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ARTICLE

# EFFECT OF DISINFECTANT AGENTS ON THE ROUGHNESS AND COLOR STABILITY OF CAD-CAM ACRYLIC RESINS FOR REMOVABLE PROSTHESES

## Efecto de los agentes desinfectantes en la rugosidad y la estabilidad del color de las resinas acrílicas CAD-CAM para prótesis removibles

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## ABSTRACT

**Objective:** To analyze the effect of 1% sodium hypochlorite (NaOCl), 2% chlorhexidine (CHX), 3% hydrogen peroxide ($H_2O_2$), and 2% glutaraldehyde (GTA) on the color stability ($\Delta E_{00}$) and surface roughness (Ra) of a CAD-CAM PMMA acrylic resin for removable prostheses.

**Material and Methods:** An experimental, longitudinal, and analytical study was conducted using 40 CAD-CAM PMMA discs (28 mm diameter × 2 mm thickness). The selected disinfectants were applied, and baseline and final measurements were obtained. Color evaluation was performed with a Vita Easyshade spectrophotometer, while surface roughness was measured with a portable roughness tester. Three consecutive readings were taken per specimen and averaged; the equipment was calibrated before each session. Statistical analysis was carried out using one-way ANOVA with Tukey's post hoc test, and the Kruskal–Wallis test when assumptions were not met ($\alpha = 0.05$).

**Results:** Significant differences were found in color variation ($p<0.05$). NaOCl showed the least change ($\Delta E = 0.83$), while CHX presented the greatest variation ($\Delta E = 3.45$). GTA and $H_2O_2$ showed intermediate changes ($\Delta E = 1.17$ and $\Delta E = 1.01$, respectively). Regarding surface roughness, significant differences were also observed ($p< 0.05$). CHX (Ra = 0.18 µm) and $H_2O_2$ (Ra = 0.37 µm) presented higher values compared to NaOCl (Ra = 0.14 µm) and GTA (Ra = 0.08 µm)

**Conclusion:** The color stability and surface roughness of the CAD-CAM PMMA acrylic resin were significantly affected by the disinfectants tested. $H_2O_2$ 3% produced the greatest increase in roughness, while GTA 2% was the most conservative. CHX 2% caused the highest color variation, whereas NaOCl 1% produced the least change.

**Keywords:** *Denture cleansers; Surface properties; Color; CAD/CAM; Polymethyl methacrylate; Denture bases*

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## RESUMEN

**Objetivo:** Analizar el efecto del hipoclorito de sodio (NaOCl) al 1 %, de la clorhexidina (CHX) al 2 %, del peróxido de hidrógeno ($H_2O_2$) al 3 % y del glutaraldehído (GTA) al 2 % sobre la estabilidad del color ($\Delta E_{00}$) y la rugosidad superficial (Ra) de una resina acrílica de PMMA fabricada mediante CAD-CAM para prótesis removibles.

**Materiales y Métodos:** Se realizó un estudio experimental, longitudinal y analítico utilizando 40 discos de PMMA (28 mm de diámetro × 2 mm de espesor) obtenidos mediante CAD-CAM. Se aplicaron los desinfectantes seleccionados y se tomaron mediciones iniciales y finales. La evaluación del color se llevó a cabo con un espectrofotómetro Vita Easyshade, mientras que la rugosidad superficial se midió con un rugosímetro portátil. Se realizaron tres lecturas consecutivas por muestra y se calculó su promedio; el equipo fue calibrado antes de cada sesión. El análisis estadístico se efectuó mediante ANOVA de un factor con la prueba *post hoc* de Tukey; en los casos en que no se cumplieron los supuestos, se utilizó la prueba de Kruskal-Wallis ($\alpha$ = 0,05).

**Resultados:** Se encontraron diferencias significativas en la variación del color ($p$<0,05). El NaOCl mostró el menor cambio ($\Delta E$ = 0,83), mientras que la CHX presentó la mayor variación ($\Delta E$ = 3,45). El GTA y el $H_2O_2$ mostraron cambios intermedios ($\Delta E$ = 1,17 y $\Delta E$ = 1,01, respectivamente).
En cuanto a la rugosidad superficial, también se observaron diferencias significativas ($p$< 0,05). La CHX (Ra = 0,18 µm) y el $H_2O_2$ (Ra = 0,37 µm) presentaron valores más elevados en comparación con el NaOCl (Ra = 0,14 µm) y el GTA (Ra = 0,08 µm).

**Conclusión:** La estabilidad del color y la rugosidad superficial de la resina acrílica de PMMA (CAD-CAM) se vieron afectadas de manera significativa por los desinfectantes evaluados. El $H_2O_2$ al 3 % produjo el mayor incremento en la rugosidad, mientras que el GTA al 2 % fue el más conservador. La CHX al 2 % provocó la mayor variación de color, mientras que el NaOCl al 1 % produjo el menor cambio.

**Palabras clave:** *Limpiadores de dentadura; Propiedades de superficie; Color; CAD/CAM; Polimetil metacrilato; Bases para dentadura*

## INTRODUCTION

Currently, removable prostheses remain a therapeutic option for oral rehabilitation in edentulous patients. It is estimated that the prevalence of total edentulism in adults over 50 years old reaches up to 21.7% in six industrialized countries.[1] Tooth loss not only affects aesthetics but also masticatory function and speech.[2] The primary causes include dental caries and periodontal disease.[3] Previous studies reported that, out of 389 extracted teeth, 37% were due to caries, 29% to periodontal disease, 33% to unknown causes, 12% to trauma, and 6% to third molar extraction.[4,5]

The use of complete dentures improves masticatory function, aesthetics, and patients' quality of life.[6] However, the oral cavity of denture wearers can serve as a reservoir for microorganisms such as *Streptococcus aureus, Candida albicans, and Streptococcus mutans*.[7,8] According to Salerno *et al.*,[9] and Garbacz *et al.*,[10] *C. albicans* not only adheres

to mucosal surfaces but also to removable prostheses, which are predominantly composed of acrylic resins. This poses a risk for denture wearers, as bacterial accumulation and poor hygiene contribute to the development of denture stomatitis, with a prevalence ranging from 15% to 70%.

The main etiological factors include poor hygiene, continuous and nocturnal use of the prosthesis, plaque accumulation, age of the device, inadequate design, and colonization by *C. albicans*.[8,10,11] Improper disinfection facilitates the formation of biofilms on the prosthetic resin, promoting fungal penetration and chronic inflammation of the oral mucosa.[12] Therefore, patient education on proper hygiene and storage of the prosthesis is essential to prevent infections and complications associated with *C. albicans* colonization.[13,14]

As a microbiological control measure, disinfectant solutions have been proposed to reduce bacterial load in biofilms, combat denture stomatitis, and limit *C. albicans* proliferation.[15-17] Poppolo *et al.*,[18] reported that agents such as 2% chlorhexidine, 1% sodium hypochlorite, 3% hydrogen peroxide, and 2% glutaraldehyde exhibit high antimicrobial efficacy, reducing the incidence of denture stomatitis.

However, the chemical components of disinfectants can alter the physicochemical properties of the polymer matrix in denture bases, affecting color stability, surface characteristics, roughness, and hardness.[19] Factors such as immersion time, solution temperature, and the disinfectants' mechanism of action play a crucial role in resin degradation, promoting the loss of plasticizers, water absorption, and color changes.[20] According to Haghi *et al.*,[21] repeated immersion in cleaning solutions alters the mechanical and physical properties of acrylic resins used for removable dentures.

Alqanas *et al.*,[20] reported that sodium hypochlorite (NaOCl) can cause significant color changes, whereas effervescent cleaners produce minimal variations. Alfouzan *et al.*,[16] indicated that 2% chlorhexidine may be less aggressive to surface roughness compared to other solutions.

Beyond the type of disinfectant, the color stability of acrylic resins is influenced by the polymerization method.[22] Conventional prostheses made of methacrylate tend to have higher roughness. In this context, the CAD-CAM system has emerged as an innovative alternative for the fabrication of complete dentures, allowing digital design and manufacturing, which enhances their mechanical and surface properties.[23] Being pre-polymerized, they exhibit greater hardness, flexural strength, dimensional elastic modulus, and hydrophobicity compared to prostheses made from thermally polymerized methacrylate.[24,25] Helal *et al.*,[26] compared different digital manufacturing techniques and concluded that milled CAD-CAM resins have lower roughness and greater resistance to disinfectant solutions than 3D-printed resins. Color change ($\Delta E_{00}$) and average surface roughness (Ra) are key parameters used to evaluate the optical stability and surface integrity of acrylic resins, following the ISO 20795-1 standard for denture base materials.

Although several studies have evaluated the antimicrobial performance of disinfectant agents, there is limited evidence regarding their effect on the surface and optical properties of CAD-CAM PMMA resins used in removable prostheses. Therefore, this study aimed to analyze the effect of 1% sodium hypochlorite, 2% chlorhexidine, 3% hydrogen peroxide, and 2% glutaraldehyde on the color stability ($\Delta E_{00}$) and surface roughness (Ra) of a CAD-CAM PMMA acrylic resin for removable prostheses.

## MATERIALS AND METHODS

### Study Design, Sample, and Ethical Considerations

This study is an experimental *in vitro*, prospective, longitudinal, and analytical investigation.

The sample size was determined using G*Power 3.1.9.7 applying the ANOVA (Fixed effects, omnibus, one-way) statistical test with a priori power analysis (Compute required sample size-given α, power, and effect size). The effect size of 0.345 was derived from a previous study.[19] Additionally, a statistical power of 0.8 and a significance level of α = 0.05 were considered. The initial sample calculation yielded 32 specimens, requiring a minimum of 8 samples per group.

However, the sample size was increased to 10 specimens per group to compensate for potential sample losses and ensure homogeneity across the four experimental groups. This study was approved under official document FACSA-CEI/090-08-2023 by the Ethics Committee of the Faculty of Health Sciences, in compliance with the ethical guidelines established by Universidad Privada de Tacna.

### Specimen Fabrication

For this study, PMMA Zahndent (Shenzhen Zahndent Medical Co., Ltd., Shenzhen, China) with dimensions of 95 × 12 mm (factory disc) and shade A2 were used. From this material, circular specimens measuring 28 mm in diameter and 2 mm in thickness were designed and milled using Zirkonzahn.Modellier software (Zirkonzahn GmbH, Gais, Italy) and the Zirkonzahn M1 milling unit (Zirkonzahn GmbH, Gais, Italy) (Figure 1)

Milling was performed dry, following the manufacturer's recommendations for prepolymerized acrylic resin materials, in order to prevent moisture absorption and preserve dimensional stability. Subsequently, the specimens were cleaned in an ultrasonic bath with 99% isopropyl alcohol for 10 minutes and then dried under controlled environmental conditions before being used in the experimental phases.

### Preparation of Disinfectant Agents

A total of 15 mL of each disinfectant was dispensed into individual containers at room temperature. For the preparation and pH adjustment of 2% glutaraldehyde, the manufacturer's instructions were strictly followed. Additionally, pH test strips were used to ensure that the value was above 1.5, confirming its proper use as a disinfectant.

### Exposure of Discs to Disinfectant Substances and Immersion Protocol

The samples were distributed into four experimental groups, each immersed in individual plastic containers according to the assigned disinfectant solution:

**Group A:** 1% Sodium hypochlorite (Enzohip, Enzodent, Lima, Peru; pH 9.5), **Group B:** 2% Chlorhexidine (Chlor X, Prevest DenPro, Jammu, India; pH 6.4 ), **Group C:** 3% Hydrogen peroxide (Dealmed, Dealmed Medical Supplies LLC, New York, USA; pH 4.5) and **Group D:** 2% Glutaraldehyde (Microbiex, Microvision, Madrid, Spain pH 5.2).

The disinfectant solutions were renewed every 24 hours to maintain their chemical stability and avoid loss of efficacy. Measurements were taken at two time points: before (T1) and after (T2) exposure. The specimens were immersed in each solution for 10 minutes daily over a 90-day period,[19] using a timer to ensure precise exposure time. After each immersion, the specimens were rinsed with distilled water at room temperature for 5 minutes to remove any residual disinfectant. All measurements were performed by a single previously trained examiner to en-

sure methodological consistency and reproducibility.

### Evaluation of Color Stability

Color stability was evaluated using the Delta E system by recording the luminosity (L*), hue (a*), and chroma (b*) values of each specimen. Measurements were performed with a Vita Easyshade spectrophotometer (Vita Zahnfabrik, Säckingen, Germany), positioned perpendicular to the surface of the discs, before and after 90 days of immersion in the disinfectant solutions.

For each specimen, three consecutive readings were taken on the L, a, b*** scale, and the mean value was used for data analysis. To minimize variability, a rigid acetate guide with a central perforation was designed to ensure precise positioning and measurement accuracy (Figure 2)

The color difference (ΔE) was calculated using the established formula:

$$\Delta E = \sqrt{((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)}$$

For clinical evaluation, ΔE was converted into NBS units (National Bureau of Standards) using the equation NBS = ΔE × 0.92. A value of up to 3.7 NBS was considered acceptable, while values above this threshold indicated clinically unacceptable color changes.[22]

The surface roughness of the specimens was measured using a portable roughness tester (Portable Surface Roughness Tester, SJ-210; Mitutoyo America Corporation, Aurora, IL, USA), which was calibrated before each use. The initial and final roughness values were recorded using the profilometer needle.

Each specimen was evaluated through three consecutive measurements along a central line, and the average of these readings was used as the representative value. Measurements were performed at a constant speed of 0.25 mm/s with a cut-off length of 0.25 mm (Figure 3). The roughness value (Ra) was expressed in micrometers (µm). A threshold of 0.2 µm was considered the critical limit for microbial retention, since values below this do not contribute to a further reduction in bacterial accumulation.[27]

### Statistical analysis

The data were organized in a Microsoft Excel 2016 spreadsheet and exported to Stata version 18 (StataCorp, College Station, TX, USA) for analysis. Descriptive statistics were obtained through tables and graphs, and inferential procedures were selected based on the evaluation of statistical assumptions in both raw data and residuals. For color difference (ΔE), the Shapiro-Wilk test indicated non-normality ($p< 0.05$), which was confirmed by residual plots and Bartlett's test for variance homogeneity; therefore, the Kruskal-Wallis test was applied, followed by Dunn's post hoc test with Bonferroni correction. For surface roughness (ΔRa), the Shapiro-Wilk test did not reject normality ($p>0.05$), residuals exhibited a normal distribution, and Bartlett's and Breusch-Pagan tests confirmed homoscedasticity ($p >0.05$); thus, one-way ANOVA was used, followed by the Bonferroni post hoc test. These tests allowed for the comparison of color stability and roughness values of PMMA discs before and after exposure to disinfectants.

## RESULTS

As observed in the results in Tables 1 and 2, exposure to disinfectant agents did not produce significant differences in ΔL values of the acrylic resin ($p> 0.05$).

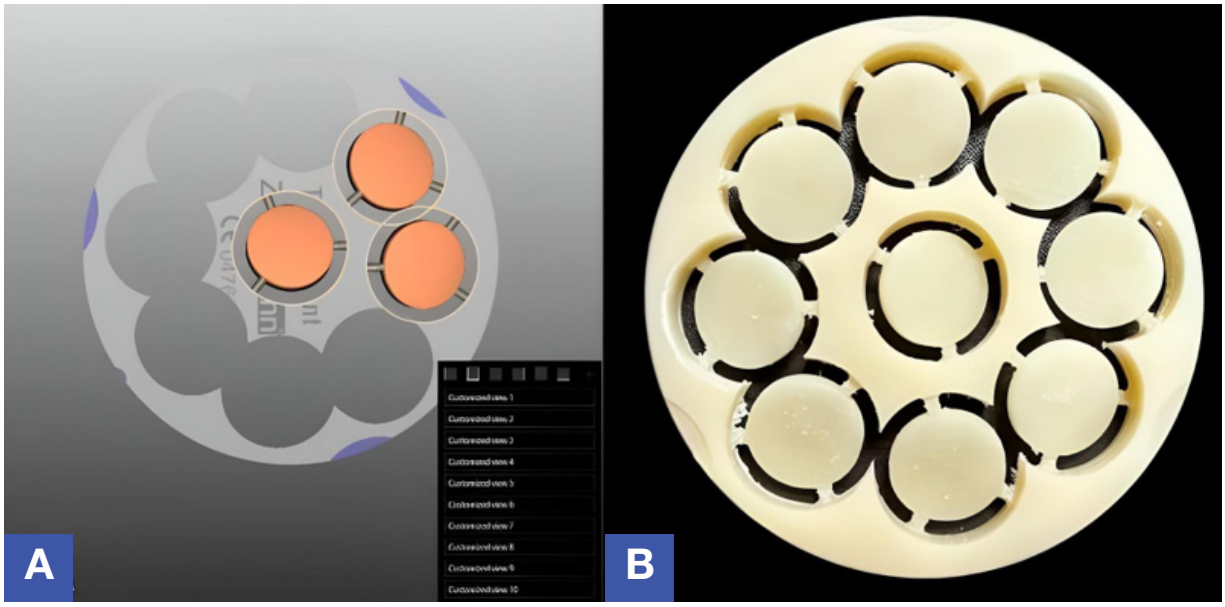
However, significant differences in Δa were observed among the groups treated with 1% sodium hypochlorite, 3% hydrogen peroxide, and 2% chlorhexidine ($p<0.05$). No significant differences were recorded in Δb values

between the groups. Significant differences in ΔE were identified among resins exposed to 1% sodium hypochlorite, 2% chlorhexidine, and 2% glutaraldehyde ($p<0.05$). Additionally, significant differences in ΔE were observed between discs treated with 2% chlorhexidine and 3% hydrogen peroxide ($p<0.05$).

Moreover, the $E^2_R$ coefficient indicates that only 16.15% of the variability in color change is attributable to exposure to disinfectant agents. The results in Table 3 indicate that only the difference between 2% chlorhexidine and 3% hydrogen peroxide was statistically significant ($p<0.05$). Additionally, the $\eta^2$ coefficient showed that 31.7% of the variability in surface roughness values of the resins is attributable to exposure to different disinfectant agents.

**Figure 1**

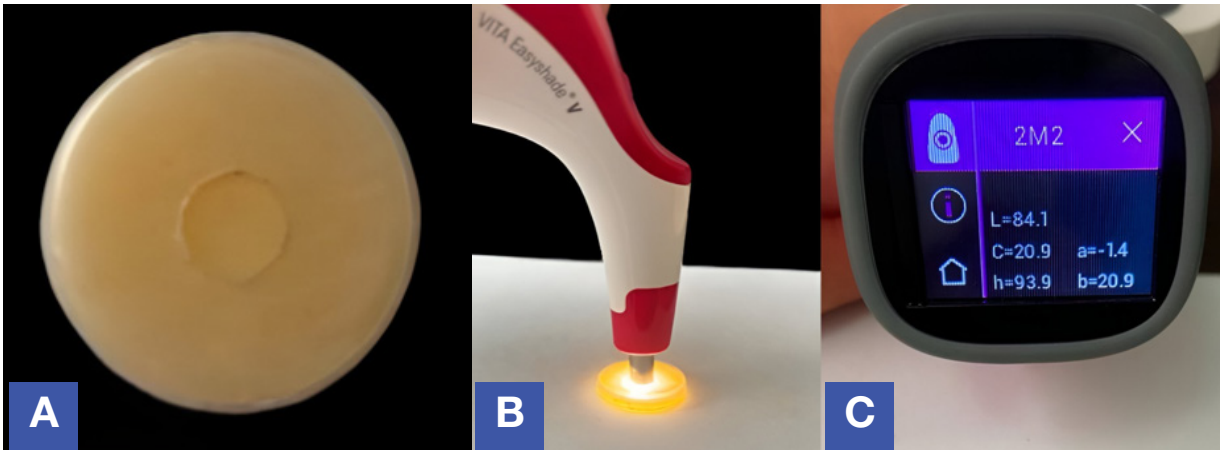
Design and fabrication of study specimens




**A:**Design of discs using specialized CAD software. **B:** Milled PMMA discs.

**Figure 2**

Evaluation of Color Stability




**A:**PMMA disc with acetate guide. **B:** Color measurement with spectrophotometer. **C:** Color values obtained with the spectrophotometer (L*, a*, b* values).

## Figure 3

Evaluation of Surface Roughness




**A:** Calibration of the profilometer. **B:** Roughness assessment of the PMMA disc.

## Table 1

Color values (ΔL, Δa, and Δb*) of the CAD-CAM acrylic resin after exposure to disinfectant agents

| Disinfectant agents | ΔL | | Δa | | Δb | |
|---|---|---|---|---|---|---|
| | Media ± SD | Median (IQR) | Media ± SD | Median (IQR) | Media ± SD | Median (IQR) |
| 1% sodium hypochlorite | 0.08 ± 0.39 | 0.08(0.79)[a] | 0.11 ± 0.05 | 0.10(0.09)[a] | -0.75 ± 0.33 | -0.76(0.30)[a] |
| 2% chlorhexidine | 2.16 ± 1.93 | 3.28(3.8)[a] | 0.76 ± 0.20 | 0.82(0.17)[b] | -0.88 ± 0.47 | -0.75(0.86)[a] |
| 3% hydrogen peroxide | 0.03 ± 1.68 | -0.43(0.27)[a] | 0.06 ± 0.12 | 0.07(0.24)[a] | -0.60 ± 0.45 | -0.71(0.50)[a] |
| 2% glutaraldehyde | 0.86 ± 5.26 | 0.05(0.86)[a] | 0.13 ± 0.34 | 0.33(0.17)[ab] | -0.33 ± 3.03 | -0.97(0.36)[a] |

Different superscript letters indicate significant differences between columns.
Kruskal-Wallis test followed by Dunn's post hoc test with Bonferroni correction.

## Table 2

Color difference values (ΔE) of the CAD-CAM acrylic resin after exposure to disinfectant agents

| Disinfectant agents | Media ± SD | Median | IQR | Min | Max | *p*-value | $E^2_R$ |
|---|---|---|---|---|---|---|---|
| 1% sodium hypochlorite | 0.86 ± 0.31 | 0.83[a] | 0.40 | 0.19 | 1.35 | <0.001* | 0.1615 |
| 2% chlorhexidine | 2.99 ± 0.89 | 3.45[b] | 1.87 | 1.73 | 3.88 | | |
| 3% hydrogen peroxide | 1.32 ± 1.23 | 1.01[ac] | 0.34 | 0.41 | 4.73 | | |
| 2% glutaraldehyde | 3.92 ± 4.57 | 1.17[bc] | 7.71 | 0.94 | 11.91 | | |

Different superscript letters indicate significant differences between groups. Kruskal-Wallis test followed by Dunn's post hoc test with Bonferroni correction. *denotes statistically significant differences ($p$< 0.001). $E^2_R$: Epsilon-squared coefficient.

**Table 3**

Surface Roughness (ΔRa) Values of CAD-CAM Acrylic Resin After Exposure to Disinfectant Agents

| Disinfectant agents | Mean | SD | Min | Max | p-value | η2 |
|---|---|---|---|---|---|---|
| 1% sodium hypochlorite | 0.14$^{ab}$ | 0.08 | 0.01 | 0.32 | 0.003* | 0.3174 |
| 2% chlorhexidine | 0.18$^{ab}$ | 0.90 | 0.06 | 0.32 | | |
| 3% hydrogen peroxide | 0.37$^{ac}$ | 0.08 | -0.06 | 0.23 | | |
| 2% glutaraldehyde | 0.08$^{ab}$ | 0.08 | -0.01 | 0.19 | | |

Different superscript letters indicate significant differences between columns.
One-way ANOVA test followed by Bonferroni post hoc test. *denotes statistically significant differences ($p< 0.05$).
η2 : Eta squared coefficient.

## DISCUSSION

This study evaluated variations in color stability and surface roughness of acrylic resins following exposure to different disinfectant agents. Regarding roughness, 3% hydrogen peroxide exhibited the highest variability, whereas 2% glutaraldehyde was the least detrimental to the specimens.

Peroxides contain oxygen-releasing compounds such as sodium perborate and sodium bicarbonate, which exert a solvent effect on plasticizers, facilitating residue removal through mechanical action.[28] Consistent with this, Costa *et al.*,[29] reported that 3% hydrogen peroxide increases surface roughness in PMMA prostheses due to its solvent action on plasticizers. Our findings reinforce this evidence, demonstrating that peroxide use in disinfection protocols increases roughness in CAD-CAM milled surfaces compared to the other tested disinfectants.

Sodium hypochlorite is widely used due to its low cost and high effectiveness, though its corrosive and irritating properties on skin and mucosal tissues are well documented.[30] In this study, 1% sodium hypochlorite caused an increase in the surface roughness of PMMA discs, aligning with Alqanas *et al.*,[20] who found that sodium hypochlorite significantly increases prosthetic surface roughness, regardless of the base material. This effect can be attributed to the oxidative degradation of the PMMA polymer chains, where NaOCl breaks carbon-carbon bonds and releases free radicals, producing microcracks and loss of surface integrity.

These results suggest that hypochlorite is not ideal for maintaining the surface integrity of complete dentures. However, its effect was less pronounced than that of 3% hydrogen peroxide.

Contrary to our findings, Haghi *et al.*,[21] reported no significant differences in roughness after immersion in hypochlorite, peroxide, distilled water, and tea extracts. This discrepancy could be attributed to methodological differences, as their study involved only 30 days of immersion, with lower concentrations and reduced exposure intervals. In this context, exposure time has been identified as a key factor in detecting surface changes when using sodium hypo-chlorite-based cleaners.

On the other hand, 2% chlorhexidine did not significantly alter the surface roughness of the specimens, exerting only 50% of the impact caused by hydrogen peroxide. These results align with Alfouzan *et al.*,[16] who concluded that chlorhexidine is one of the most favorable disinfectants for CAD-CAM processed prostheses.

Similarly, Zhang *et al.*,[31] recommended glutaraldehyde for prolonged immersion or repeated disinfection cycles due to its minimal impact on the physical properties of PMMA prostheses. Consistent with these findings, our study confirmed that 2% glutaraldehyde was the most conservative disinfectant regarding surface roughness.

Color alteration was assessed using the NBS equation: NBS = ΔE × 0.92. The values obtained in this study were 0.7636 for 1% sodium hypochlorite, 3.174 for 2% chlorhexidine, 0.9292 for 3% hydrogen peroxide, and 1.0764 for 2% glutaraldehyde. A material is considered clinically and aesthetically acceptable if NBS ≤ 3.7. In this regard, the color changes observed in our specimens met the criteria for clinical and aesthetic acceptability. However, while chlorhexidine approached the threshold, it remained within the acceptable range.

Fotovat *et al.*,[28] reported that chlorhexidine induces greater color alteration compared to hydrogen peroxide and sodium hypochlorite (0.5%). This effect is attributed to the presence of functional groups in its chemical structure, which enhance its interaction with water and other polar substances, increasing solubility and potential color change.

Although chlorhexidine is not a strong oxidizing agent, it can trigger oxidative reactions when combined with other compounds in the oral cavity or prosthetic materials. In this study, 2% chlorhexidine had the most significant impact on color stability, in agreement with these findings.

Acrylic resins have a high affinity for solvent and water absorption due to the polarity of PMMA molecules. Gad *et al.*,[32] described how denture cleaning solvents penetrate the polymer network, expanding intermolecular spaces. This process removes internal pigments while allowing external pigment infiltration, ultimately leading to color changes.

Additionally, the hydrophobic nature of milled PMMA enhances the attraction of water-soluble substances to its surface, increasing interactions with disinfectants and amplifying color variations.[19] The durability of a prosthesis is influenced by the type of disinfectant used, as it can alter its optical and mechanical properties.[16] Hong *et al.*,[22] emphasized that these alterations occur regardless of the material's polymerization method. However, disinfectants cannot be solely responsible for color change.

In this study, only 16.15% of the observed color changes were attributed to disinfectant exposure, while 83.85% was influenced by other factors, including chemical composition, polymerization technique, plasticizer content, absorption, solubility, surface treatments, and finishing protocols.

It was observed that 1% sodium hypochlorite and 3% hydrogen peroxide were the disinfectants that induced the least color variation, supporting the findings of Alqanas *et al.*,[20] who confirmed that hypochlorite and peroxide-based effervescent cleaners cause minimal color changes.

These findings emphasize that repeated use of commercial disinfectants can significantly affect color stability and surface roughness of PMMA prostheses. However, it was determined that glutaraldehyde and sodium hypochlorite exhibit a lower impact on color and roughness preservation in prosthetic bases.[28]

## CONCLUSIONS

The color stability and surface roughness of CAD-CAM acrylic resin used in removable prostheses were significantly affected by certain commercial disinfectants. Hydrogen peroxide 3% produced the greatest increase in surface roughness, while glutaraldehyde 2% was the most conservative agent. Regarding color

stability, chlorhexidine 2% caused the greatest chromatic variation, whereas sodium hypochlorite 1% resulted in the least alteration. From a clinical perspective, the use of glutaraldehyde 2% or sodium hypochlorite 1% for short immersion times, followed by thorough rinsing, is recommended to preserve the optical and surface integrity of PMMA prostheses.

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## CONFLICT OF INTERESTS

The authors declare no conflicts of interest related to this study. There are no financial, personal, or institutional relationships that could influence the results or their interpretation.

## ETHICS APPROVAL

This study has been approved by the Research Ethics Committee of the Faculty of Health Sciences at Private University of Tacna, under the approval code FACSA-CEI/090-08-2023. Although this is an in vitro study analyzing commercial polymer samples, institutional regulations require ethical approval for all research conducted within the university.

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## AUTHORS' CONTRIBUTIONS

**Dariana Cecilia Torres Huayna:** Conceptualization, Methodology, Resources, Validation, Investigation, Writing - Original Draft, Supervision, Project Administration.

**Jose Giancarlo Tozo Burgos:** Resources, Validation, Formal Analysis, Investigation, Data Curation, Writing– Review & Editing, Visualization.

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