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The effect of different surface treatments on the color change of CAD/CAM restorative materials caused by coffee

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Abstract

Aim: This study aimed to evaluate the effect of different surface treatment protocols on the color stability of two CAD/CAM restorative materials, a hybrid ceramic (Vita Enamic) and a resin-based composite (Shofu Block HC), when exposed to filter coffee.

Methodology: Sixty disk-shaped specimens (12 mm diameter, 1.5 mm thickness) were prepared from Vita Enamic and Shofu Block HC. The specimens were divided into six groups (n=10) based on the material and surface treatment: Mechanical Polishing Only, Glaze (Optiglaze) Only, and Mechanical Polishing + Glaze. After the surface treatments, baseline color measurements were performed using a spectrophotometer (Vita EasyShade V). The specimens were then immersed in a freshly prepared filter coffee solution, which was renewed daily for 15 days (simulating ~3 years of clinical exposure). Post-immersion color measurements were taken, and the color difference (ΔE) and lightness difference (ΔL) were calculated. Data were analyzed using two-way ANOVA and Tukey's HSD test ($p < 0.05$).

Results: Two-way ANOVA revealed significant main effects of Material and Surface Treatment on both ΔE and ΔL ($p < 0.001$). A significant Material × Surface Treatment interaction was found for ΔL ($p = 0.012$) but not for ΔE ($p = 0.207$). Vita Enamic demonstrated significantly lower ΔE and higher ΔL values than Shofu Block HC, indicating better overall color stability and less darkening. For both materials, Mechanical Polishing Only resulted in significantly lower ΔE than glaze only or the combination group. For ΔL, Mechanical Polishing was superior for Vita Enamic, whereas Glaze Only yielded the most unfavorable results for Shofu Block HC.

Conclusion: The color stability of CAD/CAM materials is significantly influenced by both material composition and surface treatment applied. Mechanical polishing provided the best color stability for both materials tested. Clinically, for restorations prone to coffee exposure, selecting a hybrid ceramic like Vita Enamic and finishing it with mechanical polishing is recommended to optimize long-term aesthetic performance.

Keywords: CAD-CAM, color stability, dental polishing, composite resins, coffee, surface properties

Introduction

The rise of computer-aided design/computer-aided manufacturing (CAD/CAM) technology in dentistry has led to significant improvements in the quality and efficiency of dental restorations. CAD/CAM systems enable precise digital scanning, design, and fabrication of dental prosthetics, streamlining workflows in dental practices and improving patient outcomes. This technology, which began to evolve in the 1980s, has become integral to various dental applications, particularly in the production of same-day restorations, thus enhancing clinical efficiency and patient satisfaction (1-3).

CAD/CAM technology facilitates the production of a wide array of dental materials, including ceramic and resin-based composite (RBC) restorations, which exhibit different mechanical properties and aesthetic quality. Research has demonstrated that restorations created using CAD/CAM techniques exhibit superior color stability compared to traditional laboratory-processed materials, a crucial factor for patient satisfaction and aesthetic results (4-6). The materials used, their composition, and the finishing techniques are key determinants influencing color stability, enhancing the longevity and aesthetic appeal of dental restorations (4-7). Color stability is vital, especially in environments exposed to food and drinks, ensuring high levels of aesthetic performance can significantly impact patient self-esteem and acceptance of their dental work (5,8). Furthermore, the importance of color stability in CAD/CAM restorations cannot be understated, as it directly contributes to patient satisfaction. Studies have shown that patients often report greater satisfaction with restorations that maintain a consistent color over time. For instance, CAD/CAM provisional materials have been found to outperform traditional equivalents in this aspect, thus providing advantages when longer-lasting temporary solutions are required (4,6). An increase in patient satisfaction has been associated not only with aesthetic outcomes but also with the reliable production of restorations that resist staining and wear, leading to healthier and more visually appealing smiles (7,8).

The integration of CAD/CAM technology in dentistry has resulted in the development of various dental materials, particularly within the CAD/CAM block family. This diversity includes materials ranging from ceramics to high-performance polymers, each exhibiting distinct mechanical properties and color stability, which significantly influence their clinical applications and patient outcomes. Hybrid ceramics, such as Vita Enamic, represent a unique category of CAD/CAM materials. They combine ceramic and polymer components to achieve a balance between aesthetics and mechanical strength. Research indicates that hybrid ceramics can closely mimic the properties of natural tooth structure, offering favorable flexural strength and aesthetic appeal that enhance visual outcomes in restorative dentistry (5,9). Furthermore, hybrid ceramics can undergo finishing and polishing processes similar to resin materials, making them suitable for anterior restorations, where aesthetics are a priority (9). High-performance polymers, such as Shofu Block HC, are gaining attention as alternatives in restorative dentistry. Variability in color stability is another important factor for ensuring patient satisfaction. Studies have shown that both hybrid ceramics and high-performance polymers demonstrate adequate color stability; however, differences exist based on the specific formulations and compositional characteristics of the materials (10,11). Some resin-ceramic hybrid materials have been found to exhibit superior adhesion and resistance to color degradation upon exposure to staining agents compared to pure ceramic options (9,10). This leads to enhanced reliability in aesthetic applications, where maintaining color matching over time is essential. The choice of material also affects the mechanical properties and clinical protocols used in restorative procedures. As CAD/CAM technology continues to advance, practitioners can select materials that best meet the specific needs of each case, whether for functional restorations or to enhance patient aesthetics (5,12). The ongoing evolution of material science in this area promises even more options for optimized restorations tailored to individual patient requirements (3,5,13,14).

Surface treatments, specifically polishing and glazing, play a decisive role in determining the color stability of CAD/CAM dental restorations, which, in turn, affects patient satisfaction. These finishing processes are crucial in the restoration workflow because they affect both the aesthetic appearance and functional longevity of dental materials. Polishing is recognized for its ability to create a smooth surface, thereby reducing roughness and enhancing the gloss of restorations. Research indicates that while polishing can significantly improve the surface finish, it may also adversely affect the color stability of certain materials. For example, Aldosari et al. reported that the glazed surfaces of CAD/CAM materials generally exhibited better color stability than polished surfaces, indicating a correlation between surface treatment and resistance to discoloration after exposure to staining agents, such as coffee (15). This highlights the importance of selecting an appropriate finishing technique based on the intended longevity and functionality of the restoration. On the other hand, glazing leads to the formation of a glassy surface that enhances the initial aesthetics. However, the glazing process can result in a surface that may retain coloring agents more than polished surfaces would, potentially leading to greater susceptibility to stains and discoloration over time. Tekçe et al. noted that a smooth glazed surface might not fully prevent the absorption of pigments from food and beverages, leading to discoloration despite initially appearing glossy (16). Moreover, it is essential to recognize that the material composition plays a significant role in determining the discoloration resistance of the completed restoration post-treatment. Sarikaya and Güler found that polished porcelain surfaces exhibited statistically significant color deviations compared to glazed surfaces when exposed to staining agents such as methylene blue, further indicating that while glazing might provide an initial optical advantage, its ability to retain discoloring agents could compromise long-term stability (17).

Coffee is a widely consumed beverage globally and has cultural significance in Türkiye. Among the various types of coffee, freshly brewed filter coffee is notable for its high polyphenolic content, which is associated with potential health benefits and the potential to stain dental restorations and materials. Research indicates that the brewing method significantly impacts the phenolic compound concentration in coffee. Olechno et al. have demonstrated that brewing coffee at high temperatures (such as 100°C) for extended periods increases the transfer of polyphenolic compounds into the brew, resulting in a higher total phenolic content (TPC) (18). This robust polyphenolic profile in freshly brewed filter coffee is important, as compounds such as chlorogenic acids provide color and offer recognized health benefits, including antioxidant and anti-inflammatory properties (19). While the antioxidant effects of these compounds are often emphasized, their potential for causing intense discoloration of dental materials should not be overlooked. Polyphenolic compounds in coffee, primarily chlorogenic acids, contribute to significant discoloration effects on dental materials. Korać et al. reported that coffee can induce considerable color changes in composite resins due to the penetration of these compounds into the material matrix (20). This leaching of polyphenolic compounds presents a challenge for practitioners in maintaining the aesthetic qualities of dental restorations, especially with frequent coffee consumption. In Türkiye, the tradition of drinking freshly brewed coffee, often associated with social gatherings, highlights the need for dental materials that can endure common dietary influences. The coloring effects of coffee, particularly with regular consumption, underscore the importance of considering the composition of dental materials and surface treatments to mitigate staining risks (21).

The staining effects of coffee on composite resins have been widely explored in the dental literature, reaffirming its reputation as a potent coloring agent. Numerous studies have shown that the pigments in coffee interact with the organic phase of composite materials, leading to significant discoloration over time (22–24). It has been well documented the yellow colorant pigments of coffee possess a strong affinity for polymers, thereby contributing to the observed color changes in dental composites (23). While the staining potential of coffee has been extensively studied across various composite materials and formulations, there is a notable gap in research regarding the systematic comparison of different surface treatment protocols on the color stability of CAD/CAM materials. Existing studies have primarily examined the effects of coffee as a staining medium without thoroughly investigating how various finishing techniques, such as mechanical polishing, glazing, or a combination of both, affect the resistance of different CAD/CAM blocks to discoloration. Darabi et al. and Al-Samadani highlighted the pronounced impact of coffee immersion on the color stability of composite resins, indicating that inherent material properties and surface treatments could play a critical role in mitigating these effects (25, 26). However, comprehensive comparisons of the effects of mechanical treatment alone, glazing alone, and mechanical treatment plus glazing on color stability in CAD/CAM materials remain limited. Thus, while the detrimental effects of coffee staining are well documented, future research should focus on clarifying how specific finishing processes interact with different material classes to enhance or diminish their overall color stability when exposed to common dietary agents. This insight is essential for optimizing aesthetic outcomes and patient satisfaction in restorative dentistry, particularly given the prevalence of coffee consumption worldwide, including in Turkey.

This study aimed to evaluate the resistance of Vita Enamic and Shofu Block HC CAD/CAM materials to color changes (ΔE and ΔL) caused by filter coffee after three different surface treatment protocols.

Null Hypotheses: 1) There is no significant difference in color change between the two materials. 2) There is no significant difference in color change was observed among the three surface treatments.

Materials and Methods

Two different CAD/CAM block materials were used in this in vitro study: Vita Enamic (Vita Zahnfabrik, Bad Säckingen, Germany) and Shofu Block HC (Shofu, Inc., Kyoto, Japan). A total of 60 specimens were prepared from both materials in a disk shape (diameter: 12 mm). The thickness of all specimens was standardized to 1.5 ± 0.2 mm using a digital caliper.

Study groups

The samples were divided into six groups based on the material type and surface treatment applied (n=10):

Group E-M: Vita Enamic + Mechanical Polishing Only

Group E-M+O: Vita Enamic + Mechanical Polishing + Optiglaze

Group E-O: Vita Enamic + Optiglaze Only

Group S-M: Shofu Block HC + Mechanical Polishing Only

Group S-M+O: Shofu Block HC + Mechanical Polishing + Optiglaze

Group S-O: Shofu Block HC + Optiglaze Only

Surface treatment protocols

Mechanical Polishing

A three-step manual polishing procedure was applied to 20 randomly selected specimens from each material group, following the manufacturer's recommendations. The process was performed using a water-cooled handpiece operating at 10,000 rpm with Toboom polishing discs. Each step (Coarse/Blue/150–180 grit; Medium-Fine/Brown/220–280 grit; Extra-Fine/Gray/320-400 grit) was performed for 20 seconds.

Glaze Application

Ten mechanically polished specimens and ten untreated specimens from each material group were coated with Optiglaze (GC Corp., Tokyo, Japan) according to the manufacturer's instructions. All glazed specimens were polymerized with an LED light-curing unit for 40 s on each surface.

Staining protocol and clinical correlation calculation

After all the surface treatments were completed, the specimens were immersed in distilled water at room temperature for 24 h to prepare them for baseline color measurements. Subsequently, the specimens were incubated in freshly prepared filter coffee solution. For 15 days, 200 mL of filtered coffee was brewed in a French press for 3 min using 8 g of freshly ground coffee beans (Tchibo Gold Selection; Tchibo GmbH, Hamburg, Germany), and the solution was replaced daily.

To calculate the clinical equivalent of this 15-day continuous exposure, a consumption of two cups of coffee per day and an oral exposure time of 10 min per cup were assumed. Accordingly, 15 days × 1440 min/day = 21,600 min of laboratory exposure, corresponding to 21,600 / (2 × 10 min/day) = 1,080 days, which is approximately equivalent to three years of clinical use.

Color measurement

Baseline and 15th-day color measurements of all specimens were performed using a spectrophotometer (Vita EasyShade V device; Vita ZahnFabrik, Bad Sackingen, Germany) within the CIE Lab* color space. The total color difference (ΔE) and lightness difference (ΔL) values were calculated. A ΔE value of 3.3 was considered the threshold for a clinically acceptable color change.

A graphical illustration of the study is shown in Figure 1.

Statistical analysis

Statistical analyses were performed using Jamovi (version 2.6; https://www.jamovi.org).

A two-way analysis of variance (ANOVA) was employed to evaluate the effects of material type and surface treatment on ΔE and ΔL values, and Tukey's honestly significant difference (HSD) post hoc test was used to determine intergroup differences. The level of significance was set at $p<0.05$.

Figure 2. Graphical illustration of the study.

Results

In this study, the color changes of two different CAD/CAM materials (Vita Enamic and Shofu Block HC) were evaluated after exposure to filter coffee following three different surface treatments (Optiglaze only, Mechanical Polishing only, and Mechanical Polishing + Optiglaze). The color change was analyzed based on the parameters of total color difference (ΔE) and lightness difference (ΔL).

Findings on lightness difference (ΔL)

A two-way analysis of variance (ANOVA) conducted on the ΔL values revealed that the model was statistically significant ($F(5,54) = 21.94$, $p < 0.001$, $R2 = 0.670$) (Table 1). The analysis results indicated that

- The main effect of material was statistically significant ($F(1,54) = 76.02$, $p < 0.001$), indicating a significant difference in the ΔL values between Vita Enamic and Shofu Block HC.
- The main effect of surface treatment was also significant ($F(2,54) = 12.03$, $p < 0.001$).
- The Material × Surface Treatment interaction was statistically significant ($F(2,54) = 4.81$, $p = 0.012$). This indicates that the effect of surface treatment on ΔL depends on the material used.

Owing to the significant interaction, simple effect analyses and post-hoc comparisons (Tukey HSD) were performed, yielding the following findings:

- In the Vita Enamic groups, specimens subjected to Mechanical Polishing Only exhibited a statistically significantly higher ΔL value (i.e., less darkening) than those in the Glaze Only group (Mean Difference (MD) = -1.460, p = 0.044) and the Mechanical+Glaze group (MD = +1.780, p = 0.007). No significant difference was detected between the Glaze Only and Mechanical+Glaze groups (MD = +0.320, p = 0.986).
- Conversely, in the Shofu Block HC groups, specimens with Glaze Only application showed a statistically significantly lower ΔL value (i.e., more darkening) than both the Mechanical Polishing Only group (MD = -1.890, p = 0.004) and the mechanical polishing + glaze group (MD = -1.700, p = 0.011). No significant difference was found between the Mechanical Polishing Only and Mechanical+Glaze groups (MD = +0.190, p = 0.999) (Tables 2 and 3).

Comparisons between material and surface treatment combinations demonstrated that the Vita Enamic with Mechanical Polishing Only group displayed statistically significantly higher ΔL values than almost all Shofu Block HC combinations (Shofu-Glaze: MD = +4.72, p < 0.001; Shofu-Mechanical: MD = +2.83, p < 0.001; Shofu-Mechanical+Glaze: MD = +3.02, p < 0.001) (Table 4 and Fig. 2).

Table 1. A two-way analysis of variance (ANOVA) was conducted on the ΔL values.

	Sum of squares	df	Mean square	F	p
Overall model	129.2	5	25.84	21.94	<0.001
Material	89.5	1	89.55	76.02	<0.001
Surface treatment	28.3	2	14.17	12.03	<0.001
Material & Surface treatment	11.3	2	5.66	4.81	0.012
Residuals	63.6	54	1.18		

Table 2. Post-hoc comparisons of the surface treatment.

Surface treatment		Surface treatment	Mean difference	SE	df	t	p
GLAZE	-	MANUEL	-1.675	0.343	54.0	-4.88	<0.001
	-	MANUEL+GLAZE	-0.690	0.343	54.0	-2.01	0.119
MANUEL	-	MANUEL+GLAZE	0.985	0.343	54.0	2.87	0.016

Note: Comparisons are based on estimated marginal means

Table 3. Post-hoc comparisons of the materials.

Material		Material	Mean difference	SE	df	t	p
ENAMIC	-	SHOFU	2.44	0.280	54.0	8.72	<0.001

Note: Comparisons are based on estimated marginal means

Table 4. Post-hoc comparisons of the material and surface treatment.

Material	Surface treatment		Material	Surface treatment	Mean difference	SE	df	t	p
ENAMIC	GLAZE	-	ENAMIC	MANUEL	-1.460	0.485	54.0	-3.008	0.044
		-	ENAMIC	MANUEL+ GLAZE	0.320	0.485	54.0	0.659	0.986
		-	SHOFU	GLAZE	3.260	0.485	54.0	6.716	<0.001
		-	SHOFU	MANUEL	1.370	0.485	54.0	2.823	0.069
		-	SHOFU	MANUEL+ GLAZE	1.560	0.485	54.0	3.214	0.026
	MANUEL	-	ENAMIC	MANUEL+ GLAZE	1.780	0.485	54.0	3.667	0.007
		-	SHOFU	GLAZE	4.720	0.485	54.0	9.724	<0.001
		-	SHOFU	MANUEL	2.830	0.485	54.0	5.831	<0.001
		-	SHOFU	MANUEL+ GLAZE	3.020	0.485	54.0	6.222	<0.001
	MANUEL+ GLAZE	-	SHOFU	GLAZE	2.940	0.485	54.0	6.057	<0.001
		-	SHOFU	MANUEL	1.050	0.485	54.0	2.163	0.272
		-	SHOFU	MANUEL+ GLAZE	1.240	0.485	54.0	2.555	0.127
SHOFU	GLAZE	-	SHOFU	MANUEL	-1.890	0.485	54.0	-3.894	0.004
		-	SHOFU	MANUEL+ GLAZE	-1.700	0.485	54.0	-3.502	0.011
	MANUEL	-	SHOFU	MANUEL+ GLAZE	0.190	0.485	54.0	0.391	0.999

Note: Comparisons are based on estimated marginal means

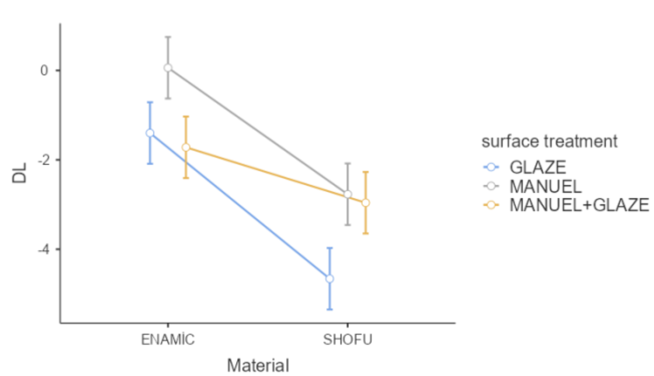

Figure 2. The interaction plot shows the estimated marginal means of ΔL for each material across the different surface treatments. Error bars represent ± 1 standard error.

Findings on total color difference (ΔE)

The two-way ANOVA performed on the ΔE values, representing the total color difference, confirmed that the model was significant ($F (5,54) = 14.70$, $p<.001$, $R2 = 0.576$) (Table 5).

- The main effect of material was significant ($F (1,54) = 41.33$, $p<.001$); Vita Enamic had significantly lower ΔE values than Shofu Block HC.
- The main effect of Surface Treatment was also significant ($F (2,54) = 14.48$, $p < 0.001$).
- However, the Material × Surface Treatment interaction was not statistically significant ($F (2,54) = 1.62$, $p = 0.207$). This finding suggests

that the relative effect of surface treatment on ΔE was similar for both materials.

As the interaction was not significant, post-hoc analyses (Tukey HSD) of the main effects were conducted:

- Comparison of Surface Treatments (Table 6): The mean ΔE of the group that underwent Mechanical Polishing Only was significantly lower than that of the groups that underwent glazing only (MD = -1.147, p<.001) and mechanical polishing + glazing (MD = -0.887, p<.001). No significant difference was found between the Glaze Only and Mechanical+Glaze groups (MD = +0.260, p = .480).
- Comparison of Materials (Table 7): Vita Enamic (when all surface treatments were combined) had a statistically significantly lower ΔE value than Shofu Block HC (Mean Difference = -1.17, p < 0.001).

The mean ΔE values for all study groups were found to be above the widely accepted clinical acceptability threshold of ΔE > 1.8 (Table 8 and Fig. 3).

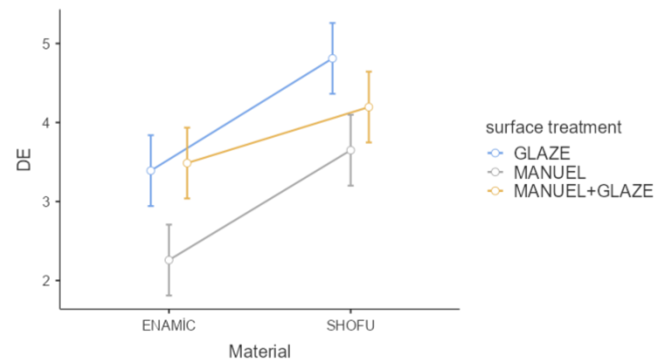

Figure 3. The interaction plot shows the estimated marginal means of ΔL for each material across different surface treatments. Error bars represent ± 1 standard error.

Table 5. Two-way analysis of variance (ANOVA) on ΔE values (Total color difference).

	Sum of squares	df	Mean square	F	p
Overall model	36.74	5	7.347	14.70	<0.001
Material	20.65	1	20.649	41.33	<0.001
Surface treatment	14.47	2	7.234	14.48	<0.001
Material & Surface treatment	1.62	2	0.810	1.62	0.207
Residuals	26.98	54	0.500		

Table 6. Post-hoc comparisons of surface treatment.

Surface treatment		Surface treatment	Mean difference	SE	df	t	p
GLAZE	-	MANUEL	1.147	0.224	54.0	5.13	<0.001
	-	MANUEL+GLAZE	0.260	0.224	54.0	1.16	0.480
MANUEL	-	MANUEL+GLAZE	-0.887	0.224	54.0	-3.97	<0.001

Note: Comparisons are based on estimated marginal means

Table 7. Post-hoc comparisons of material.

Material		Material	Mean difference	SE	df	t	p
ENAMIC	-	SHOFU	-1.17	0.183	54.0	-6.43	<0.001

Note: Comparisons are based on estimated marginal means

Table 8. Post-hoc comparisons of material and surface treatment.

Material	Surface treatment		Material	Surface treatment	Mean difference	SE	df	t	p
ENAMIC	GLAZE	-	ENAMIC	MANUEL	1.1319	0.316	54.0	3.580	0.009
		-	ENAMIC	MANUEL+GLAZE	-0.0959	0.316	54.0	-0.304	1.000
		-	SHOFU	GLAZE	-1.4207	0.316	54.0	-4.494	<.001
		-	SHOFU	MANUEL	-0.2585	0.316	54.0	-0.818	0.963
		-	SHOFU	MANUEL+GLAZE	-0.8048	0.316	54.0	-2.546	0.129
	MANUEL	-	ENAMIC	MANUEL+GLAZE	-1.2278	0.316	54.0	-3.884	0.004
		-	SHOFU	GLAZE	-2.5525	0.316	54.0	-8.075	<.001
		-	SHOFU	MANUEL	-1.3904	0.316	54.0	-4.398	<.001
		-	SHOFU	MANUEL+GLAZE	-1.9367	0.316	54.0	-6.126	<.001
	MANUEL+GLAZE	-	SHOFU	GLAZE	-1.3247	0.316	54.0	-4.191	0.001
		-	SHOFU	MANUEL	-0.1626	0.316	54.0	-0.514	0.995
		-	SHOFU	MANUEL+GLAZE	-0.7089	0.316	54.0	-2.242	0.236
SHOFU	GLAZE	-	SHOFU	MANUEL	1.1622	0.316	54.0	3.676	0.007
		-	SHOFU	MANUEL+GLAZE	0.6159	0.316	54.0	1.948	0.385
	MANUEL	-	SHOFU	MANUEL+GLAZE	-0.5463	0.316	54.0	-1.728	0.520

Note: Comparisons are based on estimated marginal means

Discussion

The findings of this study indicate that both the material type and surface treatment have a statistically significant effect on the color stability of CAD/CAM restorations.

The interaction between surface treatment protocols and the color stability of CAD/CAM dental materials can be quantified using ΔL, which reflects changes in lightness and indicates color changes when the materials are subjected to staining agents, such as coffee. This study demonstrated the significance of this interaction and highlighted the fundamental role of specific surface treatments play in increasing or decreasing susceptibility to color distortion. This result of the study is consistent with the literature. For instance, Korać et al. confirmed the staining potential of coffee in dental composites, noting substantial changes in ΔL values across different compositions and surface treatments (20). Variations in ΔL can be significantly influenced by the finishing technique applied—mechanical polishing, glazing, or a combination thereof—indicating that a single finishing approach may not yield optimal aesthetic results across all materials. The determination of the "best" surface treatment is not a one-size-fits-all scenario; it depends heavily on the material in question. Different CAD/CAM materials exhibit unique properties that respond differently to various surface treatments. For instance, while glazing may create a smooth surface that enhances gloss and aesthetic appeal, it may inadvertently form a layer more susceptible to staining than polished composite materials (27). Lauvahutanon et al. found that differences in ΔL among various CAD/CAM blocks immersed in coffee were indeed material-dependent, illustrating that some materials were less prone to discoloration when polished than those left glazed (28). Additionally, Eldwakhly et al. noted that the underlying composition of the materials—including resin matrices and filler types—can significantly affect their staining susceptibility, which is consistent with the observed ΔL changes. Higher filler content generally correlates with reduced susceptibility to staining, making the choice of surface treatment critical (27). Şişmanoğlu and Gürcan further supported the notion that resin matrix composition affects discoloration levels, with increased filler ratios leading to decreased discoloration (29).

This study showed that mechanical polishing yielded superior results, particularly for Vita Enamic. The primary reason is Vita Enamic's unique hybrid structure, consisting of an interwoven ceramic and polymer network. This composition provides a smoother and less porous surface than other materials, making it more suitable for mechanical polishing techniques that enhance the aesthetic results and color stability. This finding is also consistent with the literature. Vita Enamic's dual network structure allows it to achieve excellent flexural strength and elasticity, closely resembling the properties of natural dentin, which contributes to its durability during the polishing process (30). The combination of a ceramic framework with a polymer matrix results in an inherently smoother and less porous surface, facilitating effective mechanical polishing while minimizing potential stain penetration. The results of this study are consistent with findings by Rabiee et al., who noted that mechanical polishing improved the stain resistance of Vita Enamic, outperforming its glazed counterparts, which retained more discoloration after exposure to staining agents (31). In contrast, applying a glaze to Vita Enamic does not enhance its performance in the same way that mechanical polishing does. Although glazing can create an initially glossy appearance, it may introduce a less durable surface layer, increasing the vulnerability to staining, as the polymer matrix may absorb pigments and other coloring agents from food and beverages, leading to performance drawbacks (32). Fasbinder and Neiva highlighted that glazed surfaces tend to possess greater roughness than polished surfaces, contributing to increased stain retention and compromising the aesthetic longevity of the restoration (33). Moreover, the ideal surface treatment varies significantly based on the inherent characteristics of the material. As demonstrated by Eisa et al., the mechanical properties and surface roughness of Vita Enamic before and after polishing directly influence its stain resistance and aesthetic performance (34). Effective smoothing of the surface during mechanical polishing produces a finish that discourages the accumulation of pigments, thus preserving the original color of the restoration over time.

In this study, negative results were obtained in terms of color stability in Shofu samples (a glass polymer-based material) that had only been glazed. The application of glaze alone on Shofu, a glass polymer material, has been reported to produce concerning results regarding color stability. This phenomenon may be influenced by the characteristics of the glaze layer, which can retain pigments more readily than can the underlying, softer polymer matrix. The structural properties of Shofu affect its response to glaze treatments, particularly in its interaction with staining agents. Glaze application can result in a hardened surface layer that, while initially smooth and glossy, may become more susceptible to discoloration over time. In line with this study, Maciel et al. noted that the glazing process can lead to a surface that exhibits increased roughness after application, which may facilitate the retention of stains from dietary agents such as coffee and tea (35). This layer can create a barrier that allows external pigments to permeate more effectively than the untreated surface of the underlying polymer matrix. In contrast, mechanical polishing has been shown to enhance the discoloration performance of Shofu. The results of this study were consistent with those of previous studies. This technique reduces the surface roughness and produces a more compact surface layer. The compaction achieved through polishing minimizes the surface area exposed to staining agents, thereby significantly reducing the likelihood of color changes. Grangeiro et al. found that mechanically polished surfaces demonstrated improved resistance to color changes compared to glazed surfaces, as the polished finish limits the ingress of staining agents into the material (36). Furthermore, polishing improves the surface smoothness and helps seal the surface, thereby reducing porosity. A less porous surface allows for less penetration of pigments from staining agents into the material (37). Conversely, the application of glaze may deteriorate this compact structure, leading to a less effective barrier against discoloration. The properties of the glaze layer can create conditions that allow staining substances to infiltrate more easily, thus compromising the aesthetic integrity of the restoration.

In this study, mechanical polishing has been shown to be an effective method for maintaining color stability in both Vita Enamic and Shofu HC. This conclusion suggests that mechanical polishing may be a more reliable approach than glazing to ensure the long-term aesthetic longevity of restorative materials. Studies of ΔE values (total color difference) indicated that both materials exhibited lower color changes when subjected to mechanical polishing compared to glazing. Mechanical polishing results in a smooth surface that reduces surface roughness and porosity, which are crucial characteristics that influence the susceptibility of the material to staining by dietary agents. Stawarczyk et al. reported that polished surfaces consistently demonstrate lower ΔE values after exposure to staining substances, signifying better color stability (38). Vita Enamic's unique hybrid structure further contributes to its lower ΔE values, making it more resistant to discoloration. The combination of a ceramic network with a polymer matrix provides an increased filler content, which is associated with lower water absorption characteristics. These attributes may reduce the adsorption of dye molecules by the material, enhancing color stability (39). Gáspárik et al. noted that materials with higher filler content typically exhibit better resistance to staining, underscoring the importance of material composition in determining color stability (40). Additionally, the inherent structure of Vita Enamic allows it to interact less with staining agents, resulting in a slower discoloration rate than less dense materials. This characteristic is vital for establishing a clinically acceptable color-difference threshold, which is generally defined as ΔE values below 3.3 (41). The results of this study suggest that mechanical polishing is a superior method for ensuring color stability in both Vita Enamic and Shofu HC. This conclusion positions mechanical polishing not only as a recommended option but also as an essential practice for practitioners aiming to extend the aesthetic life of their restorations. Given the role of ΔE values in assessing color stability, choosing mechanical polishing over is a more effective and reliable approach than glazing to maintain the desired aesthetics of CAD/CAM materials in clinical practice.

For patients with high coffee consumption, clinicians should consider softening the impact of dietary staining agents on dental restorations by selecting hybrid ceramics, such as Vita Enamic. This material offers a favorable combination of aesthetic appeal and mechanical properties, providing a more predictable and longer-lasting aesthetic performance in terms of color stability. This study suggests that the hybrid structure of Vita Enamic, consisting of both ceramic and polymer networks, contributes to its reduced porosity and water absorption, thereby minimizing the absorption of dye molecules from coffee and other staining agents. Materials with higher filler contents, such as Vita Enamic, demonstrate better color stability, which is essential for patients who regularly consume beverages that cause stains. Based on the current literature, clinicians should avoid using glaze as the sole surface treatment method, particularly when using polymer-rich blocks such as Shofu Block HC. The evidence from this study suggests that mechanical polishing is superior for enhancing color stability and decreasing staining susceptibility. Polishing creates a compact, less porous surface that effectively reduces the likelihood of pigment penetration by coffee and other foods. If an exceptional gloss or shine is desired, clinicians may apply a light glaze layer over a mechanically polished surface. However, it is crucial to note that this may slightly increase the risk of discoloration due to the nature of the glaze, which can be more penetrable to staining agents than the polished surface beneath it. The combination of mechanical polishing followed by glazing may provide an aesthetically pleasing finish, but should be approached with caution, balancing the desire for shine with the potential for increased staining.

Limitations

This study had several limitations. First, the in vitro nature of the research limits the generalizability of the findings to clinical settings. The oral environment includes numerous dynamic factors, such as saliva, temperature fluctuations, mechanical forces, and microbial activity, which are difficult to replicate entirely under laboratory conditions. Second, only a single staining agent, filter coffee, was used in this study. This limits the scope of the findings, as the effects of other common staining agents (e.g., tea, red wine, and carbonated beverages) on the materials were not evaluated. Different agents may produce varying degrees of discoloration. Finally, color measurements were conducted only at the end of a two-week period, which simulates approximately three years of clinical aging under in vitro conditions. However, the potential impact of long-term exposure remains unknown, and it is unclear whether extended durations would yield different results. Therefore, further long-term studies are recommended to better understand the material performance over time.

Conclusion

The following conclusions were drawn in the scope of this in vitro study:

1. Material selection significantly influences the color stability. Vita Enamic exhibited generally higher resistance to color change induced by filter coffee compared to Shofu Block HC.
2. The surface treatment protocol plays a critical role in determining both the magnitude and direction of color change. Mechanical polishing provided the highest color stability for both CAD/CAM materials.
3. The effect of the surface treatment depended on the material. In particular, regarding the lightness parameter (ΔL), mechanical polishing yielded the most favorable results for Enamic, whereas the glaze-only application produced the most unfavorable results for Shofu.
4. In clinical practice, particularly for CAD/CAM restorations expected to be frequently exposed to staining agents such as coffee, mechanical polishing is preferred as the primary surface finishing method. Moreover, selecting the restorative material accordingly may enhance long-term aesthetic outcomes.

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