The Effect of Extrinsic Staining on 3D Printed Provisional Crowns

by

Abdullah Marafi

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This thesis was presented by

Abdullah Marafi

It was defended on

November 1, 2023

and approved by

Thomas Kunkel, DMD, Chair and Residency Program Director, Assistant Professor, Department of Prosthodontics

Samantha Manna, PhD, Assistant Professor, Department of Oral and Craniofacial Sciences

Mohsen Azarbal DMD, MDS, Associate Professor, Department of Prosthodontics

Thesis Advisor: Stavroula Antonopoulou, DDS, MS, Assistant Professor, Graduate Department of Prosthodontics

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Abdullah Marafi, DDS

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Objectives: The aim of this study was to evaluate the color stability of 3D printed resin disks using spectral reflectance data obtained at different time periods after immersion in staining solution.

Methods: Forty identical round disk specimens measuring 10 mm in diameter and 2 mm in thickness were fabricated using CAD/CAM 3D printing resin (shade B1). Half of the specimens (n=20) were polished using an acrylic bur and medium pumice. The other half was left unpolished (n=20). Each group of disks was then immersed in one of the following immersion solutions : artificial saliva, black tea, carrot juice, and red wine. Color difference ΔE was evaluated using a spectral reflectance instrument known as spectrophotometer at baseline, day 1, week 1, week 2 and week 3, against a white background.

Results: Color difference ΔE was measured using CIELAB formula. The mean ΔE values of each group were calculated. The greatest difference in color was observed in the unpolished and polished disks immersed in red wine. Polished disks showed less color difference when compared to unpolished disks. Significant differences in ΔE were detected between polished and non-polished disks immersed in red wine at week 1 ($p = 0.0159$), week 2 ($p = 0.0079$) and week 3 ($p = 0.0079$) and in carrot juice at week 3 ($p = 0.0317$).

Conclusion: Immersion in different staining solutions caused detectable color difference in the tested materials which was relative to the immersion duration and the staining solution used.

The color of the 3D printing resins is influenced by the surface finishing, which may result in visually perceptible color differences. The color stability of 3D printing material should be improved to manufacture oral appliances which provide long-term esthetics.

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Preface

I would like to extend my gratitude to all the committee members whose invaluable insights and constructive feedback have been instrumental in shaping this research. I would also like to acknowledge the Department of Prosthodontics at the University of Pittsburgh for providing the essential materials and machinery required for the successful execution of this research.

1.0 Introduction

Provisional crowns play a crucial role in preserving the integrity of the remaining teeth structure following various dental procedures such as root canal therapy or crown preparations.[1] These temporary crowns not only protect the underlying tooth from further damage and sensitivity, but also maintain proper occlusion and esthetics until the final restoration can be placed.[2] The use of provisional crowns ensures comfort and appropriate masticatory function while allowing for the evaluation of the tooth before the placement of a permanent restoration.[3]

The high esthetic expectations of patients and their frequent complaints regarding color harmonizing issues have resulted in a rise in cosmetic dental procedures. This is especially important when diets incorporate beverages such as wine, coffee, tea, and soft drinks. In fixed prosthodontics, several visits may be necessary to complete a treatment plan. Interim restorations, whether for a complete mouth rehabilitation or a single restored tooth, must ensure high color stability. Patients expect their dental restorations to resemble their natural teeth and match in color. This need encourages an ongoing development of dental materials with improved color stability.[4]

A cemented provisional resin crown will continuously interact with the oral environment, subjected to saliva and the diet of a patient. High color stability of the material used ensured longevity of the restoration.[5,6] Techniques vary regarding the means of fabrication of a provisional full coverage crown. There is a plethora of interim fixed restorative materials on the market, each with its specific indications, needs and workflow. One of the commonly used interim materials in dentistry is polymethyl methacrylate (PMMA), developed in 1940.[7] This conventional approach has various disadvantages, including polymerization shrinkage, marginal inconsistencies, and excessive heat created during the process. To prevent this, an indirect method employing computer-aided design/computer-aided manufacturing (CAD/CAM) technique has been developed.[8] A study by Bindl and Mörmann in the early 2000's demonstrated the clinical reliability and accuracy of CAD/CAM-fabricated restorations.[9] The evolution of CAD/CAM technology, as highlighted in an article by Sailer et al. has led to enhanced precision, efficiency, and esthetics in various dental applications, ranging from single crowns to complex bridges and even orthodontic appliances.[10]

The production of temporary dental crowns through CAD/CAM techniques can be achieved using either additive or subtractive methods, each with distinct advantages and limitations. Additive manufacturing, commonly known as 3D printing, involves layer-by-layer deposition of material to build the crown. This approach, as highlighted in articles by Joda et al. offers design flexibility, reduced material waste, and the ability to create complex geometries.[11] However, challenges exist in achieving the same level of mechanical properties and accuracy as traditional methods. On the other hand, subtractive methods involving milling of the crown from a solid block of material showcase high precision and excellent mechanical properties.[12]

The color stability of 3D printed dental resin crowns has garnered attention in comparison to conventional PMMA temporary crowns due to their distinct material properties. Research by Alharbi et al. demonstrates that certain 3D printed resin materials exhibit improved color stability over time when compared to conventional PMMA.[13] In this study, the aim was to evaluate the color stability of 3D printed resin composed primarily of methacrylate monomers and diurethane dimethacrylate and to determine the effect of polishing the same printed resin on color stability.

2.0 Specific Aims

Aim 1: To evaluate the color stability of 3D printed resin subjected to common staining solutions over time.

Aim 2: To determine the effect of polishing 3D printed resin on its color stability.

3.0 Material and Methods

3.1 Designing and printing

In the present investigation, the color stability of a printable resin immersed in various solutions was evaluated. Dentca Crown and Bridge (Dentca, Inc, Torracce, CA, USA) shade B1 was selected. This resin is composed of a mixture that includes methacrylate monomer (40-60%), diurethane dimethacrylate (30-50%), trimethylolpropane trimethacrylate (3-10%), initiator (< 3%), pigment (< 0.7%) and a stabilizer (<1%). Resin disks were designed using CAD software Meshmixer (Autodesk, San Rafael, CA, USA) to the following specifications: 2 mm thick and 10 mm in diameter at a 45-degree printing angle. Supporting struts were automatically added through the software. A Standard Tessellation Language (STL) file was created, which contains the digital 3D model format. The file was then sent to the corresponding RayWare (SprintRay Inc, Los Angeles, CA, USA) software to facilitate printing through SprintRay Pro 95 S (SprintRay Inc, Los Angeles, CA, USA) (Figure 1). Instructions from the manufacturer were followed for the specific corresponding third-party resin used. The printer utilizes Digital Light Processing (DLP) optical technology. A projector selectively emits light at an intensity of 23 mW/cm^2 to cure the image of a single layer in 50 microns increment. The build platform was then removed and placed in the ProWash (SprintRay Inc, Los Angeles, CA, USA) washing unit containing Isopropyl alcohol 91% for 10 minutes. All the disks were removed from the build platform using a spatula provided by SprintRay, and left in ProCure 2 (SprintRay Inc, Los Angeles, CA, USA) curing unit for the suggested 5 minutes. This machine uses a patented Light Motion Drive UV LED system, emitting light at a 385 nm wavelength.

3.2 Specimen grouping and solution selection

After finalizing the post processing steps, the disks (n=40) were divided into two equal groups. One group was polished the other group was non-polished. The fabrication of non-polished disks was completed following post-process curing. The workflow to polish the disks started by using a 3-step polishing kit by Komet Dental. The specimens were initially polished with coarse, followed by medium and finished with the fine acrylic bur, at an optimal speed of 6000 rpm. Then, a dental lathe machine (Baldor 340 Dental lathe, Ohio, USA) was used to pumice the same set of specimens under slow speed setting using a medium grit pumice (Miltex Inc., York, PA, USA) that was mixed with tap water to the desired consistency. Each individual disk was polished with the use a of rag wheel (Buffalo Dental Manufacturing Co. Inc., Syosset, NY, USA) for approximately 20 seconds each.

For each disk, a one-ounce medicine cup was numbered according to the immersion solution. Each medicine cup was filled with half an ounce of one of the corresponding immersion solutions: artificial saliva (AS), carrot juice (C), red wine (RW), or black tea (BT) (Table 1).

3.3 Color Space

Color stability was assessed using the CIELAB (L*a*b*) color space. The color space was created by the Commission Internationale de l'Eclairage (CIE) in 1976 and describes differences in color perception based on human vision.[14] Coordinates in the color space that correspond to the lightness of the color (L^*) range from 0 (black) to 100 (white). The a^* axis represents the two colors green as (–) values and magenta as (+) values. On the intersecting axis, b^* represents blue with (-) values and yellow as (+) values.[15] The color difference, ΔE^*_{ab} between two colors is evaluated using the Euclidean distance equation between the coordinates of each color in space:[16]

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

ΔE^*_{ab} has the benefit of expressing color difference in units that could be related to visual perception and have clinical advantage. Based on recommendations from the International Organization for Standardization article on guidance in color measurements in dentistry (ISO/TR 28642), it was suggested that the CIELAB perceptibility threshold (PT) is at $\Delta E^*_{ab} = 1.2$, and the acceptability threshold (AT) at $\Delta E^*_{ab} = 2.7$. A ΔE^*_{ab} of 3.3 or above is considered to be clinically unacceptable.[17] [18]

3.4 Data Collection

Color values were measured using a digital spectrophotometer (Vita Easyshade V, Bad Sackingen, Germany) at five different time points: baseline, day 1, week 1, week 2 and week 3. The spectrophotometer was calibrated for each use. Readings were made over a white background uniformly. The control color values were taken at baseline before immersion of the disks in the solutions. The solutions were replaced weekly, while being stored at room temperature. Disks were run under tap water for 10 seconds to remove any excess solution, then dried using a 2x2 gauze. Following the Commission Internationale d'Eclairage (CIE) L*a*b* system, values for L*, a* and b* were recorded. The ΔE^*_{ab} values for disks in each staining solution was calculated in Microsoft Excel using the Euclidean equation.

3.5 Statistical Analysis

Comparisons between polished and non-polished disks at each time point were made using Mann-Whitney tests. Comparisons among staining solutions at each time point for both polished and non-polished disks were made using a one-way ANOVA with Tukey's post hoc test. Statistical significance was set to $p < 0.05$ for all tests. All statistical analyses and visualizations were performed in GraphPad Prism for MacOS (Version 10.0.3, GraphPad Software, Boston, Massachusetts USA).

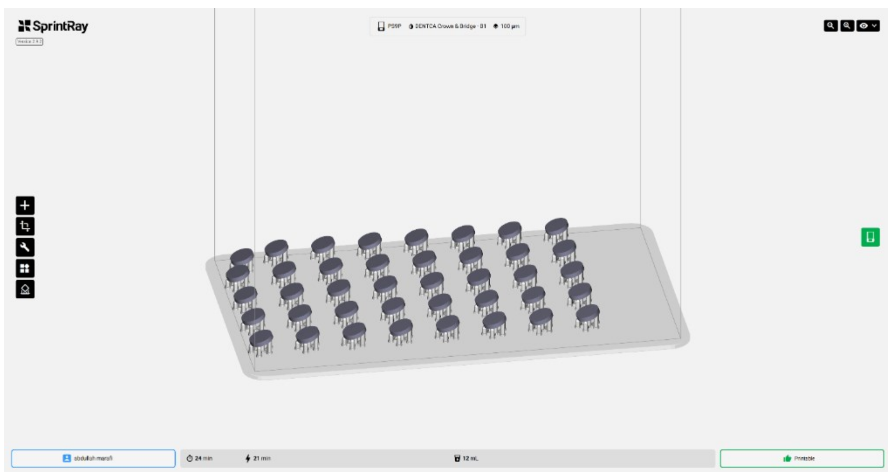

Figure 1. CAD design for disks specimens in SprintRay software.

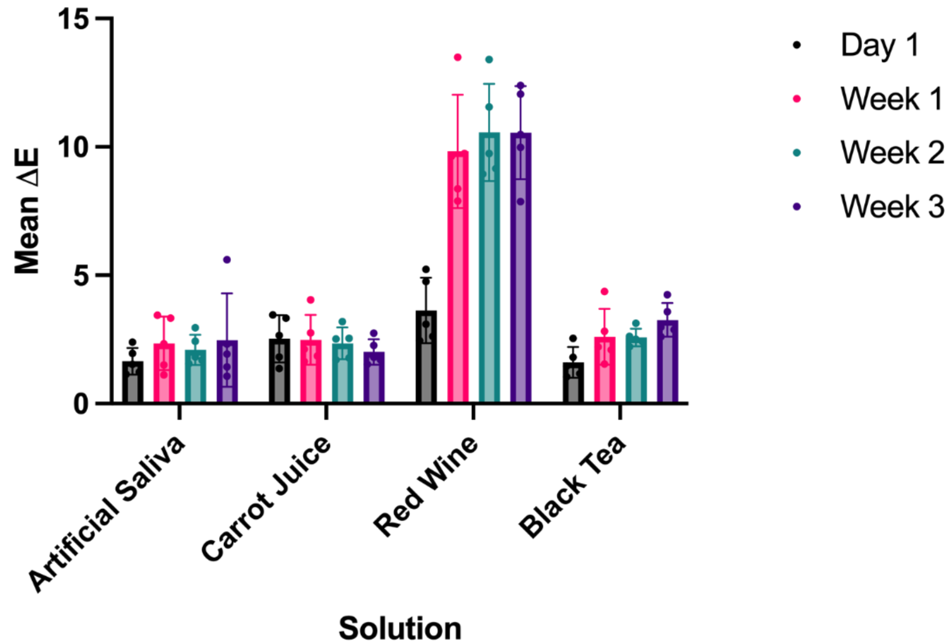

Figure 2. Mean color difference of polished disks.

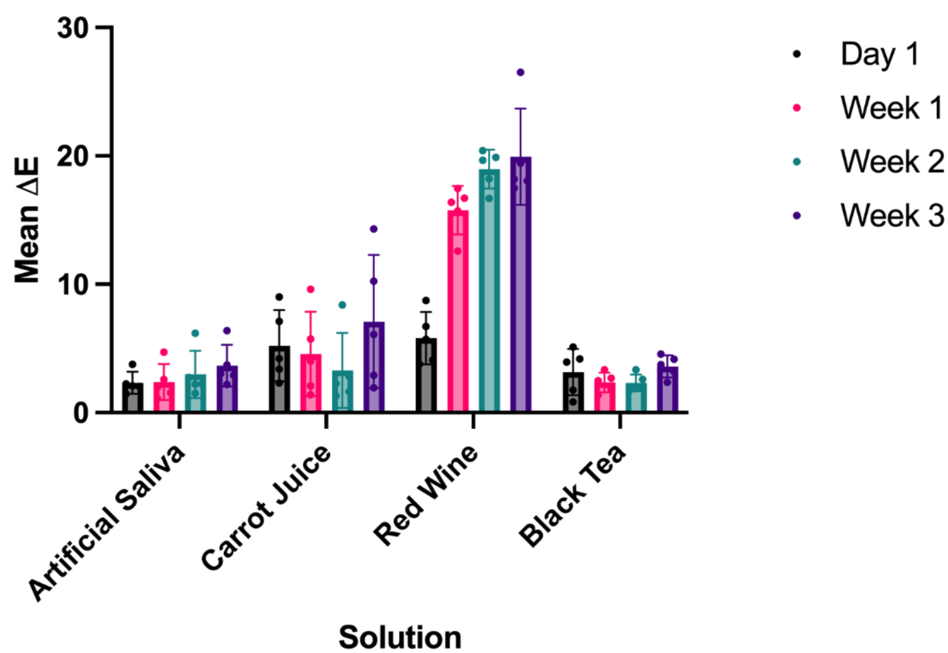

Figure 3. Mean color difference of non-polished disks.

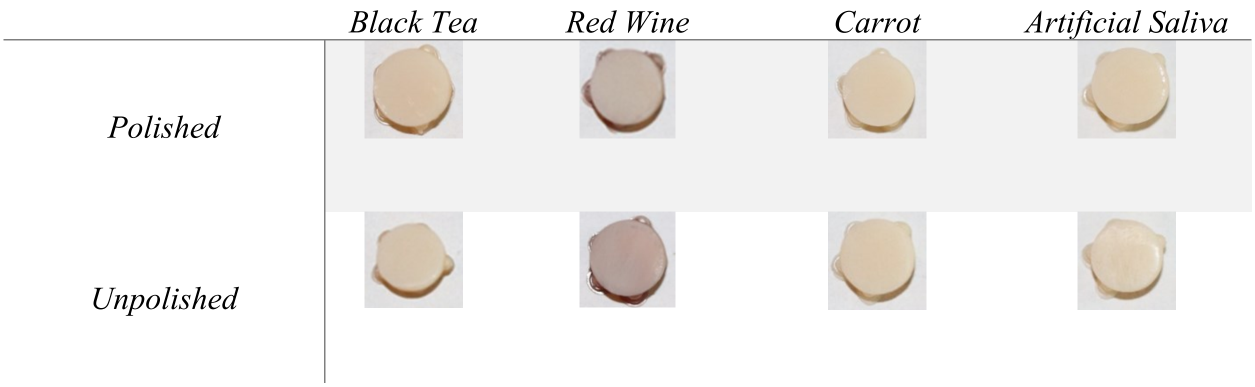

Figure 4. Visual representation of resin disks after 3 weeks in their corresponding solutions.

4.0 Results

Figure 4. presents visual color differences of the 3D printed resin disk after 3 weeks of solution storage. Means and standard deviations of all tested groups are shown in Table 2. Significant differences in ΔE were detected between polished and non-polished disks immersed in red wine at week 1 $p = 0.0159$, week 2 $p = 0.0079$, week 3 $p = 0.0079$ and in carrot juice at week 3 $p = 0.0317$ (Table 2.). At day 1, non-polished disks immersed in red wine showed the greatest mean color difference ΔE= 5.8. Similarly, on week 1, non-polished disks showed an average of ΔE= 15.7 compared to ΔE= 9.8 for polished disks. The ΔE values have exhibited a notable increase across the table, indicating a significant shift in color change within the tested samples (Figure 2.) (Figure 3.). The increase was mainly prominent in red wine and carrot juice samples. Artificial saliva and black tea showed the least color difference. Significant differences among staining solutions were found in mean ΔE at each time interval for both polished and unpolished disks except for the non-polished disks at day 1. Tukey's multiple comparisons test indicated significant differences in the mean ΔE between disks in red wine and each of the other solutions, while no other significant differences were found between artificial saliva and carrot juice, carrot juice and black tea, or black tea and artificial saliva at any time point (Table 3).

Table 1. Staining solutions used for disk immersion.

Staining Solution	*pH*	*Manufacturer*
Artificial Saliva	6.8	Artificial Saliva, Biochemazone, Chemazone INC, Canada
Black Tea	5.2	Pure Leaf Iced Tea, PespsiCo, Purchase, New York
Carrot Juice	6	Bolthouse Farms, Bakersfield, California
Red Wine	3.6	Cabernet Sauvignon, Bota Box Vineyards, Mentaca, California

Table 2. Mean color difference of polished vs. non-polished disks.

Solution	**Mean ∆E (SD)**	
	Day 1	
	Polished	**Non-polished**
Artificial Saliva	1.65 (0.52)	2.32 (0.86)
Black Tea	1.60 (0.60)	3.16 (1.79)
Carrot Juice	2.52 (0.91)	5.20 (2.77)
Red Wine	3.63 (1.27)	5.80 (2.03)
	Week 1	
	Polished	**Non-polished**
Artificial Saliva	2.34 (1.04)	2.39 (1.40)
Black Tea	2.60 (1.08)	2.35 (0.76)
Carrot Juice	2.48 (0.96)	4.56 (3.28)
Red Wine*	9.82 (2.20)	15.77 (1.88)
	Week 2	
	Polished	**Non-polished**
Artificial Saliva	2.09 (0.59)	2.98 (1.84)
Black Tea	2.57 (0.34)	2.31 (0.65)
Carrot Juice	2.35 (0.62)	3.28 (2.92)
Red Wine**	10.56 (1.89)	18.97 (1.52)
	Week 3	
	Polished	**Non-polished**
Artificial Saliva	2.47 (1.82)	3.65 (1.63)
Black Tea	3.26 (0.66)	3.60 (0.86)
Carrot Juice*	2.02 (0.49)	7.10 (5.18)
Red Wine**	10.56 (1.82)	19.94 (3.75)

SD=standard deviation

* Significant difference $p < 0.05$; ** significant difference $p < 0.01$

Table 3. Results of one-way ANOVA and Tukey's test after day 1, week 1, week 2 and week 3 of immersion period.

Non-polished	ANOVA	Tukey's Test, Red Wine vs. Artificial Saliva	Carrot Juice	Black Tea
Day 1	0.0421	0.0593 (NS)	0.9623 (NS)	0.9623 (NS)
Week 1	<0.0001	<0.0001	<0.0001	<0.0001
Week 2	<0.0001	<0.0001	<0.0001	<0.0001
Week 3	<0.0001	<0.0001	<0.0001	<0.0001

Polished	ANOVA	Tukey's Test, Red Wine vs. Artificial Saliva	Carrot Juice	Black Tea
Day 1	0.0068	0.0126	0.2331 (NS)	0.0106
Week 1	<0.0001	<0.0001	<0.0001	<0.0001
Week 2	<0.0001	<0.0001	<0.0001	<0.0001
Week 3	<0.0001	<0.0001	<0.0001	<0.0001

5.0 Discussion

The purpose of this investigation was to evaluate the color difference among 3D printed resin disks immersed in four different staining solutions: artificial saliva, red wine, carrot juice and black tea. The solutions were chosen due to their prevalence in common diets. A spectrophotometer (Vita Easyshade V, Bad Sackingen, Germany) was used to determine the color coordinates of each printed disk. The VITA Easyshade V contains a spectrometer that captures reflected light. The reflected light contains information about the surface tested. Studies have shown that the reliability and accuracy of the device in shade detecting are 96.4% and 92.6%, respectively.[19] The CIELAB color space (L^*, a^*, and b^*) was used to calculate color difference, ΔE^*_{ab}, across time for both polished and non-polished resins stored in each staining solution. It was found that red wine affected the color of the disks in week 1, week 2 and week 3, regardless of polishing state. Non-polished disks were less color stable in red wine compared to polished disks at week 1, week 2, and week 3. Moreover, surface treatment also showed differences in mean values for carrot juice at week 3. ΔE values for specimens immersed in artificial saliva and black tea did not exceed the value of 3.6, while carrot juice reached a maximum ΔE of 7.1 for non-polished disks. The highest mean value for non-polished disks immersed in red wine reached a ΔE of 19.94 (3.75).

When CAD/CAM PMMA blocks were compared to 3D printed resin, multiple studies concluded that CAD/CAM PMMA blocks were more color stable when immersed in colorant solutions.[15,20] Gruber et al. tested 176 tooth colored and pink resin specimens that were either conventionally heat polymerized PMMA resin, subtractively manufactured from a CAD/CAM block or additively manufactured through 3D printing. Four aging solutions were used in this study: thermal cycling, red wine, distilled water, and coffee. After calculating the ΔE the results showed higher color stability for both conventional heat-polymerized resin and subtractively manufactured resin when compared to 3D printed resin. Their study also showed that CAD/CAM subtractively manufactured resins and conventional resin showed similar physical properties. Parallel to our findings, red wine groups showed an increase inclination to staining in all resin groups, when compared to other staining solutions.[20] In the study by Shin et al, a colorimeter was used to measure color difference between three types of CAD/CAM blocks and two 3D printing resins. Results showed higher color stability in CAD/CAM block materials, with 3D printed resin showing perceptible color changes above their set clinic limit of 2.25 as early as 7 days. Compared to our study, red wine groups showed similar color differences after 7 days. When considering the acceptability and perceptibility tolerances of shade mismatch, a study by Douglas et al. was conducted in a clinical scenario. Twenty-eight dentists were questioned on the mismatch of two central incisors that ranged from ΔE=1 to ΔE=10. At a ΔE value of 2.6, 50% of the dentists could perceive a color difference. On the other hand, a failing restoration due to mismatch of shade was set at ΔE= 5.5 which was detectable by half of the dentists.[21] In this study, values above 5.5 were only seen for red wine groups at day 1,week 1, week 2, and week 3, and for carrot juice specimens at week 3.

Significant differences in mean values of ΔE were found among polished and non-polished groups, suggesting that surface treatment played a role in color stability. Raszewski et al. evaluated color stability of 3D printed resin with two different surface finishing processes. Specimens were either polished using a 100-micron pumice or varnished with a light polymerized agent. Based on the results of this study, applying a light polymerized varnish was considered a temporary solution to preserve the color stability of the restoration. Whereas, the effects of using pumice could last longer, as it eliminates any roughness and irregularities that could aid in adhesion of colorants..[22]

Multiple factors can affect the color stability of a 3D printed resin. Different studies have shown that built orientation can affect both mechanical and optical properties. Following a study by Hada et al, 45 degrees printing orientation showed the greatest accuracy.[23] In another study by Espinar et al., the selection between 0 and 90 degrees was evaluated to test if the printing orientation affects the translucency and color stability of 3D printing resin. Findings showed that building orientation can influence the translucency and color stability of the resin. Printing at a 90° showed higher translucency for some brands used. Choosing a printing orientation has to be assessed individually for each resin depending on its composition and how layering the resin affects its absorption and scattering values.[24]

Lee et al. investigated color stability of 3D printed resin under different printing parameters. One-hundered and eighty disks, 15 mm in diameter and 2 mm in thickness, were printed and immersed in different solutions. Three printing orientations 0°, 45° and 90° and two thicknesses 25 µm and 100 µm were investigated at 1, 3, 7, 15, and 30 days after immersion. The resin samples in 0°group had more color stability than those in 45° and 90° groups, with the same layer thickness, at the same time point. Under the same circumstances, the 100 µm resin samples presented significantly more color stability than the 25 µm samples.[25]

Moreover, water sorption of resin material could have an impact on color stability. In a study by Shin et al, it was observed that water sorption of 3D printed resin is higher that polycarbonate but lower that prefabricated PMMA material.[15] Gad et al. similarly examined three 3D printed denture base resins and heat polymerized acrylic denture base resins. Effects of thermal cycling showed higher sorption rates among the 3D printed resin compared to the heat polymerized acrylic resin.[26] Although they are not the only causes, water sorption and solubility of the printed resin can influence the color stability of 3D printed resin materials.

Different 3D printing approaches can be used to fabricate restorations, in this study, a DLP printer was utilized. DLP 3D printers cure all points simultaneously by flashing an image of a layer across the entire platform via a digital projector screen. Stereolithography apparatus (SLA) is also a common type of 3D printing which uses a laser beam that reflects on the resin tank, curing point by point. The illumination source distinguishes the two.[27] Limited studies comparing means of printing have been discussed in the literature. One study by Kim et al. evaluated color stability along with physical and mechanical properties resins fabricated using the following methods: manual, FDM, two polyjets, SLS, SLA, DLP, and milling. After 30 days of immersion, the milling method showed the highest color stability, with DLP, SLA and manual presenting similarly higher ΔE values.[28]

6.0 Limitations of the study

While the primary goal of this study was to evaluate the color stability of 3D printed resin and the effect of polishing on its color stability, it is essential to acknowledge the inherent limitations that may affect the interpretation of the findings. This study only utilized DLP 3D printing technology. Stereolithography (SLA) is generally considered to be more color stable and has better surface roughness than DLP due to the precise control of the curing process using a single, consistent light source.[29] However, both technologies can achieve clinically acceptable color stability when properly calibrated and maintained.[24] More research should be done to compare the color stability and mechanical characteristics of SLA to DLP printed prototypes. Another limitation is that only one type of 3D printed resin was tested for its color stability. Comparing more than one type of resins would ultimately show how inorganic fillers, matrix and photoinitiators affect color stability. Lastly, the resin disks in this study were stored in solutions at room temperature, in closed containers. Whereas intraorally these conditions do not stay the same. The temperature and pH fluctuates, and there is also the presence of saliva, which could potentially affect the accumulation of stains on the surfaces.[30] Providing accurate oral conditions or conducting *in vivo* studies would be required to obtain clinically relevant results.

7.0 Conclusion

Provisional resin fabricated by DLP 3D printing showed lower color stability with time than subtractively manufactured PMMA. Immersion in different staining solutions caused detectable color differences in the tested materials which were relative to the immersion duration and the staining solution used. The color of the 3D printing restorative resins is influenced by the surface finishing, which may result in visually perceptible color differences. 3D printed material should be polished as thoroughly as possible to limit the adhesion of dyes from food to their surface. When selecting a material, the provider should take into consideration the longevity and esthetic demands of the treatment. The color stability of 3D printing material should be improved to manufacture oral appliances, which require long-term esthetics.

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