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Comparison of color stability of different 3D-printed resins

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ABSTRACT

Aims: This study aimed to compare the long-term color stability of two different 3D-printed resins, one CAD/CAM resin nanoceramic block, and one nanohybrid composite resin after immersion in a coffee solution.

Methods: Specimens were prepared from four resin-based materials produced via different manufacturing techniques: subtractive manufacturing (Cerasmart-group CS), additive manufacturing (VarseoSmile Crown Plus-group VS, Crowntec-group CT), and conventional methods (Clearfil Majesty Esthetic-group CME). The samples were immersed in coffee for 45 minutes daily over 30 days and stored in distilled water for the rest of the day. Color measurements were taken using a spectrophotometer on days 1, 7, 14, and 30. Color changes (ΔE) were calculated using the CIEDE2000 formula. Data were analyzed using one-way ANOVA, and post hoc comparisons were performed using the Tukey test. A p-value <0.05 was considered statistically significant.

Results: There were significant differences among the groups on days 1, 7 and 14. At the end of 30 days, the lowest color change was observed in group VS (ΔE=4.69), while the highest was in group CS (ΔE=5.60). The differences among groups were not statistically significant (p=0.69).

Conclusion: The color change of 3D-printed resins was comparable to that of CAD/CAM nanoceramic blocks and conventional composite resins. However, all materials exhibited color changes above the clinically acceptable threshold (ΔE>1.8). Further studies are needed to evaluate the color stability of 3D printing resins and additive manufacturing techniques.

Keywords: 3D printing, CAD/CAM, composite resin, discoloration

INTRODUCTION

Composite resins are among the most widely used materials in restorative dentistry. Over time, improvements have been made to their esthetic properties, application techniques, and composition. However, discoloration over the long term remains a common clinical concern and a widely studied topic. Various factors can affect the color stability of restorative materials. Discoloration may occur via absorption or adsorption of staining substances from commonly consumed beverages such as coffee, tea, and wine. Therefore, the ability of restorative materials to resist color changes is crucial for the long-term clinical success of restorations.

Today, CAD/CAM manufacturing techniques can be classified into two main categories: subtractive and, more recently, additive manufacturing. Additive manufacturing, also known as 3D printing, eliminates the need for costly milling burs and blocks required in subtractive techniques, thereby significantly reducing post-production material waste. Unlike milling systems, dental 3D printers can produce multiple restorations simultaneously. Moreover, as 3D printing does not involve milling forces, it can be considered a passive production process.[1] The resins used in 3D printing are generally easier to repair and cause less wear on opposing dentition.[2] Some studies have also reported that restorations produced via additive manufacturing exhibit greater accuracy compared to those made with subtractive techniques.[3] Due to these advantages, 3D printing is increasingly used in various dental applications such as model fabrication, surgical guides, scaffold production, endodontics, orthodontics, removable prostheses, provisional crowns, inlays, onlays, overlays, full crowns, veneers, and implant planning.

Stereolithography (SLA) is the earliest and most widely used 3D printing technique in dentistry.[1,3] SLA primarily enables the fabrication of resin-based objects. One of the most recent advancements in additive manufacturing is masked stereolithography (mSLA), which builds upon SLA principles. Unlike traditional SLA, which uses a laser as the light source, mSLA utilizes an array of LEDs that project UV light through a liquid crystal display (LCD), curing entire layers at once. Under certain conditions, mSLA can achieve faster print times than SLA due to the simultaneous curing of complete layers rather than individual points. Furthermore, the low cost of LCD screens makes mSLA a more affordable printing technology.[4]

The color stability of resin-based restorations in the oral environment depends not only on the manufacturing technique but also on exposure to dietary staining agents. Coffee is one

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of the most commonly consumed beverages worldwide due to its flavor and stimulating effects. Chromogens, which are pigments that adhere to enamel surfaces and cause visible stains over time, are the primary cause of coffee-related discoloration.[5] Color mismatches in restorations are among the leading reasons for restoration replacements.

To overcome observer-related factors such as fatigue, ambient conditions, and subjective interpretation, modern research prefers spectrophotometers for color evaluation, offering more consistent and reproducible measurements. Since 2001, the CIEDE2000 formula, based on the CIEL*ab** system, has been recommended to minimize the difference between perceived and calculated colors.[6] The ΔE value represents the numerical difference between standardized L*, a*, and b* values and the target color. It is commonly used to assess the acceptability and perceptibility thresholds of color differences between the restoration and the surrounding dentition.[7]

Although numerous studies have investigated the mechanical properties of 3D-printed resin materials, research focusing on discoloration-an essential aspect of esthetics-remains limited. Therefore, the aim of this in vitro study was to evaluate the color changes of a resin nanoceramic CAD/CAM block, a nanohybrid composite resin, and two different 3D-printed resins after daily immersion in a coffee solution. The null hypothesis was that the type of material would not significantly affect the degree of discoloration.

METHODS

Our study is a laboratory study. No patients or living tissues were used. Therefore, ethics committee approval is not required. All procedures were carried out in accordance with the ethical rules and the principles.

This in vitro study was conducted at the Laboratories of the Faculty of Dentistry, Ordu University, Department of Restorative Dentistry. Two different resins suitable for 3D printing with LCD technology, one CAD/CAM nanoceramic block, and a conventional nanohybrid composite were immersed in a coffee solution for 30 days. Color changes were evaluated on Days 1, 7, 14, and 30. The required sample size was determined using G*Power software version 3.1.9.2 (Heinrich Heine University, Düsseldorf, Germany) based on a 95% confidence level and a significance value of 0.05. The sample size was determined to be 80 with 20 specimens for each group to account for potential specimen loss.

The workflow of the study included the following steps:

- Preparation of specimens
- Storage in distilled water and baseline color measurements
- Daily immersion in coffee solution and subsequent color measurements
- Comparison of color differences

The commercial names and compositions of the tested materials-VarseoSmile Crown Plus (BEGO, Bremen, Germany), Crowntec (Saremco, Switzerland), Cerasmart (GC Europe), and Clearfil Majesty Esthetic (Kuraray, Japan) are listed in **Table 1**.

Preparation of Specimens

Group VS-VarseoSmile Crown Plus: The 3D-printed specimens were produced using the Phrozen Mini 8K printer (Phrozen Tech, Hsinchu, Taiwan), which employs high-resolution LCD technology. Disc-shaped specimens (8 mm diameter ×2 mm thickness) were designed using Blender software (Blender Foundation, Amsterdam, Netherlands) and exported in STL format. Files were processed in Chitubox v1.7.0 (Guangdong, China) with a 0° orientation and a 50 µm layer thickness. Six base layers were defined, with exposure parameters of 4.5 seconds per layer and 40 seconds for base exposure. Lift distance and speed were set to 8 mm and 60 mm/s, respectively. Support structures (Ø0.7 mm) were attached to a 0.8 mm thick curved base.

A total of 20 specimens were printed and cleaned using an ultrasonic cleaner; first in 95% reusable ethanol for 3 minutes, then in fresh 95% ethanol for 2 minutes. Residual resin was rinsed with ethanol spray and dried with compressed air. Support structures were removed using a separating disc (Dentorium, New York, USA). Post-curing was performed using a 405 nm UV light unit (Phrozen Cure, Phrozen 3D, Taiwan) for 2 × 5 minutes. Device specifications are listed in **Table 2**.

Group CT-Crowntec: The same design, printer, and slicing parameters were used as in group VS. Exposure settings included 3.5-4.5 seconds per layer, 25-35 seconds for base layers, 6 mm lift distance, and 60 mm/min lift speed. The

Table 1. Resin-based restorative materials and their compositions used in the study						
Manufacturing method	Material	Group name	Material type	Composition	Manufacturer	Lot. Num.
Additive manufacturing	VarseoSmile Crown Plus	VS	3D printed resin	4,4'-esterification products of isopropylidenediphenol, ethoxylated and 2-methylprop-2-enoic acid (50.00-<75.00 wt%), diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide (<2.5 wt%)	VA; BEGO,Bremen, Germany	601003
	Crowntec	CT		Bis-EMA, trimethylbenzoyldiphenylphosphine oxide (0.1-1%)	Saremco Dental AG, Rebstein, Switzerland	E617
Subtractive manufacturing	Cerasmart	CS	Resin nanoceramic CAD/CAM Block	UDMA, Bis-EMA, silica (20 nm), barium oxide (0.1-1%)	GC dental products Europe, Leuven, Belgium	2104091
Conventional Fabrication	Clearfil Majesty Esthetic	CME	Nanohybrid conventionalcomposite	Bisphenol A diglycidyl methacrylate (2.5-10%), silanized barium glass filler, prepolymerized organic filler, hydrophobic aromatic dimethacrylate, hydrophobic aliphatic dimethacrylate, DL-camphorquinone, accelerators, initiators, pigments	Kuraray, Japan	6U0250
VS: VarseoSmile, CT: Crowntec, CS: Cerasmart, CAD/CAM: Computer aided design/computer aided manufacturing, CME: Clearfil Majesty esthetic, EMA: Exponential moving average						

Table 2. Additive manufacturing devices used in the study

Device type	Model	Technical specifications	Manufacturer
3D printer	Phrozen Sonic 8k Mini	Printing method: LCD Stereolithography Pixel size: 22 µm Pixel resolution: 7.536×3.240 Build volume (XYZ, mm): 165×72×180 Wavelength (nm): 405 Light Intensity (mW/cm^2): 2.8 Device weight (kg): 13	Phrozen Tech, Hsinchu,Taiwan
Washing unit	Phrozen Wash&Cure	Power output (W): 48 Input voltage (VDC): 24 Product dimensions (cm): 27.7×20.7×46.7 Washing tank capacity (L): 8 Max model size (cm): 21.8×12.3×23.5 Weight (kg): 3.5 Timer (min): 0-30	Phrozen 3D, Hsinchu City, Taiwan
Post-curing UV unit	Phrozen Wash&Cure	Power output (W): 48 Input voltage (VDC): 24 Product dimensions (cm): 35.4×30.9 × 36.8 Rotating plate diameter (cm): 19.6 Max model size (cm): 25×23.5 Weight (kg): 3.9 Timer (h): 0-2 LED wavelength (nm): 405	Phrozen 3D, Hsinchu City, Taiwan

LCD: Liquid crystal display

residual resin on the 20 specimens produced with these parameters was removed using a brush soaked in 95% ethanol until the surface achieved a matte appearance. Support structures were removed, and specimens were post-cured under the same UV lamp in two 5-minute cycles.

Group CS-CAD/CAM resin block (Cerasmart): Cylindrical blocks (8 mm diameter) were milled from Cerasmart blocks using a 5-axis CNC milling unit (Ceramill Motion 2, AmannGirrbach, Austria). The blocks were sectioned to 2 mm thickness using a precision diamond saw (Mecatome T180, France) under water cooling. 20 specimens were obtained.

Group CME-nanohybrid composite (Clearfil Majesty Esthetic): Composite discs were fabricated using silicone molds (8 mm diameter, 2 mm thick). Transparent strips were applied above and below the mold to ensure flat surfaces. The material was inserted using a spatula, compressed lightly, and polymerized with an LED curing unit according to the manufacturer's recommendations. Finishing and polishing were performed in two steps using the Clearfil Twist Dia system (Kuraray, Japan) for 15-20 seconds in a standardized direction.

Baseline Color Measurement

Baseline color measurements were obtained using a VITA EasyShade spectrophotometer (VITA Zahnfabrik, Bad Säckingen, Germany). The device was calibrated per manufacturer instructions before and between each measurement. Each sample was measured three times, and the average L*, a*, and b* values were recorded.

Aging Procedure in Coffee Solution

Each sample was immersed in a freshly prepared coffee solution (2 g Nescafe Classic in 200 ml boiling water, no sugar) for 45 minutes daily. The solution was cooled to room temperature before immersion and renewed daily to prevent contamination.[8] Specimens were stored in distilled water outside immersion periods and brushed under running tap water before each new cycle.

On days 1, 7, 14, and 30, specimens were brushed, dried, and color measurements were repeated. Measurements were made against an A4 white background with the device tip in direct perpendicular contact with the surface. The same observer conducted all measurements under identical room conditions and at the same time each day to ensure consistency.

Color Difference Calculation

Color differences were calculated using the CIEDE2000 formula:

$$\Delta E_{00}=\sqrt{\left(\frac{\Delta L\prime}{K_L S_L}\right)^2+\left(\frac{\Delta C\prime}{K_C S_C}\right)^2+\left(\frac{\Delta H\prime}{K_H S_H}\right)^2+R_T\left(\frac{\Delta C\prime}{K_C S_C}\right)\left(\frac{\Delta H\prime}{K_H S_H}\right)}$$

ΔL: Change in lightness
ΔC: Change in chroma
ΔH: Change in hue
SL, SC, SH: Weighting functions for perceptual uniformity
KL, KC, KH: Correction terms, each set to 1
RT: Rotation function accounting for chroma-hue interaction in blue areas
AΔE_{00} value below 1.8 was considered the clinically acceptable threshold.[9]

Statistical Analysis

Data analyses were conducted using SPSS software (version 20.6, IBM Corp., Chicago, IL, USA) at a 95% confidence level. One-way ANOVA was used to compare groups, followed by Tukey's post hoc test for pairwise comparisons. Results were expressed as mean±standard deviation. Statistical significance was set at $p<0.05$.

RESULTS

On day 1, mean ΔE values were; group VS=1.10, group CT=1.53, group CS=1.81, and group CME=1.25. The differences between groups were statistically significant ($p<0.0001$). Group VS showed the lowest color change, and group CS the highest. There was no significant difference between group VS and group CME, whereas group VS and group CS differed significantly.

On day 7, ΔE values were: group VS=3.02, group CT=2.72, group CS=3.35, and group CME=2.47. Differences were again statistically significant ($p<0.0001$). The highest color change was observed in group CS, and the lowest in group CME. Significant differences were found between Crowntec and Cerasmart, and between VarseoSmile and Clearfil Majesty.

On day 14, ΔE values increased to; group VS=4.53, group CT=4.51, group CS=5.80, and group CME=3.78. The differences were statistically significant ($p<0.0001$). Group CME showed the lowest ΔE, and group CS the highest. Cerasmart differed significantly from all other groups, while the difference between 3D-printed and composite groups was not statistically significant.

On day 30, the mean ΔE values were, group VS=4.69, group CT=5.59, group CS=5.60, and group CME=5.20. No statistically significant differences were found among the groups (p=0.069), although group VS still had the lowest and group CS the highest ΔE values

ΔE values for each group across all time points are summarized in **Table 3** and illustrated in **Figure**.

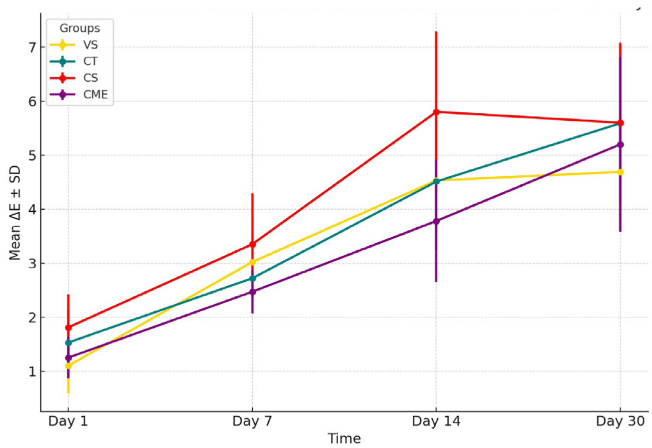

Figure. Mean ΔE values of resin-based restorative materials over a 30-day period

DISCUSSION

In this study, the optical properties of resin materials commonly used in additive manufacturing technology were investigated and compared with those of other resin-based restorative materials. After 30 days, no statistically significant differences were found among the groups, and the null hypothesis that the type of resin material does not affect color stability was accepted.

Resin materials with higher water absorption can also absorb greater amounts of water-soluble pigments.[10] The color stability of resin materials has been improved through various physical and chemical modifications. These improvements include reduced water sorption, increased filler loading, smaller particle sizes, and an optimized filler-matrix interface.

In previous studies where CAD/CAM materials were immersed in distilled water, wine, and coffee for 30 days, Cerasmart samples stored in coffee showed ΔE values above the clinically acceptable threshold. These findings are consistent with the present study. Cerasmart's high translucency may explain the greater color change observed.[11,12]

In resin-based composites, filler particle size and shape influence light scattering, while the presence of organic matrix and pigments affects light absorption.[13] Studies have reported that the filler loading by weight of the 3D-printed resins Crowntec and VarseoSmile was 33%, within the range of 30-50% as specified by the manufacturer.[14] According to manufacturer data, their particle sizes are 0.7 µm.[2] However, there is a lack of information on filler morphology. The detachment of inorganic particles from the surface over time may lead to void formation, increasing surface roughness. Additionally, the use of larger filler particles to reduce viscosity may cause sedimentation during long-term storage and heterogeneous layer printing during fabrication. A low filler content may increase light scattering and the volume of matrix requiring polymerization. Ideally, filler particles should be small and the filler content high to achieve optimal mechanical, physical, and optical properties. Smaller particles enhance light penetration.[15] Cerasmart contains 71 vol% of silica (20 nm) and barium glass (300 nm) nanosized fillers with irregular shapes.[16] Among CAD/CAM materials, Cerasmart is known to have a lower filler load. The excessive discoloration seen in the 30-day specimens may be attributed to this lower filler content. The lack of detailed chemical composition data on Crowntec and VarseoSmile limits the ability to correlate their optical behavior.

The monomers constituting the organic matrix also influence optical properties. In some studies, color stability was found to be more affected by the matrix than by filler content. According to limited manufacturer information, BisEMA-a monomer without hydroxyl groups-is used in the 3D printing resins. Another identified monomer, UDMA, has been shown to achieve three times greater polymerization than BisGMA.[17] This reduces the amount of unpolymerized monomers, which are known to contribute to discoloration. The presence of BisEMA in all materials may explain the similar ΔE values observed in VarseoSmile, Crowntec, and Cerasmart.

All specimens were fabricated in A2 shade, as specified by the manufacturers. However, Alfaro et al.[18] reported that many materials exhibit shades other than A2 when evaluated using the Vita Classic shade guide. This discrepancy may affect the reliability of color comparison studies.

Previous studies have shown that printer type can affect the color stability of resin-based restorations. In one study comparing surface roughness and stainability, Saremco Print Crowntec fabricated with DLP technology exhibited greater discoloration than Cerasmart.[19] This study employed mSLA (LCD) printing technology. The primary distinction between mSLA and DLP/SLA methods lies in their curing mechanisms. mSLA uses an array of UV-LED or LED light sources masked by an LCD screen, directing light only to areas requiring curing. DLP projects light through movable mirrors, curing an entire layer simultaneously. These differences may explain why mSLA yields smoother and more detailed surfaces.[20]

Table 3. Comparison of the mean ΔE values and standard deviations of four different resin materials over a 30-day period

	Group VS	Group CT	Group CS	Group CME	
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**p-value***
Day 1	1.10 (0.51)^{A}	1.53 (0.60)^{AB}	1.81 (0.61)^{B}	1.25 (0.38)^{A}	<.0001
Day 7	3.02 (0.57)^{AB}	2.72 (0.36)^{BC}	3.35 (0.94)^{A}	2.47 (0.40)^{C}	<.0001
Day 14	4.53 (1.06)^{A}	4.51 (1.26)^{A}	5.80 (1.49)^{B}	3.78 (1.13)^{A}	<.0001
Day 30	4.69 (0.91)^{A}	5.59 (0.53)^{A}	5.60 (1.48)^{A}	5.20 (1.62)^{A}	.069

*One-way ANOVA results, groups with different magnitudes on each day were significantly different (Tukey HSD test). Uppercase letters within the rows indicate statistically significant differences between groups at the p<0.05 level. SD: Standard deviation

Ellakany et al.[21] used a similar setup, comparing one subtractive CAD/CAM material, two additive SLA and DLP printed materials, and a conventional composite, all stored in various solutions for 1, 7, and 30 days. The DLP-printed specimens showed greater discoloration than SLA at all time points.

In another study, Krajangta et al.[22] compared the color stability and surface roughness of 3D-printed VarseoSmile and subtractively fabricated Cerasmart stored in distilled water and coffee. The Asiga DLP printer was used. They reported no significant ΔE difference between the two after 30 days, but both exceeded the clinically acceptable limit.

Due to the layer-by-layer process of additive manufacturing, printed objects exhibit anisotropic mechanical properties.[23] Anisotropy refers to property variation depending on the printing orientation.[24] Print orientation affects the number of layers and therefore influences both mechanical and optical properties. A surface roughness greater than 0.2 µm may promote bacterial adhesion.[25] The layering lines may contribute to surface roughness depending on their location on the printed object. This may affect the roughness of the buccal surface, which is more exposed to staining agents.[23] Post-curing reduces anisotropy.[26]

Tayaheri et al.[27] evaluated the degree of conversion in samples printed at 0° and 90°. Higher conversion rates were observed in the upper surfaces closer to the light source. Thus, 0° orientation places better-polymerized layers on the color measurement surface, while 90° does not, potentially affecting color stability. In this study, specimens were printed at 0°.

Post-curing has been shown to improve the mechanical and optical properties of 3D-printed resins. Lee et al.[28] investigated the effect of different post-curing durations (0, 5, 10, and 20 minutes) on color stability. As post-curing time increased, ΔE values decreased, particularly in samples immersed in coffee. Surface roughness also stabilized after 10 minutes of curing. In the present study, a 10-minute post-curing protocol was followed according to manufacturer instructions.

It is generally accepted that most indirect resin materials exhibit better color stability than direct resin-based materials due to their higher degree of conversion. However, in our study, no statistically significant difference was found among the ΔE values of all specimens.

Light-cured resin materials never achieve complete monomer conversion due to the gel effect, which reduces monomer mobility and limits polymerization. Therefore, post-curing is a critical step for additive resins.[29]

Among all groups, group CS (Cerasmart) showed the highest discoloration at all time points. This may be attributed to milling marks remaining on the surface. Shin et al.[20] found that CAD/CAM materials retained milling lines, whereas 3D-printed samples exhibited smoother surfaces under high magnification. No polishing was applied at that stage, highlighting the importance of polishing protocols in additive manufacturing. Although 3D-printed materials may be expected to demonstrate superior color stability due to smoother surfaces, multiple factors-including the fabrication and post-processing steps-play a role.

Polishing systems vary in abrasive composition and particle characteristics, affecting their efficiency.[30] In this study, polishing was performed on all specimens using a two-step Twist Dia polishing kit (Clearfil Twist Dia, Kuraray, Japan) to ensure standardization among the groups

Avunduk et al.[31] polished Crowntec and Clearfil Majesty Esthetic using one-step and multi-step procedures before immersing them in coffee. Although there were statistically significant differences in surface roughness, no significant ΔE differences were observed.

Özer et al.[32] compared the ΔE values of 3D-printed (Crowntec, VarseoSmile) and CAD/CAM (Cerasmart) materials immersed in coffee, tea, and artificial saliva. On day 1, Cerasmart showed lower ΔE values than the 3D-printed resins, but on day 7, the values were 4.87 for Cerasmart, 4.70 for Crowntec, and 6.00 for VarseoSmile. In contrast to the present study, Sof-Lex discs were used for polishing, and samples were immersed continuously, rather than for 45 minutes per day. These factors likely contributed to the differing results.

An ideal resin material should be chemically stable and impermeable to water. Adverse effects include mechanical property degradation, volume changes, discoloration, reduced wear resistance, and hydrolysis at the filler-matrix interface. Prolonged immersion increases water absorption, accelerating color change in both conventional and CAD/CAM materials.[33]

Coffee lowers pH due to its tannic acid and solvent content, increasing surface roughness.[5] The pigments in coffee have low polarity and readily penetrate polymer matrices.[6] These properties contribute to coffee's stronger staining effect compared to other beverages. Therefore, coffee was selected as the staining agent in this study.

Color measurements were made using a spectrophotometer. When properly calibrated before each measurement, the Vita EasyShade spectrophotometer offers high precision and reliability.[34] However, its calibration on opaque surfaces raises concerns about accuracy when measuring translucent resins.[10]

Nagai et al.[35] assessed discoloration in VarseoSmile and Cerasmart immersed in red wine for six months. VarseoSmile showed ΔE values above the clinical threshold, while Cerasmart did not. This discrepancy may be due to the use of a different device (Konica Minolta CM-2600d), which features an integrated light-diffusing sphere that reduces edge scattering.[34]

The CIEDE2000 formula, which refines the traditional CIELab* method, offers improved accuracy in color difference calculation.[7] This formula was used in the present study, with the clinical acceptability threshold set at ΔE <1.8.

In modern digital dentistry, 3D printers and printable resins are increasingly utilized, yet many questions remain regarding their behavior. Although recent studies have examined the discoloration of computer-aided resins, results vary significantly. This is likely due to the many variables affecting the mechanical, physical, and optical properties of 3D-printed dental materials. These include software, printer type, printing parameters, resin type, storage conditions, ambient temperature, washing and post-curing processes, light source, curing duration, and the organic and inorganic composition of the resin. Further research is needed to establish reliable clinical protocols and indications.

Limitations

This study has certain limitations. This study only used a white background to measure colour stability. The prepared coffee solution cannot fully simulate the oral environment. The effects of saliva, smoking, and oral hygiene were not considered. Furthermore, while only the polished surface of restorations is typically exposed in vivo, both surfaces of the samples in this study were immersed, possibly leading to greater discoloration than would occur clinically.

CONCLUSION

Statistically significant differences were observed among the groups on days 1 and 7, where Cerasmart (CS) showed higher color change compared to the other materials. On day 14, intergroup differences persisted, while no significant difference was found on day 30 (>0.05). All materials showed color changes above the clinically acceptable threshold. Clinically, these findings suggest that the choice of material may influence early color stability, and careful selection should be considered during the first weeks after restoration. Further clinical studies are needed to investigate the effects of printer type, post-curing treatments, and polishing on the color stability of 3D printed resin restorations.

ETHICAL DECLARATIONS

Ethics Committee Approval

Our study is a laboratory study. No patients or living tissues were used. Therefore, ethics committee approval is not required.

Informed Consent

Because the study has no study with human and human participants, no written informed consent form was obtained.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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