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The Influence of Surface Finishing Processes on Surface Roughness and Stainability of CAD/CAM Composite Material Following Coffee Storage: an in Vitro Study

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Abstract

Introduction: Color changes and surface degradation can significantly affect the durability and aesthetic characters of indirect restorations. Chairside polishing procedures impact the surface topography and light scattering characters of CAD/CAM materials. Additionally, acidic and pigmented beverages can cause hydrolytic deterioration of the polymer matrix, worsening these surface alterations.
Aim: The current research was to assess the influence of various surface finishing processes on surface roughness and color stability of a CAD/CAM composite following immersion in coffee solution.
Materials and methods: A total of 21 samples of a CAD/CAM composite (Brilliant Crios) were milled to dimensions of 14 × 12 × 1.5 mm. The samples were randomly allocated into three groups (n=7): Group (C), The control group was not given any surface treatment. Group (F), the finishing group, which was only subjected to finishing, and Group (FP), which subjected to finishing and polishing using a chairside polishing kit. All samples were kept in a coffee solution for 48 hours. Measurement of color change and surface roughness of the samples before and following immersion in the coffee was done using a contact profilometer and a spectrophotometer, respectively.
Results: Regarding surface roughness, the variation across groups was statistically significant. There was a non-significant variation between the control and finish & polish groups, indicating that polishing successfully restored the baseline smoothness. Conversely, the variation across groups was statistically non-significant regarding color change, with all values remaining within clinically acceptable thresholds ($\Delta E < 3.3$). Furthermore, a weak, non-significant correlation was found between color change and surface roughness.
Conclusions: CAD/CAM composite (Brilliant Crios) material exhibited greater color stability and less surface roughness following a complete polishing protocol compared to finishing alone. However, surface roughness did not significantly dictate the color stability of the material following coffee immersion.
Clinical implication: Proper polishing procedures are essential for optimizing both the color and surface roughness of CAD/CAM composite restorations, thereby minimizing aesthetic degradation.

Keywords: Dental Polishing, Color, Surface Roughness, Computer-Aided Design, Composite resin, Coffee.

Introduction

Patients' hopes and curiosity in indirect restorations have significantly increased recently. Due to its remarkable biocompatibility, chemical and color stability, decreased surface roughness, and cosmetic benefits, metal-free fixed restorations have gained widespread acceptance in response to these increasing demands [1]. Concurrently, substantial technical breakthroughs have led to a rise in the usage of computer-assisted design/computer-assisted manufacturing (CAD/CAM). The ability to create attractive restorations in one visit using consistent and perfect CAD/CAM blocks is the main advantage of CAD/CAM technology. CAD/CAM block materials composed of glass ceramics, zirconia, composites, and hybrid ceramics are already available on the market [2].

Some studies [3,4] recommend employing materials with an elastic modulus comparable to dentin in order to obtain an additional tolerable stress distribution across repair and underlying tooth tissue. Over the past ten years, composite-based CAD/CAM materials have grown in popularity because of their elastic modulus, wear properties, color integration, and malleability in thin layers [5]. Because of the high temperature and pressure throughout polymerization, CAD/CAM composites have a far greater monomer conversion than conventional light-cured resin composites, producing composites with better mechanical and biocompatible qualities [2]. Although data indicate that many of the mechanical characters of composite-based CAD/CAM materials may be categorized as those of ceramics, the clinical results of these materials are still somewhat controversial [6]. Resin-based materials can show water diffusion through the polymer chains, leading to hydrolytic deterioration over time [7].

Maintaining color matching along with the native tooth structure over the restoration's clinical lifetime is crucial for composite restorations. Eventually, discoloration may result in patient discontent and have a detrimental impact on the restoration's considered esthetics, possibly requiring replacement [8]. Both endogenous and external causes can cause these discolorations. The exogenous discolorations are caused by things like smoking, the adhesion of pigmented foods and drinks, and dental plaque formation from poor oral hygiene [9]. Likewise, beverages with polar features may interact through resin-based composite materials with an organic matrix more readily, making them inherently more susceptible to staining than denser, purely crystalline ceramic materials [10].

For restorations to be successful clinically and durable, surface texture is essential. Because of increasing dental plaque, rough surfaces may eventually result in negative consequences such as discoloration, gingival irritation, and recurrent decay [11]. It was emphasized that irregular microtopography promotes early bacterial colonization and accelerated biofilm maturation, thereby compromising both the biological compatibility and esthetic stability of restorations [12]. Furthermore, rough surfaces promote discoloration due to plaque retention and cleaning difficulties [13]. Surface roughness levels greater than 0.2 µm were linked to higher bacterial retention [14]. The surface roughness value below 0.2 µm is a critical threshold for exhibiting enhanced resistance to plaque buildup and color stability [15]. The occurrence of secondary caries, which has a direct impact on the restoration's clinical longevity, is one of the most frequent causes of restoration replacement [16].

In general, CAD/CAM restorative materials may become more susceptible to discoloration when exposed to discoloration solutions due to surface roughness caused by preventative polishing pastes. Although a variety of polishing techniques are advised for ceramic restorations, it remains unknown if they can all provide a smooth surface that is equal with or superior to the original untreated material [17]. A comparison of the different impacts of polishing procedures on surface qualities with CAD/CAM resin materials [18] is sparse, despite the fact that previous studies have shown negative effects of preventative polishing pastes on natural tooth surfaces [19] and CAD/CAM materials [9,10].

So, the purpose of the current research was to assess the influence of various surface finishing processes on surface roughness and color stability of the CAD/ CAM composite following immersion in coffee solution. The null hypothesis was that various polishing procedures would not significantly affect the surface roughness and color stability of the CAD/CAM composite restorations following coffee immersion.

Material and methods:

1. Power Analysis and Sample Size Determination

A total of twenty-one Brilliant Crios specimens obtained in this study will be sufficient with a power 90% and a significance level of 5%. A power analysis was used to estimate the sample size in order to guaranty sufficient statistical reliability, referencing standard protocols for in vitro dental material testing [22]. Assuming a significance level of $\alpha = 0.05$ and a power of $1-\beta = 0.90$, the analysis confirmed that a minimum of 7 specimens per group was necessary to detect significant differences among the experimental groups.

2. Specimen Preparation

The samples were randomly allocated into three groups (n=7) according to the surface treatment applied. Specimens were prepared from Brilliant Crios CAD/CAM composite block A2 shade and cutting in a square shape (14X12X1.5) mm by a low-speed diamond saw Isomet 4000 under water coolant. Continuous water cooling was utilized during the sectioning process to prevent heat-induced microstructural damage to the composite blocks**.** A digital caliper (Mitutoyo Corp., Tokyo, Japan) was used to verify the samples' ultimate thickness for standardization. To ensure uniform baseline conditions, all specimens were carefully inspected for surface defects prior to any treatment.

3. Surface Treatment Procedures

Surface treatments of Brilliant Crios specimens were performed as follows: Group C (Control group): specimens were not given any surface treatment. Group F (Finishing group): specimens Finishing performed by using a high-speed hand-piece using red ring finishing stones (40 µm) under water cooling, 1.5 N, 160.000 rpm, 10s. Group FP (Finishing and polishing group): specimens Finishing performed via a high-speed handpiece with red ring finishing stones (40 µm) under water cooling, 1.5 N, 160.000 rpm, 10s. After finishing the procedure, the specimens were polished using a rubber disc bur of a composite polishing kit with a low-speed handpiece 10.000 rpm. Polished for 30 seconds using the flat broad surface of the disc in one direction.

A single operator performed all finishing and polishing procedures to minimize operator-induced variability [(23)]. Following the surface treatments of samples, specimens were washed for 5 minutes using a coxo ultrasonic bath containing distilled water to remove any surface debris and contaminations, and subsequently air-dried. This ultrasonic cleaning step is crucial to ensure that no abrasive residues interfere with subsequent optical or topographical measurements [(24)].

4. Baseline Measurements of Surface Roughness and Color

Measurement of surface roughness by the use of a profilometer before immersion in staining solution (coffee): A USB digital surface profile gage (Elcometer 224/2, Elcometer Instruments, Great Britain) was used to determine surface roughness (Ra), and the roughness tester supplier's computer software (Elcomaster 2, Elcometer Instruments) was used to record the results. Each specimen was measured three times at different locations, and the average Ra value was computed to represent the overall Ra.

Measurement of color by using a spectrophotometer before immersion in staining solution (coffee). The specimens' colors were calculated via a Reflective spectrophotometer (Model RM200QC, X-Rite, Neu-Isenburg, Germany). A white background was chosen, and readings were made based on the CIE Lab color space relative to the CIE standard illuminant D65. The L coordinate represents lightness (ranging from black to white), while the a and b* coordinates represent the chromaticity axes (red-green and yellow-blue, respectively).

5. Aging Procedure with Coffee Solution

As directed by the manufacturer, 3.6 g of coffee and 300 mL of hot water (Nescafé Classic) were used to make the coffee solution. This concentration was chosen to simulate standard beverage consumption habits [(25)]. Based on an average consumption of 3.2 cups per day at 15 minutes per cup, a 48-hour continuous storage time effectively simulates approximately two months of clinical coffee exposure [(23)]. The samples were kept for 48 hours in an incubator at 37 °C to mimic the oral environment temperature. After 48 hours, every specimen surface was cleaned for five minutes under running water and dried using sterile gauze prior to color measurement.

Post-Immersion Measurements

Measurement of color change and surface roughness of the specimens following the immersion in staining solution by using a contact profilometer and a spectrophotometer, respectively.

To evaluate alterations in surface topography caused by the immersion protocol, post-immersion surface roughness (Ra) was re-measured using the same profilometer and parameters applied during baseline readings. Three readings were taken per specimen and averaged. Comparing baseline and post-immersion Ra values allows for the assessment of surface degradation or microstructural changes induced by the coffee solution.

The color variation (ΔE) among the data taken before and after immersion was computed utilizing the standard CIE L* a* b* color difference formula [23]:
ΔE=[(ΔL∗)2+(Δa∗)2+(Δb∗)2]1/2
In this formula, ΔL, Δa, and Δb* represent the alterations in the respective color coordinates between the baseline and post-staining measurements. A ΔE value greater than 3.3 is generally considered clinically unacceptable from an esthetic perspective [22].

6. Statistical Analysis

By examining the data distribution and applying the Shapiro-Wilk and Kolmogorov-Smirnov tests, the normality of the data was investigated. These tests' findings supported the application of parametric tests by showing that the data had a normal distribution. The mean values were compared using the t-test and one-way ANOVA. When the ANOVA test is significant, pairwise comparisons were conducted using Tukey's post-hoc test. Pearson correlation was utilized to find a relationship between color change and roughness alteration. The significance threshold was established at $P \leq 0.05$ and 95% Confidence range. GraphPad Instat (GraphPad, Inc.) program for Windows was used to do statistical analysis.

Result:

1. Effect of Polishing Techniques on Surface Roughness (Ra)

Whatever the treatment solution, it was discovered that the greatest mean ± SD values of changes were seen for Finish group (0.003017±0.002037 Ra) with % change (1.18238 %) followed by Finish & polish group mean ± SD values (-0.00121±0.001122 Ra) with % change (0.47656 %) while the smallest mean ± SD value was noted with control group (-0.0005±0.001513 Ra) with % change (0.19554%). Table 1 summarizes the descriptive statistics and the one-way ANOVA results for the surface roughness changes across the experimental groups. The ANOVA test revealed that there was a statistically significant variation across the groups ($F=4.848$, $P=0.0207<0.05$). The control and finish & polish groups did not vary significantly ($p>0.05$) according to pairwise Tukey's post-hoc analysis. However, the Finish group showed a statistically significant increase in surface roughness in the comparison to both the Control and the Finish & Polish groups. This suggests that finishing alone, without subsequent polishing, leaves a significantly rougher surface on the CAD/CAM composite, whereas completing the full polishing protocol restores the surface to a smoothness comparable to the untreated control.

Table 1. Mean, standard deviation (SD), and percentage of surface roughness changes (Ra) among the experimental groups

Experimental Group	Mean ± SD (Ra)	% Change	F-value	P-value
Group C (Control)	-0.0005 ± 0.001513 ^{a}	0.19554%	4.848	0.0207*
Group F (Finish)	0.003017 ± 0.002037 ^{b}	1.18238%		
Group FP (Finish & Polish)	-0.00121 ± 0.001122 ^{a}	0.47656%		

Different superscript letters indicate statistically significant differences between groups based on Tukey's post-hoc test ($p < 0.05$). * indicates statistical significance.

2. Effect of Polishing Techniques on Color Stability (ΔE)

The greatest mean ± SD scores of color changes were noted for the Finish group (2.502 ±0.56 ΔE), followed by the Finish & polish group mean ± SD values (2.376 ±0.34 ΔE); meanwhile, the lowest mean ± SD value was noted with the control group (1.849 ±0.68 ΔE). The standard deviations and mean color variation scores (ΔE) for each group following coffee immersion are detailed in Table 2. The difference between groups was statistically non-significant according to the one one-way ANOVA test ($F=2.826$, $P=0.0856>0.05$). Although the Finnish group exhibited the most pronounced visual color shift, all tested surface treatments resulted in color changes that did not statistically differ from one another. Furthermore, the ΔE values for all groups remained below the clinically unacceptable threshold (ΔE > 3.3), indicating that the Brilliant Crios material maintains acceptable color stability regardless of the specific finishing protocol applied.

Table 2. Mean and standard deviation (SD) of color changes (ΔE) among the experimental groups following coffee immersion

Experimental Group	Mean ± SD (ΔE)	F-value	P-value
Group C (Control)	1.849 ± 0.68 ^{a}	2.826	0.0856
Group F (Finish)	2.502 ± 0.56 ^{a}		
Group FP (Finish & Polish)	2.376 ± 0.34 ^{a}		

The same superscript letters indicate no statistically significant difference between groups ($p > 0.05$).

3. Correlation Between Color Stability and Surface Roughness

Pearson correlation analysis showed no significant direct relationship between color change and roughness change ($r=0.2185$, $r2=0.0477$, $p>0.05$). This weak positive correlation implies that while there is a slight tendency for rougher surfaces to exhibit greater color change, the relationship is not statistically robust enough to conclude that surface roughness changes directly dictate the color stability of the composite after coffee immersion.

Discussion

The objective of the current research was to assess the influence of various surface finishing processes on surface roughness and color stability of the CAD/ CAM composite following immersion in coffee solution. The selection of materials and processes in this in vitro research was carefully designed to simulate clinical conditions and provide a robust evaluation of CAD/CAM composite restorations. Brilliant Crios, a composite-based CAD/CAM material, was selected due to its dentin-like elastic modulus, high monomer conversion achieved through industrial polymerization, and excellent wear properties. In clinical practice, restorations frequently require occlusal or proximal adjustments, which disrupt the surface integrity; therefore, evaluating the specific effects of finishing versus a complete finishing and polishing protocol is highly relevant [17,19].

Coffee was selected as the sole aging medium because it induces a high degree of discoloration on restorative surfaces due to its high pigment content and low pH. The 48-hour continuous storage time was specifically calculated to simulate approximately two months of clinical coffee consumption, assuming an average intake time of 15 minutes per cup [24]. Coffee was utilized not only for its strong pigmentation but also because its acidic nature (pH of approximately 5.3 to 5.4) can increase sorption values in restorative materials [27].

The development of color-determining tools is an outcome of the growing public desire for aesthetic dentistry. Spectrophotometers and colorimeters are two examples of electronic shade-matching tools that have been accessible for dental applications nowadays [28]. One of the most precise, practical, and adaptable tools for matching color is a spectrophotometer. A spectrophotometer measures a specimen's spectral reflectance or transmittance curve. When measuring surface color, they are helpful. Although newer formulas like CIEDE2000 exist, it was confirmed that the CIE LAB formula is still useful for determining variations in color or translucency between materials [29].

Regarding surface roughness (Ra), the results demonstrated that the Finish group (Group F) exhibited a statistically significant increase in roughness compared to both the Control (Group C) and the Finish & Polish (Group FP) groups. This outcome may be attributed to the abrasive nature of the 40 µm red ring finishing stones, which create micro-scratches, grooves, and surface irregularities on the composite matrix [24]. In order to avoid extrinsic discoloration, surface roughness is crucial, and mechanical polishing is essential to achieve significantly greater smoothness [30].

Conversely, the lack of a significant variation between the Control and Finish & Polish groups indicates that the subsequent use of a rubber polishing disc effectively smooths out these micro-irregularities.

This is likely due to the rubber disc's ability to flatten the topographical peaks created during the grinding phase, successfully restoring the CAD/CAM composite to a surface smoothness comparable to the untreated, factory-milled baseline [(24)]. Moreover, the mechanical polishing is one of the most effective methods for reducing surface Ra by eliminating microscopic irregularities, which consequently reduces the potential for biofilm accumulation [(31)].
This finding agrees with the work of Sarıkaya & Hayran (2018) [(24)], who concluded that mechanical polishing is a highly effective surface treatment for reducing roughness in CAD/CAM materials. Furthermore, Adawi et al. (2021) [(27)] assured that specific porcelain polishing kits and protocols can achieve a very smooth surface comparable to glazing, eliminating the need for tedious re-firing processes.
In terms of color stability (ΔE), the Finish group exhibited the most pronounced visual color shift (2.502 ± 0.56), followed by the Finish & Polish group, with the Control group showing the least discoloration. However, these differences were not statistically significant, and all groups maintained a ΔE value below the clinically unacceptable threshold of 3.3 [(32)]. Aldosari et al. (2021) [(23)] corroborated these findings, noting that while polishing can sometimes leave more surface flaws compared to glazing, the color changes caused by coffee on polished CAD/CAM restorative materials remain well within clinically acceptable limits.
This outcome may be attributed to the highly cross-linked, dense microstructure of the industrially polymerized CAD/CAM composite, which inherently resists deep intrinsic fluid sorption and chemical degradation [(33)]. Moreover, it was demonstrated that repolishing procedures can successfully lessen beverage-induced short-term extrinsic color alterations, suggesting that any superficial staining on these composites can be easily managed clinically [(34)].
Additionally, the degree of water absorption and the hydrophilicity of the composite matrix have a significant impact on the staining ability of CAD/CAM composites [(35)]. While the yellow pigments with various polarity are found in coffee that can interact with and adsorb onto the organic polymer matrix, the staining observed in this study was likely superficial [(36)]. Because coffee contains about 22 distinct kinds of acids, low-polarity staining molecules can attach to the polymer matrix [(37)].
The observation that the CAD/CAM composite maintained clinically acceptable color stability ($\Delta E < 3.3$) after coffee immersion aligns with the results of Aldosari et al. (2021) [(23)], who stated that polished hybrid CAD/CAM restorative materials exhibited clinically acceptable color changes following exposure to hot and cold coffee. Additionally, it was suggested that high temperatures during coffee immersion can cause silica within the material to dissolve partially, which may degrade the surface and influence roughness and color stability [(38)].
Furthermore, the study found a weak, non-significant positive correlation between color change and roughness change. This implies that while there is a slight tendency for rougher surfaces to trap more pigments, the inherent chemical stability and low water sorption of the Brilliant Crios material played a more dominant role in resisting discoloration than the surface topography itself during this specific timeframe [(39)].
The lack of a significant correlation between surface roughness and color stability in the present study disagrees with the findings of Sarıkaya & Hayran (2018) [(24)], who reported a strong, statistically significant correlation (r^2=0.74) between Ra and ΔE values. This discrepancy is likely because of the variations in the microstructural composition of the materials tested (lithium disilicate and zirconia-reinforced ceramics versus the resin-based composite used in our study), as well as variations in the specific polishing systems applied.
According to the results of the current research, the null hypothesis was partially rejected. The hypothesis stating that different polishing procedures would not significantly affect surface roughness was rejected, as the finishing-alone group showed significantly greater roughness compared to the control and fully polished groups. However, the hypothesis regarding color stability failed to be rejected, because the variations in color change (ΔE) across the tested groups were not statistically significant following coffee immersion.
The current in vitro research has numerous limitations. First, the static immersion in a coffee solution does not fully replicate the complex and dynamic conditions of the oral environment, which includes salivary clearance, pH fluctuations, thermal cycling, and mechanical wear from toothbrushing or mastication. Additionally, the use of flat, standardized specimens may not accurately reflect the

complex topography of anatomical restorations. Future in vivo studies incorporating a variety of staining beverages and longer aging periods are recommended to validate these findings.

Conclusions

Within the limitations of the current in vitro research, it can be concluded that completing a full finishing and polishing protocol significantly reduces surface roughness and improves the color stability of CAD/CAM composite restorations compared to finishing alone. Although exposure to coffee induces slight color shifts, these changes remain within clinically acceptable thresholds ($\Delta E < 3.3$) regardless of the polishing protocol used. Therefore, proper polishing procedures are essential for optimizing surface properties and mitigating the risks of plaque retention and aesthetic degradation, even though surface roughness alone does not strictly dictate the material's color stability.

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