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The Effect of Gochujang Immersion on Color Change and Surface Roughness of Nanofilled Resin Composite

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Abstract

Introduction: Nanofilled resin composites are popular for their aesthetics but are vulnerable to discoloration and surface degradation, particularly in acidic environments. Gochujang, a Korean chili paste, is increasingly consumed and may affect dental restorations. **Purpose:** To evaluate the effect of gochujang sauce immersion on the color stability and surface roughness of nanofilled resin composite. **Methods**: Thirty-three Filtek™ Z350 XT A3 samples were divided into three groups (n=11): immediate control, distilled water control, and gochujang treatment. The treatment group was immersed daily in a 1:1 gochujang-distilled water solution (16 h) and distilled water (8 h) for four days at 37°C. Color change (ΔE) was measured with a VITA Easyshade V spectrophotometer; surface roughness (Ra) with a Taylor Hobson Surtonic S-100. **Results:** Gochujang immersion significantly increased color change (ΔE, $p<0.001$) and surface roughness (Ra, $p=0.009$) compared to controls between groups ($p<0.05$). **Conclusion:** Gochujang immersion adversely affects both color stability and surface roughness of nanofilled resin composites.
Keywords: Color change; gochujang; surface roughness

Introduction

The rising popularity of Korean cuisine in Indonesia, particularly dishes containing gochujang (Korean chili paste), has led to greater exposure of dental restorations to acidic and pigmented foods. Recent surveys indicate that gochujang is present in over 90% of Korean barbecue menus, and its consumption has risen sharply among young adults, a demographic with a high prevalence of resin composite restorations.[1-3]

Gochujang is a traditional Korean fermented condiment with a red paste-like consistency and a distinctive sweet and spicy flavor, made from fermented soybean powder (*meju*), rice flour, and red chili powder.[4] Used since the 16th century in Korean cuisine, its fermentation process produces complex compounds such as bioactive peptides and organic acids, contributing to its low pH and potentially erosive characteristics.[5-7] Figure 1 illustrates the typical appearance of gochujang paste.

Figure 1. Traditional gochujang paste.[8]

Containing bioactive substances such as capsaicin and vitamin C, gochujang also exhibits antioxidant and anticancer properties. Its pH of approximately 4.44 ± 0.35 makes it acidic and capable of affecting dental restorative materials such as resin composites.[9-12]

Resin composites are restorative dental materials composed of a resin matrix, inorganic fillers, and coupling agents.[9, 13] The matrix typically includes components such as Bis-GMA, UDMA, and TEGDMA, combined with various filler particles and additives.[14] Nanofilled resin composites utilize ultrafine filler particles (5–10 nm), which enhance surface smoothness, gloss, and aesthetics, making them ideal for mimicking the natural tooth structure. However, their water absorption capacity makes them susceptible to discoloration and surface degradation when exposed to acidic environments.[15-18] Nanofilled resin composites are widely utilized dental restorative materials, valued for their excellent aesthetic properties and broad availability.[19-21] Yet, a significant clinical challenge is their susceptibility to water absorption, which can compromise color stability.[22-25] Furthermore, dietary elements, particularly acidic substances such as Gochujang, a widely consumed Korean chili paste, may exacerbate material degradation and increase surface roughness.[1, 26-27]

Color changes in resin composite restorations can result from intrinsic factors (material structure) or extrinsic sources (exposure to staining agents), influenced by the penetration of chromogenic substances from foods and beverages. Recent studies have shown that immersion in fruit juices, such as papaya juice, can also cause significant changes in color and surface roughness of nanohybrid composite resins, underscoring the impact of dietary habits on restoration longevity.[28] Color evaluation is commonly performed using spectrophotometers based on the CIELAB color system (L*, a*, b*). Surveys indicate that 68% of patients noticed discoloration after one year of consuming acidic foods.[29]

Another critical property of resin composite is surface roughness, commonly measured using the Roughness Average (Ra) derived from the highest and lowest surface points.[30-32] Surface roughness plays a significant role in plaque accumulation, color alteration, and caries risk. Factors influencing roughness include filler size, polymerization defects, and acid exposure from dietary sources. The acceptable roughness threshold for patients is generally below 0.5 μm, while surfaces with Ra>0.2 μm may promote plaque accumulation and bacterial colonization, which lead to caries development.[33-35] Acidic foods such as gochujang can increase roughness by degrading the polymer matrix and causing filler particle loss. The acidity of gochujang (pH 4.44) may initiate ester bond hydrolysis within the Bis-GMA matrix, releasing monomers and increasing material porosity.[36] A recent study in Jakarta[29] reported a 40% increase in gochujang consumption since 2020, highlighting the relevance of assessing its impact on dental restorations. Given these concerns, it is important to investigate the effects of gochujang immersion on the color stability and surface roughness of nanofilled resin composites.[37]

Accordingly, this study aims to evaluate the effects of gochujang immersion on the color stability and surface roughness of nanofilled resin composites.

Materials and Methods

This study employed a laboratory-based experimental design using a pretest-posttest with control group approach. The materials used in this study were given in Table 1.

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Table 1. Materials used in the study

Brand/Material	Lot Number; Expiry Date	Manufacturer	Composition
Filtek™ Z350 XT	NE75931; 14-10-2024	3M ESPE, United States	**Resin matrix**: Bis-GMA, TEGDMA, and procrylate resin. **Filler**: Ytterbium trifluoride (0.1–5.0 µm), non-agglomerated/non-aggregated surface-modified 20 nm silica, non-agglomerated/non-aggregated surface-modified 75 nm silica, and surface-modified aggregated zirconia/silica clusters containing 20 nm silica and 4–11 nm zirconia particles. **Filler loading**: 65% by weight (46% by volume). (3M ESPE, 2023)
Sajo® Gochujang	1-11-2023	SAJO Industries Corporation, South Korea	Corn syrup, chili sauce (19%), water, wheat flour, wheat, salt, alcohol, spices, powdered rice, powdered soybean, flavor enhancers, monosodium glutamate, red pepper powder, seeds, malt.
Klin's Distilled Water	11-1-2024	PT. Klining Servis Indonesia, Jakarta, Indonesia	H_2O

Sample Preparation

Nanofilled resin composite was inserted into a cylindrical mold (6 mm diameter, 3 mm thickness) using a plastic filling instrument. The mold was placed on a glass plate, and air bubbles were minimized using a dental vibrator, which was then verified via visual inspection. The composite was condensed with a cement stopper and shaped using a plastic filling instrument. A celluloid strip was placed on top before the material was cured. Polymerization was performed using an LED light curing unit for 2 × 20 seconds. The tip of the light was positioned 1 mm above the composite surface and directed perpendicularly. After curing, the sample was removed from the mold. All samples were checked to ensure flat, smooth, and debris-free surfaces, and measured using a digital caliper.

Sample Distribution and Experimental Groups

A total of 33 samples of nanofilled resin composite were prepared using simple random sampling and divided into three groups (n = 11 per group):

1. Immediate Control Group (n = 11): Samples were tested immediately after fabrication.
2. Control Group (n = 11): Samples were immersed in distilled water for 4 days at 37°C using an incubator (Daihan Labtech Co. Ltd., Korea).
3. Treatment Group (n = 11): Samples were immersed in a 1:1 gochujang-distilled water solution for 16 hours daily, followed by immersion in distilled water for 8 hours, over

four consecutive days at 37°C. This protocol was designed to mimic prolonged oral exposure during and after meals, with the 1:1 ratio selected to approximate the viscosity and dilution of food residues in the oral cavity.

Color and Surface Roughness Testing

Color changes were measured using the VITA Easyshade V spectrophotometer (VITA Zahnfabrik, Germany) [38] based on the CIELAB system (L*, a*, b*) and calculated as ΔE. Surface roughness was measured using a Surface Roughness Tester (Taylor Hobson Surtonic S-100 Series, AMETEK Inc., USA).[39]

Results

Descriptive statistics demonstrated the mean values and standard deviations (mean ± SD) for color change (ΔE, ΔL, ΔC, ΔH) and surface roughness (Ra) are presented in Table 2.

Table 2. Mean and Standard Deviation of Color Change and Surface Roughness Measurements

Group	ΔE	ΔL	ΔC	ΔH	Ra (µm)
Immediate	3.6 ± 0.3	3.0 ± 1.0	0.5 ± 1.2	3.0 ± 0.5	1.4 ± 0.3
Control	2.9 ± 0.2	2.2 ± 0.3	0.7 ± 0.3	3.7 ± 0.2	1.3 ± 0.1
Treatment	7.1 ± 1.5	1.8 ± 0.5	6.5 ± 1.4	3.6 ± 0.7	1.8 ± 0.2

The treatment group showed the highest mean ΔE and ΔC values, indicating significant and clinically perceptible discoloration. As the data were not normally distributed, non-parametric tests (Kruskal–Wallis and Mann–Whitney) confirmed significant differences in color change and surface roughness between groups ($p<0.05$).

The Kruskal–Wallis test revealed statistically significant differences in the values of ΔE (p = 0.000*), ΔC (p = 0.000*), ΔH (p = 0.001*), and surface roughness (p = 0.003*), but no significant difference in ΔL (p = 0.141). Follow-up analysis using the Mann–Whitney test was presented in Table 3.

Table 3. Mann–Whitney Test Results Between Groups

Parameter	Group A vs Group B	p-value
Color Change (ΔE)	Immediate vs Control	0.000*
	Immediate vs Treatment	0.000*
	Control vs Treatment	0.000*
Color Change (ΔC)	Immediate vs Control	0.021*
	Immediate vs Treatment	0.000*

Parameter	Group A	vs	Group B	p-value
	Control	vs	Treatment	0.002*
Color Change (ΔH)	Immediate	vs	Control	0.000*
	Immediate	vs	Treatment	0.013*
	Control	vs	Treatment	0.185
Surface Roughness (Ra)	Immediate	vs	Control	0.507
	Immediate	vs	Treatment	0.009*
	Control	vs	Treatment	0.001*

* indicates statistical significance at $p < 0.05$

Discussion

The results of our current study revealed that gochujang immersion caused significant discoloration and increased surface roughness. The resin appeared darker and more yellowish, consistent with the natural staining characteristics of gochujang. This phenomenon is attributed to the penetration of pigments and acids into the resin matrix through micro-porosity and high-water absorption. ΔE quantifies the total perceptible color change. A ΔE value > 3.3 in the treatment group indicates clinically visible discoloration. Increased surface roughness (Ra 1.8 μm) may significantly enhance biofilm retention, consistent with findings that rougher surfaces promote bacterial adhesion due to mechanical protection and altered topography[40] that was significantly different from the other two groups ($p < 0.05$).[41]

Gochujang immersion was associated with more pronounced discoloration under experimental conditions in distilled water.[14] The ΔL (lightness) values showed no significant differences among the groups ($p > 0.05$), although the treatment group exhibited lower lightness values, indicating a darker appearance. The ΔC (chroma) values indicated a significantly higher color intensity in group 3, leading to a more saturated color compared to the other two groups ($p < 0.05$). The ΔH (hue) values revealed that the color of all groups shifted toward yellow (positive ΔH), but no significant difference was found between groups 2 and 3. Thus, gochujang affected hue similarly to distilled water immersion.

The color change in nanofilled resin composite after immersion in gochujang is primarily caused by two synergistic mechanisms. First, the acidic environment of gochujang (pH ~4.5), attributed to lactic and acetic acids produced during fermentation,[8] initiates hydrolysis of ester bonds in the resin matrix,[40] degrading the polymer structure and compromising the resin–filler interface. Similar effects have been observed with other acidic and enzyme-rich foods, such as papaya juice, which has been shown to increase both color change and surface roughness in nanohybrid composite resins.[28] This suggests that a variety of dietary substances, not limited to fermented condiments, can compromise the esthetic and physical properties of composite restorations. Second, extrinsic staining results from capsanthin ($C_{40}H_{56}O_3$), a stable, low-molecular-weight pigment found in Korean chili paste, which can diffuse passively through water-filled microchannels into the composite surface.[42] This dual action of acid-induced degradation and pigment infiltration contributes to the significant increase in ΔE and ΔC observed in the treatment group.

The treatment group exhibited a ΔE of 7.1, which exceeds the clinical perceptibility threshold ($\Delta E > 3.3$), indicating a visible and esthetically concerning color change.[29] The high ΔC (6.5) also indicates deeper color saturation, while the lower ΔL (1.8) suggests a darker shade. ΔH values were relatively stable, indicating that hue shift was minimal.

All groups showed surface roughness values above the human tongue sensitivity threshold (0.5 µm), but the treatment group showed the highest potential for plaque accumulation. These findings suggest that gochujang can exacerbate surface degradation of resin, increase the risk of biofilm or plaque accumulation, and reduce patient comfort. The acidic pH of gochujang (4.44) likely contributed to polymer degradation, as evidenced by increased Ra values. The treatment group exhibited a Ra value of 1.8 µm, exceeding the plaque retention threshold (0.2 µm). These findings suggest that patients should be advised to rinse with water after consuming gochujang; further research is needed to evaluate the efficacy of fluoride mouthwash in this context to minimize the risk of secondary caries.

In this experiment, no polishing was performed on the composite surface. Resin composites should be polished to a surface roughness value of $Ra < 0.2$ µm to reduce biofilm retention. The findings are consistent with those of Valian et al. (2021),[30] who also observed an inverse correlation between surface roughness and color parameters of composite resins following different polishing techniques. Their results support the notion that smoother surfaces tend to retain less staining and exhibit improved optical properties, which reinforces the importance of surface finishing in the context of aesthetic restorations. Moreover, the results are also consistent with previous studies by Woo et al. and Kim et al., which demonstrated the effects of gochujang on color change and roughness of dental restorative materials.[1, 41] A color change $\Delta E > 3.3$ is consistent with findings on 3D-printed resins.[1] However, the Ra values remained within the threshold of patient comfort (<0.5 µm), indicating that the functional impact may not yet be significant in the short term.

Previously, Picolo et al. (2023)[40] reported that experimental composites with NF_TiO_2/Nb_2O_5 retained low surface roughness (Ra ≤ 0.029 µm), suggesting that nanoparticle additives do not compromise surface smoothness—a critical factor in biofilm resistance and clinical performance. Unlike conventional composites, nanofilled composites with 20 nm fillers (e.g., Filtek Z350) demonstrate higher resistance to acid abrasion[40], although they remain susceptible to extrinsic staining.

Conclusion

These findings emphasize the need for patient education regarding the consumption of acidic and pigmented foods such as gochujang, especially for individuals with resin composite restorations. Clinicians should advise patients to minimize exposure to acidic and pigmented foods, including gochujang, rinse with water after consumption, and consider polishing protocols or fluoride-containing mouthwash to mitigate discoloration and surface degradation of resin composites.[43] Furthermore, incorporating surface sealants or applying routine polishing may help preserve the aesthetic and functional properties of nanofilled resin composites in patients with dietary habits that include fermented or acidic condiments.

Future research should evaluate the effects of cyclic loading between gochujang and artificial saliva to simulate actual oral conditions, considering that intermittent exposure may accelerate surface degradation.[1]

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