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ASSESSING THE IMPACT OF SURFACE TREATMENTS ON THE COLOR STABILITY OF 3D PRINTED CERAMIC-REINFORCED RESIN (IN VITRO STUDY)

Ahmed A. Eshra[1*] BDS, Ihab A. Hammad[2] PhD, Yasser M. Aly[3] PhD

ABSTRACT

INTRODUCTION: Ceramic-reinforced resin materials have become increasingly popular for dental restorations due to their aesthetic appeal and durability. However, these materials are subject to various factors, such as staining agents and different surface treatment techniques, which can affect their color stability. Despite their widespread use, there is a lack of comprehensive information regarding how surface treatments influence the color stability of ceramic-reinforced resins.

AIM OF THE STUDY: The objective of this study was to investigate how different surface treatment protocols impact the color stability of ceramic-reinforced resin crowns.

MATERIALS AND METHODS: A total of fifty-four specimens (10 x 10 x 1.5 mm) were divided into two groups based on material type: Flexcera and Varseosmile Crown Plus (both ceramic-reinforced resins manufactured through additive processes). Each group was further subdivided into three categories depending on the polishing method used: pumice (P), polishing discs (PD), and a control group (C). Initial color measurements were taken using a spectrophotometer, followed by immersion in coffee at 37°C for one, three, and seven days to assess color changes.

RESULTS: Varseosmile exhibited the greatest color change (ΔE00), especially in the control group. Flexcera showed notable discoloration when treated with pumice, while polishing discs produced the most consistent color stability across all time points. The immersion time had a significant effect on discoloration, with more pronounced changes observed as the duration of immersion increased.

CONCLUSION: The color stability of ceramic-reinforced resin materials was significantly influenced by the surface treatment methods used.

KEYWORDS: Color, Ceramic reinfored resin, Additive manufacturing, Spectrophotometer, Color stability.

RUNNING TITLE: Impact of Surface Treatments on 3D Resin Color Stability.

1-BDS 2017, Faculty of Dentistry, Alexandria University.
2-Professor of Fixed Prosthodontics, Department of Conservative Dentistry, Faculty of Dentistry, Alexandria Universi
3-Assistant Professor of Fixed Prosthodontics, Department of Conservative Dentistry, Faculty of Dentistry, Alexandria University.

Corresponding author:
ahmed.eshra94@gmail.com

INTRODUCTION

The use of computer-aided design/computer-aided manufacturing (CAD/CAM) technology in dental restoration production has become increasingly significant, with many traditional methods now being replaced by this more advanced process. The CAD/CAM system, which consists of optical scanners, CAD software, and manufacturing devices, is widely adopted in dental practices due to its technological advancements (1, 2). This system offers more straightforward and precise procedures compared to conventional methods, resulting in improved processing accuracy. Moreover, it allows for digital visualization and communication of the prosthesis design, with the design data being stored as a digital file (stl) (1-4).

Alongside the growth of CAD/CAM, three-dimensional (3D) printing, also known as additive manufacturing, is gaining momentum (5). This technology presents a solution to the limitations of traditional milling systems in dentistry, thanks to the development of 3D printing materials and advancements in 3D printer technology. It is now used to create biomaterials for dental treatments, surgeries, and medical devices (6). Specifically, in dentistry, 3D printing is employed for the production of dental implants, orthodontic models, metal restorations, implant surgery guides, temporary crowns, and final ceramic-reinforced resin crowns.

While subtractive manufacturing yields restorations with good marginal fit and strength, the process involves the removal of excess raw material, which contributes to its higher cost (7). Additionally, several factors impact the accuracy of milled restorations, such as the machinability of the material, wear of milling burs, milling strategy, and the machine's axis configuration. Furthermore, this technique may struggle with producing complex geometries (8).

In recent years, 3D printing processes have been introduced in the dental field to produce restorations. This additive manufacturing process builds up material layer by layer to form a final product. The benefit of this method is its ability to reduce fabrication costs by minimizing material waste (9). The layer-by-layer approach also facilitates the formation of chemical bonds between the layers, thereby enhancing the restoration's mechanical properties (10).

The staining resistance of dental restorations is just as important as their fracture resistance and other mechanical qualities. In clinical practice, poor color stability and staining could prompt the need for restoration replacement. Several factors influence color stability, including: 1) intrinsic factors (aging), 2) extrinsic factors (plaque buildup and staining from diet), and 3) surface degradation and absorption of staining agents. Once the material is chosen, appropriate surface finishing can help mitigate the effects of extrinsic factors (11, 12).

Staining of restorations can lead to patient dissatisfaction and additional costs for replacement. Thus, stainability is an important factor when selecting a restorative material. Discoloration can be measured using tools like spectrophotometers and colorimeters, and color differences (ΔE) are calculated by comparing baseline and post-immersion color readings. According to Shigemi et al., a ΔE value of 2.6 or greater is noticeable to the human eye, whereas a ΔE value up to 5.6 is considered clinically acceptable (13). The threshold for detecting color differences is higher in the oral cavity due to background distractions, such as the mucosa and the shadows cast by the lips, which can make small color differences harder to discern (14).

Restorations can be finished using various techniques, including pumice and polishing discs. However, the impact of polishing on the staining of ceramic-reinforced resin crowns over time is not fully understood. This study aims to examine how different surface treatment protocols affect the color stability of ceramic-reinforced resin crowns (13).

Null Hypothesis

There is no significant difference in the color stability of ceramic-reinforced resin crowns when different surface treatments are applied.

MATERIALS AND METHODS

The sample size for this study was determined based on a 5% alpha error and 80% study power. The overall mean [±SD] of ΔE for 3D-printed materials, regardless of surface treatment, was calculated to be 3.245 [±0.8] (15). Using the difference between means, it was estimated that 7 specimens per group were required, yielding an effect size of 1.732. To account for potential processing errors, this was increased to 9 specimens per group. The total sample size was calculated as Number per group × Number of groups × Number of subgroups = 9 × 3 × 2 = 54 specimens.

Software and Materials

Sample size calculations were performed using Rosner’s method (16) with G*Power 3.1.9.7. A total of 54 specimens were prepared, evenly divided between two tested 3D-printed ceramic-reinforced resin materials: Flexcera and Varseosmile.

Specimen Design and Production

The specimens were designed using 3D modeling software (Meshmixer, California, US) creating a standard size of 10 × 10 × 1.5 mm. The designs were exported as STL files for printing. A group of 27 specimens was printed for each material using a BEGO 3D printer (Bremen, Germany). (Figure 1) Specimen dimensions were verified using a digital caliper (Hogetex digital caliper 150 mm; Hogetex) with an accuracy of ±0.03 mm to ensure precision.

The 27 specimens for each material were further divided into three subgroups based on surface treatment: pumice polishing (P), polishing discs (PD), and the control group (C) (2). (Figure 2)

Surface Treatment

Specimens were ultrasonically cleaned in distilled water for 10 minutes before being randomly divided into subgroups. The polished groups were treated using a three-stage polishing system (OptraFine Assortment; Ivoclar AG) with a low-speed handpiece. The process began with light blue and dark blue instruments operating at 10,000 rpm under water cooling, followed by polishing with a brush and diamond polishing paste (OptraFine HP; Ivoclar AG) at 8,000 rpm.

Polishing was standardized: light pressure was applied in one direction for 30 seconds, then the specimen was rotated 90° and polished again for 30 seconds. Each specimen underwent three minutes of polishing. For consistency, a new polishing kit was used for each subgroup, and all polishing was performed by the same operator. After treatment, specimens were cleaned ultrasonically in distilled water for 10 minutes (17).

Color Measurement

Color measurements were carried out using a VITA Easyshade Advance 5.0 spectrophotometer (VITA Zahnfabrik). (Figure 3) Calibration was performed according to the manufacturer’s instructions. Measurements were taken in “Tooth Single” mode, positioning the probe tip at 90° to the center of each specimen surface (17). Two readings were recorded for accuracy.

To simulate oral conditions, measurements were conducted at the same time of day (noon) on a black background. (Figure 4) One side of each specimen was designated as the test surface, while the opposite side was coated with clear nail polish (Last & Shine No:130; Amanda Milano) to prevent staining.

Color data was expressed in *L*, *a*, and b*** coordinates based on the CIELab system (13). The color difference (ΔE) was calculated using the formula:

$\Delta E= [(\Delta L^*) 2 + (\Delta a^*) 2 + (\Delta b^*) 2] ½$

Immersion and Storage

Specimens were stored in 100 mL of Nescafé coffee solution to simulate real-world staining conditions. A 24-hour immersion period was equivalent to approximately 30 days of exposure to food and beverages. The specimens were stored in an incubator (Dentalfabrik Leipzig, Germany (1990)) at 37°C in labeled opaque plastic containers (LocknLock, Korea) to avoid confusion. (Figure 5) The coffee solution was renewed at each measurement interval to prevent bacterial contamination (18).

Measurement Timeline

Color measurements were taken at three intervals: day 1, day 3, and day 7. Each specimen was measured three times, and the average value was recorded for accuracy.

This standardized protocol ensured consistency and reliability throughout the study while simulating clinical conditions.

Figure (1): BEGO 3D printer (Bremen, Germany).

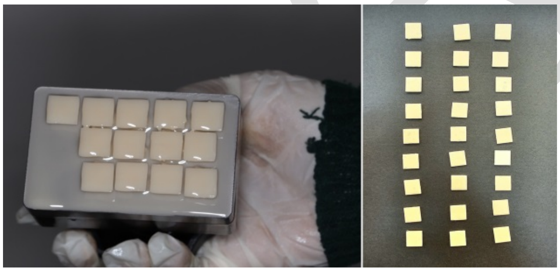

Figure (2): Subgroup samples.

Figure (3): VITA Easyshade Advance 5.0 spectrophotometer (VITA Zahnfabrik).

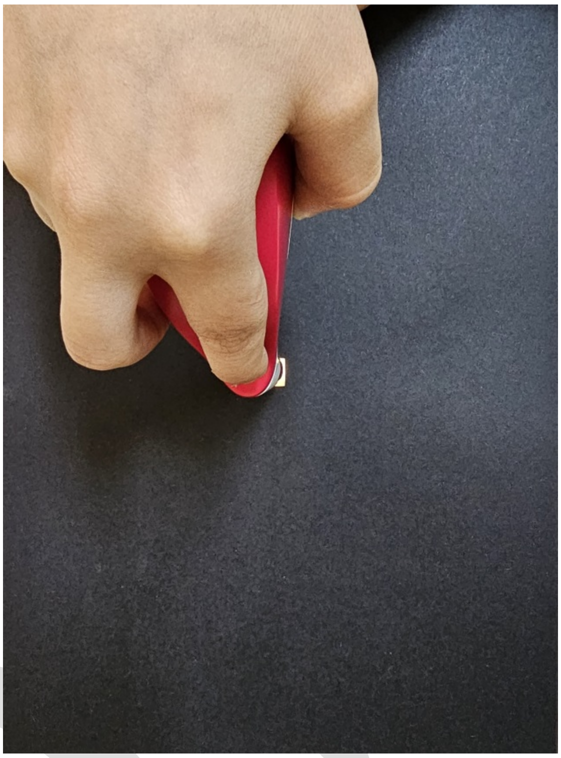

Figure (4): Simulate oral conditions by black background.

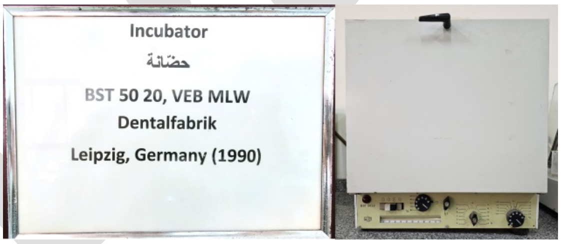

Figure (5): Incubator (Dentalfabrik Leipzig, Germany (1990)).

RESULTS

The mean ΔE values after surface polishing for Varseosmile and Flexcera were evaluated at day 1 (T1), day 3 (T3), and day 7 (T7). For Varseosmile, ΔE increased over time in the control group (10.24 at T1 to 20.79 at T7), while polishing discs and pumice treatments resulted in significantly lower values (3.71–7.89 and 4.11–8.10, respectively). Flexcera's control group followed a similar pattern (5.03 to 11.83), but polishing discs (6.40–10.59) and pumice (7.58–19.38) showed differing trends.(Table 1)

The three-way ANOVA revealed significant effects for material, surface treatment, and time ($p < 0.001$), with time having the greatest effect ($ΠP^2 = 0.909$). Significant interactions occurred between material, surface treatment, and time. Pairwise comparisons showed no significant difference between Varseosmile and Flexcera overall ($p = 0.151$), but surface treatments revealed higher ΔE in the control group compared to polishing discs and pumice. (Table 2)

ΔE increased significantly over time, with T1 showing lower values than T2 and T3 (p < 0.001). At all time points, Varseosmile showed significant differences compared to Flexcera across most surface treatments. Polishing discs generally resulted in the lowest ΔE values, while control groups had the highest, confirming the influence of polishing techniques on color stability. (Table 3)

Table (1): Mean values of ΔE after surface polishing at different time points

Materials	Surface Treatment	ΔE (T1)	ΔE (T3)	ΔE (T7)
		Mean ±SD		
Varseosmile	Control	10.24 ±1.29	15.88 ±2.00	20.79 ±1.58
	Polishing Discs	3.71 ±0.73	6.68 ±0.63	7.83 ±0.88
	Pumice	4.11 ±1.15	6.58 ±1.83	7.98 ±1.81
Flexcera	Control	5.03 ±0.61	9.55 ±0.80	11.83 ±0.91
	Polishing Discs	6.40 ±0.82	10.41 ±1.29	8.77 ±1.52
	Pumice	18.82 ±5.29	11.06 ±1.75	7.54 ±1.41

T_1: day 1, T_3: day 3, T_7: day 7

Table (2): Three-way factorial ANOVA results for comparison of color parameter changes

Effect	Mean Square	F test	p value	ηP^2
Material	222.43	55.952	<0.001*	0.608
Surface treatment	158.58	39.891	<0.001*	0.526
Time	269.87	137.51	<0.001*	0.656
Material x Surface treatment	427.67	107.582	<0.001*	0.857
Material x Time	97.49	49.68	<0.001*	0.580
Surface treatment x Time	144.83	73.80	<0.001*	0.672
Material x surface treatment x Time	68.90	35.11	<0.001*	0.661

* Statistically significant difference at p value<0.05, $\eta P2$: Partial Eta Squared

Table (3): Pairwise comparisons and mean differences of ΔE between different variables

Variables	Groups	Compared to	Mean diff	95% CI	p value
Materials	Varseosmile	Flexcera	-0.624	-1.39, 0.14	0.151
Surface treatment	Control	Polishing Discs	2.56	1.79, 3.33	<0.001*
		Pumice	2.26	1.49, 3.03	<0.001*
	Polishing Discs	Pumice	-0.29	-1.06, 0.47	1.00
Time	T1	T2	-2.48	-3.06, -1.91	<0.001*
		T3	-3.35	-3.87, -2.83	<0.001*
	T2	T3	-0.87	-1.30, -0.43	<0.001*

*Statistically significant difference at p value<0.05

DISCUSSION

After analyzing the data, it became clear that the null hypothesis had to be rejected. The processing techniques, surface treatments, and immersion in coffee significantly impacted the color stability of ceramic-reinforced resins.

The materials used in this study—Varseosmile and Flexcera—were chosen because of their excellent optical properties, and ability to closely mimic the natural color of teeth. Shade A2 was specifically selected because it makes even subtle color changes more detectable (17). To ensure accurate readings, specimens were designed to be 10 mm in diameter, which is broader than the spectrophotometer tip, avoiding edge loss during measurements (17). The thickness of 1.5 mm was also intentional, as it simulates the typical reduction during tooth preparation and enhances the visibility of color changes, particularly when the thickness is less than 2.5 mm (17). For consistency with ISO 13655 guidelines, a black background was used during color measurements, mimicking clinical conditions.

For precise and reliable measurements, the VITA Easyshade Advance spectrophotometer (fifth generation) was utilized. Its accuracy and reliability have been well-documented, with studies reporting over 90% accuracy (2, 3, 4). Additionally, perceptibility and acceptability thresholds of 2.6 and 5.6, as defined by Shigemi et al., were used to assess color differences in this study (19).

Nescafé Classic was the coffee of choice for immersion because of its popularity and relevance in simulating real-life conditions. It has been widely used in dental research due to its proven ability to stain restorative materials (18). Studies have shown that coffee-induced color changes depend on the material type, the resin matrix's ability to absorb water, and the type and amount of fillers in the composite (18).

When comparing Varseosmile and Flexcera, the results revealed that Varseosmile had higher ΔE values across all conditions, making it more prone to color changes. This aligns with previous research showing that resin-based materials are susceptible to staining due to their hydrophilic nature, which allows water and staining agents to diffuse into the material. Drinks like coffee, tea, and wine—containing tannins and acids—can further accelerate this process (20, 21).

While Varseosmile also showed noticeable color changes, it performed slightly better than Flexcera. This difference may stem from its composition. Flexcera's resin matrix could contain different monomers or crosslinking agents that improve its stain resistance. Additionally, variations in filler content and surface porosity might play a role. A material with densely packed fillers absorbs less water and stains, contributing to its better performance compared to Varseosmile (22).

Surface treatments and immersion times further highlighted the materials' behaviors. Polishing discs and pumice treatments consistently improved color stability compared to the untreated control groups. These findings agree with Abouraya et al., who demonstrated that polishing reduces surface roughness, preventing staining agents from being trapped in surface irregularities (23). Rougher surfaces are more likely to attract and hold food pigments, coffee stains, and other contaminants, leading to faster discoloration.

Polishing discs, in particular, are effective in achieving smoother surfaces and minimizing micro-roughness. This smooth finish reduces opportunities for staining agents to adhere, enhancing the aesthetic longevity of restorations. Pumice, while still effective, may not create as smooth a finish as polishing discs, leaving some surface irregularities where stains can accumulate. This explains why polishing techniques—particularly with polishing discs—are critical for maintaining the visual appeal of resin-based restorations.

In conclusion, this study highlights how material composition, surface treatments, and immersion times influence the color stability of ceramic-reinforced resins. Proper selection of materials and polishing techniques can significantly enhance the longevity and aesthetic outcomes of restorative treatments, ensuring that they remain visually appealing for longer periods.

The limitations of the current study include that conditions of this in vitro study did not mimic the clinical situation in terms of the influence of saliva and masticatory forces. Additionally, the uniform flat disk-shaped specimens did not replicate the curved contour of the restorations. Moreover, consumption of different foods and beverages might influence the color change susceptibility.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions can be made:

Different surface treatment techniques have a significant impact on the color stability of dental restorations.

Varseosmile showed the most noticeable color changes (highest ΔE values), making it more prone to discoloration, while Flexcera performed slightly better, showing greater resistance to staining.

Among the surface treatments, polishing discs provided the best color stability by effectively smoothing the surface, whereas pumice was less effective. Both treatments, however, helped reduce surface roughness and minimized staining.

Longer exposure times resulted in increased discoloration for both materials. This highlights the importance of selecting the right materials and applying appropriate surface treatments to ensure better long-term performance in clinical practice.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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