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ORIGINAL RESEARCH

Evaluation of Surface Roughness and Color Stability of CAD/CAM Restorative Materials After Exposure to Different Staining Agents

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ABSTRACT

Background: The aesthetic longevity of CAD/CAM restorative materials is influenced by surface roughness and color stability. Various staining agents encountered in daily life can impact these properties, potentially affecting clinical outcomes. This study evaluates the surface roughness and color stability of different CAD/CAM restorative materials after exposure to commonly consumed staining agents. **Materials and Methods:** Three CAD/CAM restorative materials—lithium disilicate glass-ceramic, hybrid ceramic, and zirconia—were selected for evaluation. A total of 60 specimens (n=20 per material) were fabricated and polished. Baseline surface roughness (Ra) and color values (CIE L*ab**) were recorded using a profilometer and a spectrophotometer, respectively. The specimens were immersed in staining solutions (coffee, red wine, and cola) for 14 days, with distilled water as the control. Post-immersion measurements were taken, and statistical analysis was performed using ANOVA and Tukey's post-hoc test ($p<0.05$). **Results:** Lithium disilicate exhibited the highest color change ($\Delta E=6.2\pm0.5$) after exposure to red wine, followed by hybrid ceramic ($\Delta E=4.8\pm0.4$) and zirconia ($\Delta E=3.1\pm0.3$). Surface roughness increased significantly in lithium disilicate ($Ra=0.54\pm0.02$ µm) and hybrid ceramic ($Ra=0.47\pm0.03$ µm) after immersion in coffee, whereas zirconia demonstrated minimal changes ($Ra=0.31\pm0.02$ µm). Statistical analysis indicated significant differences among materials and staining solutions ($p<0.05$). **Conclusion:** Lithium disilicate and hybrid ceramics showed higher susceptibility to staining and surface roughness alterations compared to zirconia. Among the staining agents, red wine caused the most significant color change, while coffee led to increased surface roughness. Zirconia exhibited superior resistance to both parameters, making it a more durable option for long-term aesthetic restorations.

Keywords: CAD/CAM, restorative materials, color stability, surface roughness, staining agents, lithium disilicate, zirconia, hybrid ceramic.

INTRODUCTION

The demand for highly aesthetic and durable restorative materials has led to the widespread use of computer-aided design and computer-aided manufacturing (CAD/CAM) technology in dentistry. CAD/CAM materials, including lithium disilicate glass-ceramics, hybrid ceramics, and zirconia, are widely used for fabricating crowns, veneers, and inlays due to their superior mechanical properties and aesthetic appeal (1,2). However, their long-term clinical success depends on factors such as surface roughness and color stability, which can be affected by exposure to various staining agents in the oral environment (3).

Surface roughness is a critical parameter influencing plaque accumulation, wear resistance, and overall aesthetics of dental restorations. A smooth surface reduces bacterial adhesion and enhances the longevity of restorations, whereas increased roughness can lead to discoloration, biofilm formation, and surface

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degradation (4,5). Polishing techniques and material composition play significant roles in determining the final surface texture, which, in turn, influences susceptibility to staining (6).

Color stability is another essential factor for maintaining aesthetic integrity over time. Various dietary substances such as coffee, red wine, tea, and cola contain pigments capable of causing discoloration in restorative materials (7,8). Studies have shown that lithium disilicate ceramics exhibit higher susceptibility to staining compared to zirconia, which demonstrates greater resistance due to its lower porosity and dense microstructure (9). Additionally, the degree of color change depends on the composition of the material, surface finish, and duration of exposure to staining agents (10).

Despite extensive research on the mechanical and optical properties of CAD/CAM materials, there is limited comparative data on the effects of different staining agents on their surface roughness and color stability. Therefore, this study aims to evaluate and compare the changes in surface roughness and color stability of lithium disilicate, hybrid ceramic, and zirconia after immersion in common staining solutions over a defined period. The findings will provide insights into material selection for long-lasting aesthetic restorations.

MATERIALS AND METHODS

Specimen Preparation

In this study, three CAD/CAM restorative materials were evaluated: lithium disilicate glass-ceramic (IPS e.max CAD, IvoclarVivadent), hybrid ceramic (Vita Enamic, Vita Zahnfabrik), and zirconia (Katana Zirconia, Kuraray Noritake). A total of 60 disk-shaped specimens (n=20 per material) were fabricated using a CAD/CAM milling system, with dimensions of 10 mm in diameter and 2 mm in thickness. The specimens were polished according to the manufacturers' recommendations using diamond finishing burs and polishing kits.

Baseline Surface Roughness and Color Measurement

Prior to immersion in staining solutions, the initial surface roughness (Ra) of each specimen was measured using a contact profilometer (Mitutoyo SJ-210, Japan). Three measurements were taken from different areas of each specimen, and the mean value was recorded.

For color assessment, a spectrophotometer (Vita Easyshade V, Vita Zahnfabrik) was used to record the baseline color parameters based on the CIE L*a*b* system. Three readings were taken per specimen, and the mean values were recorded to establish the initial color baseline.

Staining Protocol

The specimens were divided into four subgroups (n=5 per material) and immersed in different staining solutions:

- **Group 1 (Control):** Distilled water
- **Group 2:** Coffee (Nescafé Classic, Nestlé)
- **Group 3:** Red wine (Merlot, 12% alcohol)
- **Group 4:** Cola (Coca-Cola, The Coca-Cola Company)

Each specimen was immersed in 20 mL of the respective solution and stored at 37°C in an incubator. The solutions were refreshed every 24 hours for a total duration of 14 days.

Post-Immersion Measurements

After the immersion period, surface roughness and color measurements were repeated using the same methods described earlier. The color change (ΔE) was calculated.

Statistical Analysis

Data analysis was conducted using SPSS software (version 26.0, IBM Corp.). A one-way analysis of variance (ANOVA) followed by Tukey's post-hoc test was performed to determine significant differences between groups. A p-value of <0.05 was considered statistically significant.

RESULTS

Surface Roughness Changes

The surface roughness (Ra) values of the CAD/CAM restorative materials before and after immersion in staining agents are presented in **Table 1**. Lithium disilicate showed the highest increase in roughness after exposure to coffee (Ra = 0.54 ± 0.02 µm), followed by red wine (Ra = 0.50 ± 0.03 µm) and cola (Ra = 0.48 ± 0.02 µm). Hybrid ceramic exhibited a moderate increase in roughness, with the highest value recorded after coffee immersion (Ra = 0.47 ± 0.03 µm). Zirconia demonstrated the least alteration in surface roughness, with minimal changes observed in all staining groups (Ra < 0.31 µm). The control group (distilled water) showed no significant surface roughness changes for any material (**Table 1**).

Color Stability Changes

Color change (ΔE) values after exposure to different staining agents are summarized in **Table 2**. Among the materials tested, lithium disilicate demonstrated the greatest color change, particularly after red wine immersion (ΔE = 6.2 ± 0.5), followed by cola (ΔE = 5.1 ± 0.4) and coffee (ΔE = 4.5 ± 0.3). Hybrid ceramic exhibited moderate staining, with ΔE values ranging from 3.8 to 4.8, depending on the staining solution. Zirconia showed the least discoloration, with the highest ΔE recorded after red wine exposure (ΔE = 3.1 ± 0.3). The control group (distilled water) exhibited negligible color change (ΔE < 0.6) across all materials (**Table 2**).

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Statistical Analysis

ANOVA revealed significant differences in surface roughness and color change among the different materials and staining solutions ($p < 0.05$). Post-hoc analysis indicated that lithium disilicate was significantly more affected by staining solutions compared to zirconia ($p < 0.01$). Coffee and red wine caused the most substantial changes in both surface roughness and color stability, while cola had a moderate impact. The control group remained stable in both parameters, confirming that staining agents contribute to the degradation of CAD/CAM materials.

Table 1: Surface Roughness Before and After Staining

Material	Ra Before (µm)	Ra After Coffee (µm)	Ra After Red Wine (µm)
Lithium Disilicate	**0.25**	**0.54**	**0.5**
Hybrid Ceramic	**0.3**	**0.47**	**0.42**
Zirconia	**0.22**	**0.31**	**0.28**

Table 2: Color Change (ΔE) After Staining

Material	ΔE After Coffee	ΔE After Red Wine	ΔE After Cola
Lithium Disilicate	**4.5**	**6.2**	**5.1**
Hybrid Ceramic	**3.8**	**4.8**	**4.3**
Zirconia	**2.5**	**3.1**	**2.9**

DISCUSSION

The findings of this study indicate that CAD/CAM restorative materials exhibit varying degrees of surface roughness and color changes when exposed to different staining agents. Lithium disilicate demonstrated the highest susceptibility to both surface alterations and color changes, while zirconia exhibited the least changes, highlighting its superior resistance to staining and surface degradation.

Surface roughness is a critical factor influencing plaque accumulation, wear resistance, and aesthetics of dental restorations (1,2). The results of this study showed that coffee and red wine caused significant increases in surface roughness, particularly in lithium disilicate and hybrid ceramic specimens. These findings align with previous studies reporting that acidic staining agents can degrade the surface integrity of glass-ceramic-based materials, leading to increased roughness and potential bacterial adhesion (3,4). The roughening effect may be attributed to the acidic nature of coffee and red wine, which can erode the surface glaze and increase porosity, making the material more prone to further staining (5,6). In contrast, zirconia exhibited minimal surface roughness alterations, likely due to its dense microstructure and high wear resistance, which makes it less susceptible to chemical degradation (7).

Color stability is a major concern in esthetic dentistry, as discoloration can compromise the longevity of restorations (8,9). In this study, red wine caused the most significant color change in all materials, followed by cola and coffee. This aligns with previous research suggesting that red wine's polyphenolic content and acidic pH contribute to deep pigmentation and enamel degradation (10,11). Lithium disilicate exhibited the highest ΔE values, indicating its greater vulnerability to color alterations, which could be attributed to its higher glass content and increased water absorption (12). Hybrid ceramic also showed moderate staining susceptibility, which may be due to its resin component that can absorb pigments over time (13). Conversely, zirconia demonstrated the lowest color changes, confirming its superior resistance to staining, as reported in earlier studies (14).

The variations in staining susceptibility among the tested materials can be explained by differences in microstructure and composition. Lithium disilicate contains a high proportion of glass matrix, making it more prone to pigment absorption and structural degradation (15). Hybrid ceramic, which combines ceramic and polymer components, exhibits intermediate staining resistance, as the polymer content can absorb staining agents (16). Zirconia, being a polycrystalline material with minimal glass phase, resists staining due to its dense and inert structure (17).

The clinical implications of these findings suggest that material selection should be based on the patient's dietary habits and esthetic expectations. For patients who frequently consume staining agents such as coffee and red wine, zirconia may be a preferable option due to its superior resistance to discoloration and surface degradation (18,19). However, if lithium disilicate or hybrid ceramics are used, additional protective measures such as glazing, surface coatings, or periodic polishing may be required to maintain long-term esthetics (20).

Despite the valuable insights provided by this study, some limitations must be acknowledged. The in vitro nature of the experiment may not fully replicate the oral environment, where factors such as saliva, temperature fluctuations, and mechanical wear can influence surface roughness and staining dynamics (21). Additionally, the duration of staining exposure in this study was limited to 14 days, whereas long-term clinical performance may vary (22). Future research should explore extended immersion periods, different polishing protocols, and the impact of artificial saliva

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on material stability to enhance clinical relevance (23,24).

CONCLUSION

In conclusion, lithium disilicate and hybrid ceramics exhibited significant surface roughness and color changes when exposed to staining agents, with red wine causing the most pronounced effects. Zirconia demonstrated superior resistance, making it a more durable option for esthetic restorations. These findings emphasize the importance of material selection and post-placement care to ensure the longevity and aesthetic success of CAD/CAM restorations.

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