Evaluation of Color Stability of 3D Printed Resins After Exposure to Various Colorants: an in vitro study

Abstract

Purpose
This study investigates the color stability of four types of 3D printed resins: TempPrint (TP) (GC, Tokyo, Japan), Varseo Smile Teeth (VST) (Bego GmbH, Bremen, Germany), TrinQ (TQ)(Bego), and V-Print(VP) (Voco GmbH, Cuxhaven Germany) when exposed to various colorants over a 30-day period.

Methods
A total of 200 disk-shaped specimens (10 mm × 2 mm) were printed using a DLP printer and exposed to four colorants: wine, Coca-Cola, tea, coffee and distilled water. Color changes were measured at 7, 15, and 30 days and total color differences (ΔE) were calculated.

Results
The results revealed significant discoloration across all resins, with wine and coffee inducing the most pronounced color changes. TP (GC) demonstrated the least discoloration in all solutions, particularly in water and Coca-Cola. VST (Bego) showed the highest degree of discoloration, especially in wine and coffee, with ΔE values reaching 20.54 after 30 days of immersion in coffee. TQ (Bego) and VP (Voco GmbH, Cuxhaven Germany) exhibited intermediate levels of discoloration, with coffee causing the most severe color changes. Statistical analysis indicated significant differences in color stability between the resins, with wine and coffee causing more discoloration.

Clinical significance These findings suggest that while all resins undergo color change when exposed to common beverages, the extent of discoloration varies based on resin composition, highlighting the need for material selection based on expected environmental exposure in practical applications.

Authors

G. Verniani[1,*]
E. Ferrari Cagidiaco[2]
M. Pollis[3]
W. S. Haichal[4]
A. Casucci [5]

[1]DDS, PhD, MSc. Post-doc student, Department of Prosthodontics, University of Siena, 53100 Siena, Italy
[2]DDS, PhD, MSc. Post-doc student, Department of Prosthodontics, University of Siena, 53100 Siena, Italy
[3]DDS. Assistant professor , Orofacial Pain Unit, University of Siena, 53100 Siena, Italy
[4]PhD student, Department of Medical Biotecnologies, University of Siena, 53100 Siena, Italy
[5]DDS, Phd, MSc. Research and senior teaching assistant, Division of Gerodontology and Removable Prosthodontics, University Clinics of Dental Medicine, University of Geneva, Geneva, Switzerland

**corresponding author*

DOI

10.23805/JO.2025.724

Keywords

prosthodontics, 3d printing, addictive manufacturing, color stability, discoloration.

INTRODUCTION

In the field of prosthodontics, 3D printing has been used to produce master casts, interim restoration, removable dentures, and custom trays (1-3). Today, the integration of 3D printing techniques is becoming more profound, thanks to the production of new materials with different fillings. 3D printed materials have been used mainly for interim restoration or medium-term use but lately have been propose for long term use since their improved mechanical properties (4-7). In fact, the presence of nanofillers inside the resin formulation have demonstrated to improve flexural strength values and wear resistance (8,9). The characteristics of the co-monomers involved will determine the hydrophilicity, mobility and kinetic parameters as well as optical and aesthetic properties of the future restoration (10-13). When used for dental restorations, particularly in the anterior region , where appearance is crucial, special attention is given to its natural look (14-16). It is important to consider the potential for discoloration over time, especially from common beverages like wine, tea or coffee, before choosing the restoration material (17). The discoloration can result from a combination of internal and external factors, including the absorption of water, the accumulation of surface stains, and the chemical composition of the resin itself (18). Moreover, restorations must be resistant to discoloration by external factors such as food, beverages and smoke (15). Recent studies have highlighted inferior color stability in 3D-printed materials compared to CAD/CAM milled ones (19-21). After just 7 days of storage, 3D-printed resins exhibited color differences exceeding the clinical threshold (2.25) across all experimental groups (22). Shin et al. (2020) (23) reported significantly higher color differences in all 3D-printed resins (22.85–4.74) compared to CAD/CAM milled blocks (0.64–4.12) after 30 days of immersion in grape juice, curry, or coffee. Similarly, a study by Song et al. (22) observed high ΔE values in 3D-printed materials after 8 weeks of exposure to coffee or black tea. In dental research, the CIELAB system is the most commonly used to evaluate color changes of materials. This system utilizes three axes to define colors: L, representing lightness (ranging from L=0 for black to L=100 for white); a, indicating the green (a<0) to red (a>0) spectrum; and b, denoting the blue (b<0) to yellow (b>0) spectrum. The CIEDE2000 color difference formula, derived from these coordinates, has been extensively applied in recent studies to assess color changes in dental materials and tooth structures (24).
In most of the previous studies reported, only one or two 3D printed temporary resins are compared to milled materials or conventional polymers for temporary restorations, without focusing on the difference between color resistance of 3d printed materials and their chemical composition. The aim of this in vitro study is to evaluate color stability of four different 3D printed resins after different time exposure until 1 month of immersion in different solutions. The null hypothesis are:
there is not statistically significative difference between the four 3D printed materials in color stability
there is not any statistically significative difference in ΔE between the four different solutions at 7, 15 or 30 days

METHODS

A total of 200 disk-shaped specimens, (10 mm x 2 mm) were prepared following ADA No.12 [25] using a CAD software MESHMIXER 3.5 (Autodesk, USA) and the generated Standard Tessellation Language (STL) file was exported. 4 different 3D printed resins available on the market were selected for this study. The Samples were divided in 4 groups (50 samples per group) according to the 3d printing resin material used: as reported in Table 1. A single experienced lab technician realized all the samples for this study. The STL file was sent to the DLP printer Asiga MAX UV (wavelength = 385, pixel resolution = 62) and printed at a 0◦ build orientation.
For all the samples the printing process was the same following instruction of manufacturers. After the printing process, the specimens were cleaned with Liquidtech BT for 20 min using a wash machine (Meccatronicore S.R.L., Pergine Valsugana, Italy) and then polymerized for 40 min using a cure machine (Model MTC-BB-CURE-COMPACT, Meccatronicore S.R.L.). After the curing procedure was finished, a slow-speed rotary tool was employed to eliminate any excess of material and the support structures of the specimen. All specimens were then polished using 600-grit sandpaper and measured with a digital caliper accurate to ±0.02 mm.
The colorants used in this study included Wine (Castellare, Siena, Italy), Coca Cola (The Coca-Cola Company, Georgia, USA), Tea (Lipton, Unilever Korea Co., Ltd., Seoul, Korea), coffee (Illy instant coffee, illy caffè S.p.A, Italy) and distilled water (used as the control group). The coffee solution was prepared by dissolving 11.7 g of coffee powder in 200 mL of warm water. Tea was prepared by placing one tea bag (Lipton, Unilever Korea Co., Ltd., Seoul, Korea) in 500 cc of boiling water for 15 minutes. Distilled water, Coca Cola and Wine were used as provided. All specimens were kept in distilled water for 24 hours prior to immersion. 10 specimens of each of the 4 materials were tested with each solution. All specimens were immersed in the prepared colorants and stored for 30 days in a 37°C incubator (JSR incubator JSGI-150T, Gongju, Korea) under dark conditions.
Color measurements were taken using a colorimeter

Name	Manufacturer	Material	Batch n°
VST	BEGO (Bego GmbH, Bremen, Germany)	4,4-Isopropylidenediphenol, ethoxylated 2-methylprop-2enoic acid. Silanized dental glass, methyl benzoylformate, diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide. Inorganic fillers (particle size 0.7)30-50% of the mass.	600850
VP c&b temp	VOCO (Voco GmbH, Cuxhaven Germany)	UDMA Bis-EMA TEGDMA 50-100% 25-50% 5-10%	6898
TQ	BEGO (Bego GmbH, Bremen, Germany)	4,4-Isopropylidenediphenol, ethoxylated 2-methylprop-2enoic acid, Benzeneacetic acid, alpha. -oxo-, methyl ester; diphenyl(2,4,6-trimethylbenzoyl) phosphine oxide.	600,851
TP	GC (GC, Tokyo, Japan)	Urethane dimethacrylate (UDMA) dimethacrylate component quartz (SiO2) photoinitiator synergist UV-light absorber.	2212091

Table 1. 3D printable resins tested

Resin	Liquid	ΔEt1	ΔEt2	ΔEt3
		mean ± std	mean ± std	mean ± std
TP (GC)	Water Wine Coca Cola Thè Coffe	1.92 ±1.55 10.01 ±4.10 2.26 ±1.73 8.64 ±4.16 11.28 ±4.02	1.70 ±1.42 17.14 ±4.81 1.89 ±1.38 8.58 ±3.85 14.40 ±5.69	1.91 ±1.02 16.64 ±5.22 1.95 ±0.86 10.44 ±3.91 16.55 ±4.16
VST(Bego)	Water Wine Coca Cola Thè Coffe	3.36 ±0.99 8.12±4.54 1.52 ±1.12 9.90 ±2.46 14.09 ±3.84	3.33 ±0.58 21.68 ±3.97 2.63 ±4.98 10.71 ±2.35 16.02 ±3.83	4.72 ±2.07 15.95 ±6.06 4.13 ±0.74 16.98 ±2.19 20.54 ±7.11
TQ (Bego)	Water Wine Coca Cola Thè Coffe	1.55 ±2.89 9.97 ±3.70 1.14 ±1.14 8.49 ±2.32 10.92 ±5.16	1.65 ±3.03 20.96 ±4.09 1.27 ±0.98 9.31 ±2.55 13.30 ±3.13	2.04 ±3.15 17.44 ±5.12 2.07 ±2.58 11.76 ±2.37 15.04 ±4.37
VP (Voco)	Water Wine Coca Cola Thè Coffe	3.59 ±1.41 11.48 ±2.59 1.49 ±1.29 9.78 ±2.41 11.37 ±2.49	3.47 ±1.32 20.55 ±3.23 1.27 ±0.90 11.40 ±4.14 15.84 ±4.62	2.98 ±1.21 15.21 ±3.58 2.39 ±0.99 11.00 ±3.13 17.81 ±5.39

Table 2. Mean ΔE values and their standard deviations are reported for each solution at each time point.

(ColorReader CR2, 3Nh, Guangzhou, China) with baseline color assessments conducted prior to immersion. Color values were recorded at 7, 15 and 30 days after storage in the colorants. The L, a, and b values of the specimens after immersion in distilled water for one day served as the control. The L* value reflects the brightness of an object, while a* indicates the color spectrum from red to green, and b* represents the spectrum from yellow to blue. The results were recorded as ΔL, Δa, and Δb values calculated using the following formulas, and the total color difference, ΔE, was computed with the formula provided:

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

Statistical analysis

SPSS version22.0 (IBM, Armonk, NY, USA) (*P* = .05) was used to perform all statistical tests. The data of color stability test were conducted with nonparametric analysis using Kruskal-Wallis test and Mann-Whitney U-test because these data were partially content with the normality.

RESULTS

The ΔE values or degree of discoloration after 7,14 or 30 days of storage in the different solutions are presented in Table 2.

In general, water caused low values of color changes across all materials, with TP (GC) showing the lowest ΔE values (1.92 ± 1.55 at 7 days, 1.70 ± 1.42 at 15 days, and 1.91 ± 1.02 at 30 days). When immersed in wine, TP(GC) exhibited a significant increase in color change over time, with ΔE values of 10.01 ± 4.10 at 7 days, 17.14 ± 4.81 at 15 days, and 16.64 ± 5.22 at 30 days. Similarly, VST (Bego)demonstrated notable discoloration, particularly after 15 and 30 days (21.68 ± 3.97 and 15.95 ± 6.06, respectively). TQ (Bego) and VP (Voco) also showed considerable discoloration, with TQ (Bego) reaching ΔE values of 9.97 ± 3.70 at 7 days, 20.96 ± 4.09 at 15 days, and 17.44 ± 5.12 at 30 days, while VP (Voco) had values of 11.48 ± 2.59 at 7 days, 20.55 ± 3.23 at 15 days, and 15.21 ± 3.58 at 30 days. For Coca-Cola, TP (GC) and TQ (Bego) showed minimal discoloration, with ΔE values below 3 at all time points. In tea, TP (GC) showed moderate discoloration, with ΔE values of 8.64 ± 4.16 at 7 days, 8.58 ± 3.85 at 15 days, and 10.44 ± 3.91 at 30 days. VST(Bego) demonstrated higher color change, with ΔE values increasing from 9.90 ± 2.46 at 7 days to 16.98 ± 2.19 at 30 days. TQ (Bego) exhibited similar trends, with values of 8.49 ± 2.32 at 7 days, 9.31 ± 2.55 at 15 days, and 11.76 ± 2.37 at 30 days. VP (Voco) showed a gradual increase in color change with ΔE values of 9.78 ± 2.41 at 7 days, 11.40 ± 4.14 at 15 days, and 11.00 ± 3.13 at 30 days. For coffee, the most significant discoloration was observed in all resins, particularly in VST(Bego). Post-hoc analysis using the Mann-Whitney U-test indicated that coffee and wine caused significantly more discoloration than water and Coca-Cola for all resins tested. Significant variations in discoloration were observed across different resins, with VST(Bego) and VP (Voco) generally showing more pronounced color changes compared to Temp Print (GC) and TQ (Bego).

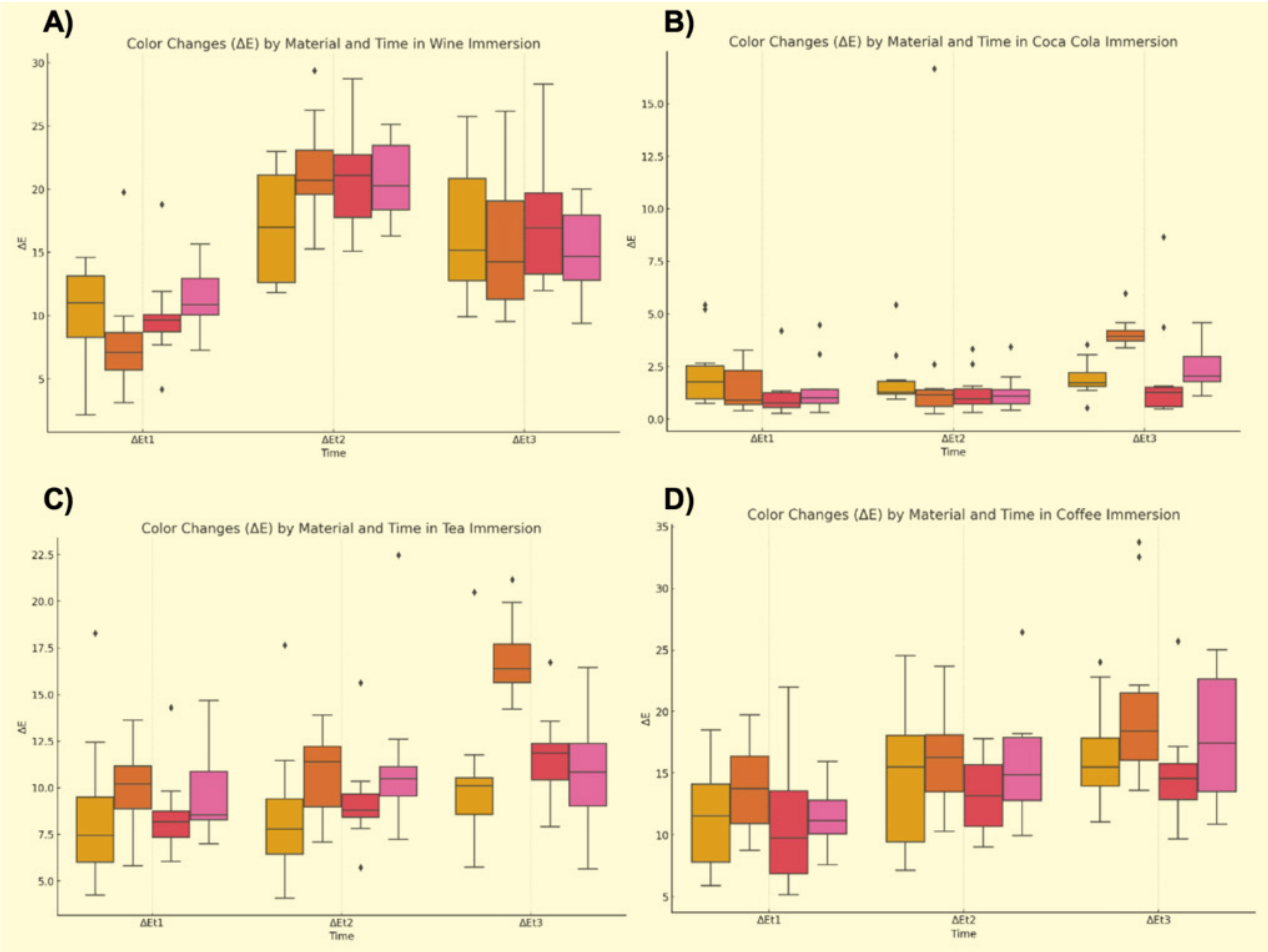
Wine caused significant discoloration across all resins as reported in Graph 1A. VST(Bego) exhibited the greatest overall discoloration in wine, particularly after 15 and 30 days. While TP (GC) showed moderately lower color changing at 30 days. Coca-Cola produced relatively minor discoloration compared to wine and coffee, but there were still notable differences between the resins. TP (GC) exhibited the least discoloration in Coca-Cola followed by TQ (Bego) .VST(Bego) and VP (Voco) experienced more noticeable changes, with VST (Bego). Tea produced moderate discoloration in all resins as reported in Grap 1 C, with the highest ΔE values observed in VST (Bego). Temp Print (GC) showed moderate discoloration, with values similar to TQ (Bego). VP (Voco) also demonstrated considerable discoloration in tea. Coffee caused the most significant discoloration across all resins as shown in Graph 1D, with VST (Bego) showing the highest ΔE values. TP (GC) also exhibited considerable color change , while TQ (Bego) and VP (Voco) showed significant but slightly lower discoloration in coffee.

DISCUSSION

In the present study, the aim was to ass the color changes of 4 different types of 3D printed materials after 30 days of immersion in different solutions. Statistically significative differences were found between the 4 tested 3D printable materials and different solutions thus the null hypotheses were rejected.

VST (Bego) exhibited the highest susceptibility to discoloration, especially in coffee and wine, with maximum ΔE values of 20.54 and 21.68, respectively. These results suggest that this material may be less suitable for clinical scenarios where frequent exposure to staining substances is expected. TP (GC) showed moderate discoloration, with lower ΔE values compared to VST (Bego), particularly in tea and wine. This indicates better resistance than VST but not complete immunity to color changes. TQ (Bego) and VP (Voco) displayed significant but slightly lower discoloration compared to VST, particularly in coffee.

The most aggressive liquids for discoloration were wine and coffee. Previous research indicates that immersing restorations in coffee for one week in vitro can yield results comparable to seven months of exposure in vivo (26,27). In this study the specimens were immersed in the solutions for 30 days which is roughly equivalent to 2.5 years of exposure in the oral cavity simulating long-term color changes (28). Distilled water caused minimal color changes, confirming its role as a neutral control solution. Tea and Coca-Cola had intermediate effects on color changes, depending on the material tested. The higher ΔE values that were observed after immersion of the specimens in wine probably due to the fact that wine's acidic nature, combined with its chromogenic potential, likely exacerbates staining by degrading the surface of the restoration and allowing pigments to penetrate in the material (29). Acidic environments not only cause overall color changes but also impact the intensity of the color, especially in composites with specific filler compositions. Nanofillers have been shown to improve surface smoothness and abrasion resistance, thereby enhancing both the aesthetic



Graph 1. Color changes by material and time in different solution A:wine; B:Coca Cola; C:Tea; D:Coffe ; yellow: TP, orange: VSP, red:TQ, pink:VP

durability and mechanical strength of restorations (30). In particular, the addition of glass silica and zirconia nanoparticle demonstrated to improve the flexural strength of 3D-printed resin, and it could be speculated that these nanofillers have a positive influence on discoloration resistance since the results obtained by TP (GC).

This in vitro study has limitations. All specimens were printed at a 0° orientation, however, the influence of the printing angle on color and translucency should be explored further.[31] A standardized protocol for washing and curing was used in this study, but future investigations could assess the impact of different. To validate the clinical use of the tested materials, additional tests are needed, such as dimensional stability, surface hardness, and impact resistance evaluations. These tests would complement the findings on color stability by providing a more comprehensive assessment of the long-term performance of the materials.

CONCLUSIONS

This study highlights significant differences in discoloration resistance among the tested 3D printable materials. The findings suggest that materials with nanofillers, like Temp Print, may provide improved aesthetic and mechanical properties, making them more suitable for clinical use in challenging environments. These findings emphasize the importance of selecting resin materials based on their exposure to staining agents in practical applications.

Future research should further investigate the impact of resin composition and curing methods on long-term color stability. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Kihara H, Sugawara S, Yokota J, Takafuji K, Fukazawa S, Tamada A, Hatakeyama W, Kondo H. Applications of three-dimensional printers in prosthetic dentistry. J Oral Sci. 2021;63:212–216. https://doi.org/10.2334/josnusd.21-0072.
2. Schweiger J, Edelhoff D, Güth JF. 3D Printing in Digital Prosthetic Dentistry: An Overview of Recent Developments in Additive Manufacturing. J Clin Med. 2021;10:2010. https://doi.org/10.3390/jcm10092010.
3. Balestra D, Lowther M, Goracci C, Mandurino M, Cortili S, Paolone G, Louca C, Vichi A. 3D Printed Materials for Permanent Restorations in Indirect Restorative and Prosthetic Dentistry: A Critical Review of the Literature. Materials. 2024;17:1380. https://doi.org/10.3390/ma17061380.
4. Cerbino V, Verniani G, Bonadeo G, Ferrari Cagidiaco E. Dimensional stability of 3D-printed fixed prosthetic restorations. J Osseointegr. 2022;15:79–86.
5. Tahayeri A, Morgan M, Fugolin AP, Bompolaki D, Athirasala A, Pfeifer CS, Ferracane JL, Bertassoni LE. 3D printed versus conventionally cured provisional crown and bridge dental materials. Dent Mater. 2018;34:192–200. https://doi.org/10.1016/j.dental.2017.10.003.
6. Verniani G, Casucci A, Val M, Ruggiero G, Manfredini D, Ferrari M, Ferrari Cagidiaco E. A Randomized Controlled Clinical Trial on Press, Block Lithium Disilicate, and 3D Printed Partial Crowns in Posterior Teeth: One-Year Recall. Prosthesis. 2024;6:887-895. https://doi.org/10.3390/prosthesis6040064.
7. Hobbi P, Ordueri TM, Öztürk-Bozkurt F, Toz-Akalın T, Ateş M, Özcan M. 3D-printed resin composite posterior fixed dental prosthesis: a prospective clinical trial up to 1 year. Front Dent Med. 2024;5:1390600. https://doi.org/10.3389/fdmed.2024.1390600.
8. Casucci A, Verniani G, Barbieri AL, Ricci NM, Ferrari Cagidiaco E, Ferrari M. Flexural Strength Analysis of Different Complete Denture Resin-Based Materials Obtained by Conventional and Digital Manufacturing. Materials. 2023;16:6559. https://doi.org/10.3390/ma16196559.
9. Alzahrani SJ, Hajjaj MS, Azhari AA, Ahmed WM, Yeslam HE, Carvalho RM. Mechanical Properties of Three-Dimensional Printed Provisional Resin Materials for Crown and Fixed Dental Prosthesis: A Systematic Review. Bioengineering. 2023;10:663. https://doi.org/10.3390/bioengineering10060663.
10. Asmussen E, Peutzfeldt A. Influence of UEDMA, BisGMA and TEGDMA on selected mechanical properties of experimental resin composites. Dent Mater. 1998;14:51–56. https://doi.org/10.1016/s0109-5641(98)00009-8.
11. Cook WD, Moopnar M. Influence of chemical structure on the fracture behaviour of dimethacrylate composite resins. Biomaterials. 1990;11:272–276. https://doi.org/10.1016/0142-9612(90)90009-f.
12. Mangal U, Seo JY, Yu J, Kwon JS, Choi SH. Incorporating Aminated Nanodiamonds to Improve the Mechanical Properties of 3D-Printed Resin-Based Biomedical Appliances. Nanomaterials. 2020;10:827. https://doi.org/10.3390/nano10050827.
13. Majeed HF, Hamad TI, Bairam LR. Enhancing 3D-printed denture base resins: A review of material innovations. Sci Prog 2024;107:368504241263484. https://doi.org/10.1177/00368504241263484.
14. Aydın N, Karaoğlanoğlu S, Oktay EA, Kılıçarslan MA. Investigating the color changes on resin-based CAD/CAM Blocks. J Esthet Restor Dent. 2020;32:251–256.
15. Ergücü Z, Türkün LS, Aladag A. Color stability of nanocomposites polished with one-step systems. Oper Dent. 2008;33:413–420.
16. Shishehian A, Firouz F, Khazaee S, Rajabi H, Farhadian M, Niaghiha F. Evaluating the color stability of 3D-printed resins against various solutions. Eur J Transl Myol. 2023;33:11493. https://doi.org/10.4081/ejtm.2023.11493.
17. Kim JE, Choi WH, Lee D, et al. Color and translucency stability of three-dimensional printable dental materials for crown and bridge restorations. Materials. 2021;14:650.
18. Menon A, Ganapathy DM, Mallikarjuna AV. Factors that influence the colour stability of composite resins. Drug Invent Today. 2019;11:3.
19. Revilla-Leon M, Umorin M, Özcan M, Piedra-Cascon W. Color dimensions of additive manufactured interim restorative dental material. J Prosthet Dent. 2020;123:754–760.
20. Krajangta N, Klaisiri A, Leelaponglit S, Intralawan N, Tiansuwan P, Pisethsalasai N. Color alteration of CAD/CAM 3D-printed, milled resin-ceramic hybrid material compared to enamel. Dent Mater J. 2024;43(3):386-393. https://doi.org/10.4012/dmj.2023-275.
21. Atria PJ, Lagos I, Sampaio CS. In vitro evaluation of surface roughness, color stability, and color masking of provisional restoration materials for veneers and crowns. Int J Comput Dent. 2020;23:343–350.
22. Song SY, Shin YH, Lee JY, Shin SW. Color stability of provisional restorative materials with different fabrication methods. J Adv Prosthodont. 2020;12:259–264. https://doi.org/10.4047/jap.2020.12.5.259.
23. Shin JW, Kim JE, Choi YJ, et al. Evaluation of the Color Stability of 3D-Printed Crown and Bridge Materials against Various Sources of Discoloration: An In Vitro Study. Materials. 2020;13:5359. https://doi.org/10.3390/ma13235359.
24. Luo MR, Cui G, Rigg B. The development of the CIE 2000 colour-difference formula: CIEDE2000. Color Res Appl. 2001;26:340–350. https://doi.org/10.1002/col.1049.
25. Swaney AC, Paffenbarger GC, Caul HJ, Sweeney WT. American Dental Association specification No. 12 for denture base resin: second revision. J Am Dent Assoc. 1953;46:54–66.
26. Intralawan N, Wasanapiarnpong T, Didron PP, Rakmanee T, Klaisiri A, Krajangta N. Surface discoloration of 3D printed resin–ceramic hybrid materials against various stain beverages. J Int Dent Med Res. 2022;15:1465–1471.
27. Elsaka S, Taibah S, Elnaghy A. Effect of staining beverages and bleaching on optical properties of a CAD/CAM nanohybrid and nanoceramic restorative material. BMC Oral Health. 2022;22:96.
28. Neppelenbroek KH, Kuroishi E, Hotta J, Marques VR, Moffa EB, Soares S, et al. Surface properties of multilayered, acrylic resin artificial teeth after immersion in staining beverages. J Appl Oral Sci 2015; 23: 376–382.
29. Chakravarthy Y, Clarence S. The effect of red wine on colour stability of three different types of esthetic restorative materials: An in vitro study. J Conserv Dent 2018; 21: 319–323.
30. Qaiser S, Devadiga D, Hegde MN. Esthetic rehabilitation with nanohybrid composite: case report series. J Adv Oral Res 2020; 11: 251–256.
31. Espinar C, Della Bona A, Tejada-Casado M, Pulgar R, Pérez MM. Optical behavior of 3D-printed dental restorative resins: influence of thickness and printing angle. Dent Mater 2023; 39: 1429–1436.