, permanent resins have attracted significant interest due to their durability and aesthetic versatility.[2] These resins are utilized in various dental applications, including models, prosthetic bases, metal substructures, occlusal appliances, and surgical guides. More recently, they have also been used for restorations, including crowns, inlays, onlays, and lamina veneers.[3,4]

What is already known on this topic?

- *Acidic challenges (such as gastric acid from conditions like gastroesophageal reflux disease or bulimia nervosa) are known to cause erosion and changes in the surface properties of conventional restorative materials (ceramics and composite resins).*
- *Additively manufactured (3-dimensional (3D)-printed) permanent resin materials are increasingly used for definitive restorations, and their color stability and surface roughness are critical for long-term success. However, prior to this study, data on how gastric acid exposure affects these 3D-printed resins were not available.*

What does this study adds on this topic?

- *This study provides the first data on the effects of simulated gastric acid exposure on 3D-printed permanent resin materials, showing that these materials generally maintain their color within acceptable limits even after prolonged acid exposure.*
- *One of the tested 3D-printed resins (a DLP-printed resin with a specific composition) demonstrated a significantly greater increase in surface roughness after acid exposure compared to others, highlighting that material composition and printing technology can influence resistance to acid. Clinicians may need to consider a patient's risk of acid exposure when choosing among different 3D-printed resins for permanent restorations.*

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The AM method encompasses various techniques based on the layer-by-layer manufacturing principle. In dental applications, vat polymerization is widely used as a light source to achieve polymerization of the resin.[5] The lighting system applied for the resin polymerization is dependent on the particular method of 3D printing adopted; in contrast, stereolithography (SLA) mandates the use of a laser, whereas digital light processing (DLP) operates through the deployment of a projector. The SLA utilizes a focused laser beam to selectively cure resin layers, offering high precision but potentially longer processing times. In contrast, DLP employs a projector that simultaneously cures an entire resin layer, enabling faster production but occasionally resulting in reduced resolution depending on layer thickness and resin viscosity. Due to differences in resolution, layer thickness, and resin viscosity between SLA and DLP methods, surface roughness and subsequent susceptibility to staining and reduced color stability might vary among restorations fabricated using these techniques. Several printing features, including layer thickness, manufacturing precision, and print orientation, have been examined throughout research.[6,7]

One of the critical factors affecting the performance of resins is their interaction with environmental factors.[8,9] However, limited data are available on how resin surfaces respond to both intrinsic (gastric juice) and extrinsic (dietary) acidic agents. Regardless of the acid source, exposure can lead to advanced structural changes on tooth surfaces.[10] In particular, gastric acid leads to significantly greater degradation than dietary acids.[11] Conditions including gastroesophageal reflux disease (GERD), persistent acute nausea, or bulimia nervosa occurring in the course of gestation can facilitate the ascent of gastric secretions into the oral cavity.[12] Although data on the prevalence of bulimia nervosa are limited, eating disorders are most commonly seen in females in adolescence or early adulthood.[13] The study demonstrated that dental erosion occurs in 24% of GERD patients, and among individuals with dental erosion, 33% had GERD.[14] Increased intraoral acidity may contribute to erosive tooth wear and negatively impact restorative materials' surface characteristics and color stability.[15,16]

Spectrophotometers are used to measure color changes using the CIELAB or CIEDE2000 formulae.[17] These formulas include 2 key parameters: the perceptibility threshold (PT) and the acceptability threshold (AT), providing a standardized quality control framework for interpreting results in dental research and clinical dentistry.[18] The 50 : 50% PT indicates that half of the observers can perceive the color difference between 2 items, while the other half cannot. In contrast, the 50 : 50% AT indicates that half of the observers found the observed color difference acceptable, while the other half found it unacceptable.[17]

Numerous studies have investigated the effects of gastric acid on various restorative materials;[11,16,19-26] nevertheless, the influence of this factor on the enduring resins generated through 3D printing methodologies has yet to be thoroughly examined. To the best of knowledge, there are currently no studies evaluating the effect of gastric acid exposure on 3D-printed permanent resin materials. Thus, this in vitro study aimed to assess how gastric acid affects color stability and surface roughness in permanent resin material, simulating intraoral conditions in patients experiencing gastric acid exposure. The study hypothesized that simulated gastric acid exposure would have no effect on the color stability and surface roughness of 3D-printed permanent resin materials.

MATERIAL AND METHODS

The necessity for Ethics Committee Approval and informed consent was assessed as unwarranted for this analysis, as it strictly related to in vitro manufactured disks originating from 3D-printed permanent resin materials, absent of any human or animal subject participation. The determination of the sample size was conducted utilizing the G*Power V3.1.9.6 software, incorporating a 95% CI ($1-\alpha$), a 95% test power ($1-\beta$), and an effect size of $f=0.595$. This analysis indicated that a total of 60 specimens (15 per group) would be required. In the study, 4 different permanent resins suitable for 3D printing were analyzed: VarseoSmile TriniQ (Bego; VST), Crowntec (Saremco Dental; CR), C&B Ceramic Resin (PowerResins; CB), and Permanent Crown (Formlabs; PC) (Table 1). For the purpose of specimen fabrication, a standardized disc-shaped file (in STL format), characterized by a diameter of 10 mm and a thickness of 2 mm, was meticulously designed utilizing dental computer-aided design (CAD) software (Exocad DentalCAD; exocad GmbH).[9] The specimens, characterized by their horizontally aligned disc shape, were placed on the build platform, with a layer thickness established at 50 μm, following the manufacturer's guidelines. Specimens composed of VST and CR resins were fabricated using a DLP printer (Varseo XS, Bego, Germany). Additionally, specimens made from CB resin were also produced with a DLP-type printer (Dentafab 3D Printer, Dentafab, Türkiye), while those consisting of PC were fabricated using a SLA printer (Form 3B+, Formlabs, MA, USA).

Following the printing process, all samples underwent a cleaning procedure utilizing 99% isopropyl alcohol in accordance with the specifications provided by the manufacturer. In the case of CR, VST, and CB resins, a light-polymerization apparatus (Otoflash G171; NK Optik, Germany) was employed to administer a total of 4000 flashes, with 2000 flashes applied to each surface to guarantee uniform curing. The specimens composed of PC resin were subjected to a cleaning protocol in an automated washing apparatus (Form Wash; Formlabs) utilizing 99% isopropyl alcohol for a duration of 3 minutes, then post-cured in a Form Cure (Formlabs) device at 60°C for 20 minutes. To obtain a standard surface finish, the support structures of all samples were removed using discs followed by a water-cooled polishing process.

Table 1. Composition of the Permanent Resins Used in the Study

Material	Code	Type	Composition	Manufacturer
VarseoSmile TriniQ	VST	Additively manufactured composite resin	4,4'-isopropylidenediphenol, ethoxylated and 2-methylprop-2-enoic acid, Benzene acetic acid, alpha-oxo-methyl ester, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide	BEGO
Crowntec	CT	Additively manufactured composite resin	4,4'-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid, silanized dental glass, pyrogenic silica, initiators. Total content of inorganic fillers (particle size 0.7 μm) is 30-50 wt%	Saremco
C&B MFH	CB	Additively manufactured composite resin	Methacrylic oligomers, methacrylate monomers, inorganic urethane methacrylate oligomers, acrylate monomers, filler, phosphine oxides, pigment, methacrylate monomer, phosphine oxide	Nexdent
Permanent Crown	PC	Additively manufactured composite resin	4,4'-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid, silanized dental glass, methyl benzoylformate, Diphenyl (2,4,6-trimethyl benzoyl) phosphine oxide	FormLabs

A dual-stage diamond polishing apparatus (Clearfil Twist Dia, Kuraray, Japan) was used for polishing the 3D printing resins. Polishing was carried out at 10 000 rpm for 20 seconds, starting with a coarse pre-polish followed by a high-gloss polish, to yield a smooth and homogeneous surface. Subsequent to the polishing process, the specimens underwent a cleansing procedure utilizing deionized water, and the ultimate dimensions were ascertained employing a digital caliper (Absolute Digimatic; Mitutoyo, Japan). The specimens were then categorized and stored in a dark environment to prevent changes due to light exposure.

Specimens were subjected to immersion in 5 mL of a simulated gastric acid solution for a duration of 18 hours at a temperature of 37°C within an incubator (Cultura, Ivoclar, Zurich, Switzerland). The pH of the simulated gastric acid solution was meticulously calibrated to 1.2 through the dissolution of 0.113% (0.06 M) hydrochloric acid (HCl) in deionized water.[20] Considering reports that patients with bulimia nervosa vomit on average 3 times a day and that restorative materials are exposed to gastric contents for less than 1 minute per vomiting episode,[24] the total immersion time used in this study corresponds to approximately 2 years of cumulative gastric acid exposure. This methodology enables clinically relevant simulation of long-term gastric acid effects on the surface properties of 3D printed permanent resins.

Color Parameters Measurements

A spectrophotometric device (VITA Easyshade V, Bad Säckingen, Germany) was employed to evaluate colorimetric parameters. Color differences were evaluated by recording CIELAB metric values at the moment before and after being immersed in a simulated gastric acid solution. During the spectrophotometric measurements, all specimens were placed on a neutral gray background to minimize any background-related color bias and to enhance measurement accuracy. Prior to each measurement of the specimens, the spectrophotometer underwent calibration. Following an 18-hour soak, the specimens were cleansed with deionized water, and the CIELAB values were later re-examined. The average values of L* (lightness), a* (red-green axis), and b* (yellow-blue axis) were compared. The total color change (ΔE) for each sample was calculated using the following formula:

$$\Delta Eab = [*(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2]^{1/2}$$

Where L* represents lightness (0 = black, 100 = white), a* represents the degree of redness (positive values) or greenness (negative values), and b* represents the degree of yellowness (positive values) or blueness (negative values). The relative values ΔL*, Δa*, and Δb* represent the differences before and after immersion. Color differences are classified according to clinical relevance:

- ΔE <1: The color change is not perceptible to the human eye.
- ΔE > 1: Color change is perceptible but clinically acceptable.
- ΔE > 3.3: Color change is considered clinically unacceptable.[20]

This classification allows a standardized assessment of the aesthetic stability of 3D printed permanent resins exposed to simulated gastric acid conditions.

Surface Roughness Measurements

The evaluation of surface roughness was carried out using a contact profilometer (Perthometer M2; Mahr, Germany). The profilometer was subjected to precise calibration, with a tracing length of 1.75 mm and a cutoff value of 0.25 mm. The roughness parameter Ra, which represents the arithmetic mean deviation of the surface profile, was used to quantify surface texture. Assessments were made for every specimen before (T1) and after (T2) an 18-hour immersion in acid. Three measurements were taken at the center of each specimen, and the mean Ra value was calculated. This approach enabled a comprehensive assessment of the effects of acidic conditions on the surface properties of the 3D-printed permanent resins.

Statistical Analysis

Statistical investigations were carried out employing NCSS 2007 (Number Cruncher Statistical System; Kaysville, UT, USA). Descriptive statistical techniques (mean, standard deviation, median, frequency, ratio, minimum, maximum) were employed to assess the research data, and the distribution of the data was examined via the Shapiro–Wilk test. The ANOVA test was implemented for comparisons involving 3 or more groups of quantitative data, with Bonferroni correction applied during post hoc analyses. The paired *t*-test was utilized for assessments of repeated measurements. The threshold for statistical significance was established at $P < .01$ and $P < .05$.

RESULTS

Color Parameters Evaluation (L, a*, b*, ΔE)

Color coordinates were obtained with a digital spectrophotometer at T1 and T2 periods. A one-way ANOVA test and post hoc Bonferroni correction were used for comparisons between groups. Group-CR had significantly higher L* (luminance) values than the other groups during T1 and T2 periods ($P = .001$). a* (red-green) and b* (yellow-blue) values also showed significant differences between the groups ($P = .001$ for each parameters) (Table 2).

Color change (ΔE) values did not show a statistically significant difference between the groups ($P > .05$). However, some differences were observed in terms of color change between T1 and T2 periods within the groups. The ΔE value was 1.7 ± 1.1 in Group-CR, 1.02 ± 1.66 in Group-VST, 1.22 ± 0.75 in Group-CB, and 1.01 ± 0.23 in Group-PC. These values indicate that the color change was within clinically acceptable limits (Table 3).

Surface Roughness Assessment

Comparison of the groups' Ra values before (T1) and after (T2) gastric acid exposure revealed significant differences among the groups (one-way ANOVA, $P = .001$; Bonferroni post hoc). At T1, Ra values of Group-CR and Group-VST (0.24 ± 0.06) were significantly lower than Group-CB (0.39 ± 0.11), while statistical significance was found between Group-CB and Group-PC (0.26 ± 0.07) ($P = .001$). Similar differences were observed in the T2 period, and the Ra value of Group-CB (0.47 ± 0.17) was significantly higher than the other groups ($P = .001$) (Table 4).

Table 2. Comparison of Color Parameters (L, a, b*) Measured at Different Time Points Among Groups

	Groups	n	Mean ± SD	Min-Max (Median)	*P*
T1-L	***CR***	15	89.85 ± 0.31	89.3-90.4 (89.73)	***.001*****
	VST	15	85.98 ± 0.35	85.1-86.5 (86.07)	
	CB	15	85.67 ± 0.91	83.43-86.53 (85.93)	
	PC	15	82.53 ± 0.45	81.8-83.2 (82.6)	
T2-L	***CR***	15	90.99 ± 0.24	90.5-91.33 (90.97)	***.001*****
	VST	15	86.97 ± 0.27	86.33-87.3 (87.03)	
	CB	15	89.52 ± 0.76	87.93-90.7 (89.63)	
	PC	15	83.37 ± 0.38	82.73-84 (83.37)	
T1-a	***CR***	15	0.26 ± 0.15	0-0.5 (0.33)	***.001*****
	VST	15	1.07 ± 0.08	0.9-1.2 (1.07)	
	CB	15	1.64 ± 0.23	1.23-2 (1.7)	
	PC	15	0.86 ± 0.1	0.7-1.1 (0.83)	
T2-a	***CR***	15	0.16 ± 0.08	0-0.3 (0.17)	***.001*****
	VST	15	1.08 ± 0.05	1-1.13 (1.1)	
	CB	15	1.49 ± 0.27	1.1-1.97 (1.53)	
	PC	15	1.07 ± 0.09	1-1.2 (1)	
T1-b	***CR***	15	27.86 ± 1.25	26.1-30.6 (27.73)	***.001*****
	VST	15	23.21 ± 1.96	16.27-24.43 (23.63)	
	CB	15	29.8 ± 0.94	28.37-31.63 (29.67)	
	PC	15	38.12 ± 1.25	36.73-40.03 (37.47)	
T2-b	***CR***	15	26.18 ± 0.68	25.33-27.43 (26.03)	***.001*****
	VST	15	23.23 ± 0.27	22.73-23.57 (23.27)	
	CB	15	30.39 ± 1.26	26.87-31.93 (30.5)	
	PC	15	37.14 ± 1.24	35.43-39.2 (36.83)	

ANOVA test.
CR: Crowntec; CB: C&B MFH; PC: Permanent Crown VST VarseoSmile TriniQ T1: Before gastric acid exposure; T2: After gastric acid exposure
*$P < .05$.
**$P < .01$.

DISCUSSION

The study hypothesized that simulated gastric acid exposure would have no effect on the color stability and surface roughness of 3D-printed permanent resin materials. However, the results revealed significant differences in L, a*, and b* color coordinates ($P = .001$), although the total color change (ΔE) did not differ significantly among groups ($P > .05$). Additionally, significant differences were observed between the groups concerning surface roughness values ($P = .001$). Given these findings, the study hypothesis was partially rejected, indicating that gastric acid exposure does have measurable effects on the color stability and surface characteristics of 3D-printed permanent resins

The principal aim of restorative dentistry is to restore the lost dental structure through the utilization of a substance that closely corresponds to the optical and mechanical characteristics of the natural tooth.In this way, the restoration provides both the appearance of anatural tooth and functionally successful in long-term use .[20] It is also important to consider that restorative materials encounter various intraoral environments throughout their lifetime. Dentists can clinically detect oral manifestations associated with gastroesophageal reflux by reviewing the patient's medical history and medications related to acid reflux diagnosis. According to studies, 40% of the adult population has been reported to experience GERD symptoms at some point in their lives.[27] Therefore, when planning prosthetic restorations for patients with

Table 3. Comparison of Color Difference (ΔE) Values Measured at Different Time Points Among Groups

	Groups	n	Mean ± SD	Min-Max (Median)	P
ΔE	***CR***	15	1.7 ± 1.1	0.1-4.23 (1.47)	.264
	VST	15	1.02 ± 1.66	0.07-6.77 (0.47)	
	CB	15	1.22 ± 0.75	0.24-2.65 (1.04)	
	PC	15	1.01 ± 0.23	0.66-1.45 (1.02)	

ANOVA test.
CR, Crowntec; CB, C&B MFH; PC, Permanent Crown; VST, VarseoSmile TriniQ.
*P < .05.
**P < .01.

gastroesophageal reflux, clinicians should carefully consider the chemical resistance and durability of restorative materials against gastric acid exposure. The resistance to chemical abrasion is essential for dental materials intended for intraoral use and significantly influences restorative material selection.[20] The objective of the present research was to examine this particular circumstance, which is commonly seen in the oral environment, and the recently widely used permanent resins in terms of surface roughness and color.

In vitro simulation of acidic conditions affecting dental ceramic surfaces is influenced by variables including immersion duration, acid concentration, and temperature.[25] In this study, the working pH was set at 1.2, and the samples were immersed at 37°C for 18 hours. Furthermore, CAD-CAM materials underwent exposure to acidic environments for durations of 6-18 hours, which have been approximated to reflect 2-8years of clinical exposure of dental structures to instances of emesis, respectively.[26] In an alternative investigation, monolithic zirconia was subjected to immersion in an acidic solution for a duration of 96 hours, an experimental condition purported to replicate in excess of a decade of dental exposure to emesis under clinical circumstances.[11] Although repeated short-term immersions (such as multiple brief episodes per day) might better simulate specific clinical scenarios, such as those encountered in GERD or bulimia nervosa, the continuous immersion method used in this study effectively provided insights into material behavior under sustained acidic conditions. Upon reviewing existing studies, it appears that the literature lacks a distinct agreement concerning the methodologies employed for the simulation of gastric acid and their corresponding equivalent exposure times in vivo. According to the ISO 6872 standard, exposing dental materials to 4% acetic acid for 16 hours at 80°C during solubility testing is considered clinically equivalent to a 2-year exposure period.[28]

Table 4. Comparison of Surface Roughness Values Measured at Different Time Points Among Groups

	Groups	n	Mean ± SD	Min-Max (Median)	P
T1	***CR***	15	0.24 ± 0.06	0.14-0.33 (0.24)	***.001****
	VST	15	0.24 ± 0.06	0.12-0.31 (0.25)	
	CB	15	0.39 ± 0.11	0.26-0.67 (0.34)	
	PC	15	0.26 ± 0.07	0.15-0.39 (0.28)	
T2	***CR***	15	0.24 ± 0.04	0.16-0.3 (0.24)	***.001****
	VST	15	0.25 ± 0.07	0.13-0.34 (0.27)	
	CB	15	0.47 ± 0.17	0.22-0.82 (0.47)	
	PC	15	0.27 ± 0.06	0.16-0.41 (0.28)	

ANOVA test.
CR, Crowntec; CB, C&B MFH; PC, permanent crown; VST VarseoSmile TriniQ T1, before gastric acid exposure; T2, after gastric acid exposure;
*P < .05.
**P < .01.

Surface roughness and topographic irregularities on dental restorations result in increased plaque buildup, discoloration, and bacterial adhesion.[29] This study found that surface roughness values for permanent resins in 3 groups (VST, CR, PC) were within the clinically acceptable threshold of 0.2 μm,[29] while only 1 group (CB) exceeded this limit. The pre-treatment values of the VST and CR groups were 0.24 ± 0.06 μm, PC was 0.26 ± 0.07 μm, while the value of the CB group was 0.39 ± 0.11 μm. This is thought to be due to differences in the compositions of the resins, different 3D printing devices, and post polymerization processes even before exposure to acidic environment.

In patients with GERD, gastric fluid with a low pH entering the oral environment impacts both natural teeth and the surface characteristics of restorative materials. Resin composite CAD/CAM materials such as Paradigm MZ100 and Lava Ultimate have been reported to undergo surface modifications when exposed to gastric acid.[26] In addition, it has been reported that gastric acid exposure has varying degrees of effect on various properties of some CAD/CAM ceramic materials and causes certain surface changes even in zirconia.[11,20,22] In this study, it was remarked that the surface roughness increased after the simulated gastric fluid application, especially the Ra value of the CB group was 0.47 ± 0.17 μm, which was significantly higher than the other groups. The higher surface roughness values observed in the CB group after gastric acid exposure may be attributed to its specific resin composition, including differences in filler types, filler particle sizes, and the polymerization process utilized, which could collectively affect the material's resistance to acidic degradation. Meanwhile, it was observed that VST, CR, and PC materials exhibited more stable surface properties. This situation highlights the importance of considering the patient's acidic oral environment during the selection of permanent resin materials and underscores the need for monitoring long-term clinical performance.

The color stability of restorative materials is critical to maintaining long-term aesthetic success. Studies have investigated the color alterations of 3D-printed permanent resins after aging in various liquids.[30-32] Resins produced via AM technology have been reported to undergo more color change compared to CAD/CAM-fabricated and conventional heat-polymerized materials.[31] Additionally, 3D-printed resin specimens submerged in coffee have shown increasing color change over time.[32] In this study, the color stability of

4 different 3D-printed permanent resin materials was evaluated after exposure to simulated gastric acid. The ΔE values ranged from 1.01 to 1.70 depending on the material; these values indicate that the color changes were perceptible but remained within clinically acceptable limits. Notably, none of the materials had a ΔE below 1, which suggests that acidic exposure did cause slight changes in the materials' color coordinates at a microscopic level. Although all resin groups demonstrated color changes within clinically acceptable limits, Group-CR exhibited the highest ΔE value among the tested materials. This slight increase in color alteration could potentially be related to differences in resin composition, specifically variations in filler content, type of resin monomers, and polymerization characteristics, which may influence the resin's susceptibility to chemical degradation under acidic conditions. Although these differences do not result in a dramatic deviation from the original tooth color, a slight change in the restoration's appearance can be observed.

In general, ΔE values below 1 indicate clinically imperceptible color changes, whereas values between 1 and 3.3 are perceptible but clinically acceptable.[20] Since the ΔE values obtained in this study fell within the 1-3.3 range, the overall color stability of these materials was maintained, although subtle color changes were detectable at a microscopic level. Therefore, the results suggest that 3D-printed permanent resins retain their aesthetic appearance despite prolonged acid exposure, with minor variations potentially attributable to material composition and manufacturing technology. In the current study, color differences were calculated using the CIELAB formula, which is widely used in dental studies due to its simplicity, broad acceptance, and extensive comparability within the existing dental literature.[20] Although the CIEDE2000 formula is considered more advanced due to its improved correlation with visual assessments and increased sensitivity,[17] the CIELAB system was selected to ensure direct comparability of the findings with previous studies that utilized similar methodologies and thresholds (e.g., ΔE <1 and ΔE between 1-3.3) for clinical relevance.

The DLP and SLA are among the most commonly used 3D-printing technologies for fabricating dental restorations, offering high precision and rapid production.[33] In the realm of printing, low-viscosity resins are commonly selected to uphold the dimensional accuracy of restorations.[34] It has been reported that restorations produced with SLA-type 3D printing exhibit better mechanical strength and contain fewer fractures, cavities, and microbubbles compared to those produced with DLP, although this difference was not found to be statistically significant.[35] According to the findings, the PC group produced with SLA-type printing showed statistically significant less roughness compared to CB, while no difference was observed in the surface roughness compared to VST and CR produced with DLP-type printing. The layered structure of 3D-printed materials—affecting factors like the degree of polymerization and filler content—emerges as an important factor determining surface roughness under prolonged acidic exposure. Previous studies comparing SLA- and DLP-printed resins have reported differences in their mechanical and optical properties, largely attributable to the specific curing mechanisms and polymerization precision of each method.[31,32] The SLA-produced resins typically demonstrate superior surface smoothness and higher resolution, potentially translating to improved mechanical strength and aesthetic outcomes. Conversely, DLP-produced resins may exhibit variations in surface texture and optical properties due to differing light exposure uniformity and layer curing dynamics. These differences are crucial in restorative dentistry, where surface characteristics significantly influence long-term clinical success and patient satisfaction.[33-35]

The limitation of this study is the reliance on simulated gastric acid exposure, which is insufficient to mimic the complex oral environment. For example, other environmental factors such as saliva, thermal cycling, and the presence of different mechanical forces may also affect the performance of restorative materials, including these factors may provide a more accurate reflection of clinical conditions. In addition, considering that 3D-printed permanent resins were not exposed to gastric acid in previous studies, this situation limits the ability to make comparisons. In the future, clinical follow-up studies that take such factors into account will allow for a more comprehensive evaluation of the extended performance of 3D-printed permanent resin materials.

CONCLUSION

Within the parameters of this in vitro study, the color stability of 3D printed permanent resin materials under simulated gastric acid remained generally within clinically acceptable limits, while significant differences were observed in surface roughness depending on the material type. In particular, the CB group produced using DLP technology exhibited higher surface roughness after gastric acid exposure compared to the other groups. This suggests that the layered structure and composition differences of 3D printing materials may have negative effects on surface properties in long-term acid exposure. The findings suggest that material selection is of critical importance in restorative treatment planning for patients with conditions such as bulimia, prolonged severe nausea during pregnancy, or gastroesophageal reflux, and these factors should be considered in the monitoring of long-term clinical performance.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

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Informed Consent: N/A.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – G.D., P.Ş.; Design – G.D., P.Ş.; Supervision – G.D.; Resources – G.D., P.Ş.; Materials – G.D., P.Ş.; Data Collection and/or Processing – G.D., P.Ş.; Analysis and/or Interpretation – G.D.; Literature Search – G.D.; Writing Manuscript – G.D.; Critical Review – P.Ş.

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