Research article

The effect of clove flower extract immersion on the surface roughness of heat-cured and cold-cured acrylic: an experimental study

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ABSTRACT

Introduction: Heat-cured and cold-cured acrylic resins are commonly used as denture base materials in dentistry. Denture cleansers are essential for maintaining denture hygiene, and clove flower extract has been identified as a natural alternative due to its antifungal properties against *Candida albicans*. However, its high phenol content may increase the surface roughness of acrylic resins. Clinically, the acceptable roughness limit for acrylic resin is less than 0.2 µm. Increased surface roughness can lead to denture stomatitis, papillary hyperplasia, and chronic candidiasis. This study aimed to analyze changes in the surface roughness of heat-cured and cold-cured acrylic resins after immersion in clove flower extract. **Methods:** This true experimental study involved 32 samples divided into eight treatment groups. The samples were immersed in clove flower extract at concentrations of 1.6%, 1.8%, and 2% in distilled water, with distilled water serving as the control, for 23 days. Surface roughness was measured using a surface roughness tester. Data were analyzed using the Shapiro-Wilk test, paired sample t-test, ANOVA, Kruskal-Wallis test, and Mann-Whitney test. **Results:** The results showed a significant difference ($P < 0.05$) in surface roughness changes between heat-cured and cold-cured acrylic resins after immersion in clove flower extract at all concentrations. Cold-cured acrylic resin exhibited greater changes in surface roughness than heat-cured acrylic resin. **Conclusion:** The increased surface roughness in cold-cured acrylic resin is attributed to its higher residual monomer content, which allows greater absorption of clove flower extract. These findings suggest that clove flower extract may affect the durability of acrylic resin materials used in dentures.

Keywords

Surface roughness, clove flower extract, denture cleanser, heat-cured acrylic resin, cold-cured acrylic resin

Efek perendaman ekstrak bunga cengkeh terhadap kerataan permukaan akrilik yang dipanaskan dan didinginkan: penelitian eksperimental

ABSTRAK

Pendahuluan: *Resin akrilik* heat-cured *dan* cold-cured *merupakan bahan yang umum digunakan sebagai basis gigi tiruan dalam kedokteran gigi. Pembersih gigi tiruan berperan penting dalam menjaga kebersihan gigi tiruan, dan ekstrak bunga cengkeh telah diidentifikasi sebagai alternatif alami karena sifat antifungalnya terhadap Candida albicans. Namun, kandungan fenol yang tinggi dalam ekstrak bunga cengkeh dapat meningkatkan kekasaran permukaan resin akrilik. Secara klinis, batas kekasaran permukaan resin akrilik yang dapat diterima adalah kurang dari 0,2 µm. Peningkatan kekasaran permukaan dapat menyebabkan stomatitis gigi tiruan, hiperplasia papilar, dan kandidiasis kronis. Penelitian ini bertujuan untuk menganalisis perubahan nilai kekasaran permukaan antara resin akrilik* heat-cured *dan* cold-cured *setelah perendaman dalam ekstrak bunga cengkeh.* ***Metode:*** *Penelitian ini merupakan studi eksperimental murni dengan 32 sampel yang dibagi menjadi delapan kelompok perlakuan. Sampel direndam dalam ekstrak bunga cengkeh dengan konsentrasi 1,6%, 1,8%, dan 2%, serta air suling sebagai kontrol, selama 23 hari. Pengukuran kekasaran permukaan dilakukan menggunakan surface roughness tester. Analisis data dilakukan dengan uji* Shapiro-Wilk, paired sample t-test, *ANOVA,* Kruskal-Wallis, *dan* Mann-Whitney. ***Hasil:*** *Hasil penelitian menunjukkan adanya perbedaan signifikan (P< 0,05) dalam perubahan kekasaran permukaan antara resin akrilik* heat-cured *dan* cold-cured *setelah perendaman dalam ekstrak bunga cengkeh pada semua konsentrasi. Resin akrilik* cold-cured *mengalami peningkatan kekasaran permukaan yang lebih besar dibandingkan dengan resin akrilik* heat-cured. ***Simpulan:*** *Peningkatan kekasaran permukaan pada resin akrilik* cold-cured *disebabkan oleh kandungan monomer sisa yang lebih tinggi, sehingga mampu menyerap lebih banyak ekstrak bunga cengkeh. Hal ini menunjukkan bahwa ekstrak bunga cengkeh dapat memengaruhi ketahanan bahan resin akrilik yang digunakan dalam gigi tiruan.*

Kata kunci

Kekasaran permukaan, ekstrak bunga cengkeh, pembersih gigi tiruan, resin akrilik heat-cured, resin akrilik cold-cured

INTRODUCTION

Polymethyl methacrylate (PMMA) acrylic resin represents a cornerstone biomaterial in contemporary prosthodontics and orthodontics, serving as the primary constituent for denture bases and removable orthodontic appliances.[1] The widespread utilization of PMMA stems from its exceptional dimensional stability under intraoral conditions, coupled with favorable physical and mechanical properties that align with clinical requirements. Contemporary dental practice extensively employs PMMA due to its biocompatibility, aesthetic appeal, and relatively straightforward processing characteristics. The material demonstrates excellent adaptation to oral tissues while maintaining structural integrity under masticatory forces. Heat-cured and cold-cured variants of PMMA represent the most frequently utilized polymerization methods in clinical applications.[1]

These different activation processes significantly influence the resultant physical properties of the final prosthetic device.[2] The polymerization mechanism directly affects critical parameters, including surface characteristics, mechanical strength, and dimensional accuracy. Understanding these variations is crucial for optimizing clinical outcomes and patient satisfaction. Surface roughness emerges as a particularly important physical property that determines the long-term success of acrylic resin prostheses. The relationship between polymerization methods and surface texture continues to attract significant research attention in the prosthodontic literature.[1,2]

The maintenance of prosthetic devices through appropriate cleansing protocols represents a fundamental aspect of oral healthcare delivery. Denture cleansers serve as essential therapeutic agents that eliminate food debris, bacterial biofilms, and microbial accumulations that naturally accumulate on prosthetic surfaces.[3,4]

Clove (*Syzygium aromaticum*) has potential as a plant-derived denture cleansing agent because it contains eugenol and other phenolic compounds with documented antibacterial and antifungal activities.[5-7] However, the selection of a natural cleansing agent should consider not only its antimicrobial effectiveness but also its compatibility with denture base materials. Previous evidence has shown that prolonged exposure to clove-derived solutions may alter the surface roughness and mechanical properties of polymethyl methacrylate acrylic resin.[2] Therefore, the effect of clove flower extract on the physical properties of acrylic resin requires further investigation before its clinical application.

This economic constraint particularly affects developing nations, where access to dental care remains challenging. The growing demand for cost-effective alternatives has stimulated research into natural antimicrobial agents derived from indigenous plant sources.4 Natural products offer potential advantages, including reduced toxicity, environmental sustainability, and enhanced patient acceptance. The exploration of plant-based cleaning agents represents an innovative approach toward democratizing oral healthcare. Traditional medicine systems have long recognized the therapeutic potential of various botanical extracts for oral health applications. Contemporary research increasingly validates these traditional practices through scientific methodology and clinical evaluation.[3,4]

Syzygium aromaticum, commonly known as clove, represents one of the most extensively studied botanical species for dental applications.[5] This aromatic spice, native to Indonesia and widely cultivated throughout Southeast Asia, possesses remarkable antimicrobial properties that have been recognized for centuries. The primary bioactive compounds in clove extracts include eugenol, eugenyl acetate, and various phenolic compounds that demonstrate potent antibacterial and antifungal activities. Previous investigations have documented the efficacy of clove extracts against major oral pathogens, including *Candida albicans*, *Streptococcus mutans*, and various periodontal bacteria.[6]

The antimicrobial spectrum of clove extract encompasses both gram-positive and gram-negative bacterial species commonly associated with oral infections. Research has demonstrated that clove extract maintains its antimicrobial activity across different extraction methods and concentrations.[7] The phenolic compounds present in clove extracts exhibit bacteriostatic and bactericidal effects through multiple mechanisms, including cell membrane disruption and enzyme inhibition. These properties make clove extract an attractive candidate for developing alternative denture cleansing solutions. The abundance and accessibility of clove in Indonesian markets further support its potential as a cost-effective cleaning agent.[5,7]

Several studies have investigated the antimicrobial efficacy of clove extracts against oral pathogens, with consistently positive results reported across different research methodologies. Recent investigations have demonstrated that clove extracts achieve antimicrobial activity comparable to that of conventional chemical disinfectants while exhibiting lower toxicity profiles.8 The minimum inhibitory concentration (MIC) values for clove extract against common oral bacteria fall within therapeutically achievable ranges for topical applications. Clinical studies have shown that clove-based formulations effectively reduce bacterial counts in denture wearers without causing adverse reactions.

However, limited research has examined the potential effects of clove extracts on the physical properties of acrylic resins. Previous studies have primarily focused on antimicrobial activity rather than material compatibility and surface modifications. The interaction between phenolic compounds and polymer surfaces remains inadequately characterized in the dental literature. This knowledge gap represents a significant limitation in the clinical application of plant-based cleaning agents. Understanding the material science aspects of clove extract interactions with acrylic resins is essential for safe clinical implementation. Research examining the effects of natural extracts on prosthetic material properties remains limited in the current literature.[3,5]

Surface roughness is a critical parameter in the clinical performance of acrylic resin prostheses, with established threshold values that determine clinical acceptability.9 The internationally recognized clinical limit for acrylic resin surface roughness is 0.2 micrometers, beyond which bacterial adhesion and plaque accumulation increase significantly. Surfaces exceeding this threshold exhibit enhanced microbial retention, increasing the risk of denture stomatitis, chronic candidiasis, and other oral pathologies.

The relationship between surface roughness and microbial colonization has been extensively documented through in vitro and clinical studies.[10] Rough surfaces provide mechanical retention sites for bacterial attachment and biofilm formation, creating a cycle of increasing contamination and inflammation. Chemical cleaning agents may potentially alter surface topography through different mechanisms, including chemical etching, polymer degradation, or surface oxidation.[11]

The balance between achieving adequate antimicrobial activity and maintaining optimal surface properties represents a key challenge in denture care product development. Previous research has shown that various commercial denture cleansers can modify the surface roughness of acrylic resin through different mechanisms.[12] Some studies report surface-smoothing effects, while others document increased roughness following chemical treatment.[13-15] These conflicting findings highlight the complexity of chemical-material interactions and the need for systematic investigation of natural alternatives.

This study further examines whether clove flower extract can be applied without increasing surface roughness beyond clinically acceptable limits while potentially providing antimicrobial benefits. In addition, the differential responses of acrylic resins processed through distinct polymerization methods are investigated, based on the premise that variations in activation processes may influence material-extract interactions. The specific objectives of this research include the quantitative assessment of changes in surface roughness following clove extract immersion, a comparative analysis of heat-cured and cold-cured acrylic resins, and the identification of optimal treatment protocols for clinical application.

The study hypothesizes that immersion in clove flower extract will not significantly increase surface roughness beyond clinically acceptable thresholds for either heat-cured or cold-cured acrylic resins. Furthermore, any observed surface modifications are expected to remain within acceptable clinical parameters and to provide adequate antimicrobial activity. This research contributes to the development of evidence-based protocols for natural denture cleansing agents and enhances understanding of plant extract–polymer interactions in dental applications.

Previous studies have predominantly investigated the antimicrobial and biological activities of clove-derived preparations, while those evaluating their effects on acrylic resin have generally focused on a single resin type or clove oil formulation.[2,5,7] To the best of our knowledge, limited evidence is available regarding the concentration-dependent effects of clove flower extract on acrylic resins produced using different polymerization methods. The novelty of the present study lies in the direct comparison of surface roughness changes between heat-cured and cold-cured acrylic resins following prolonged immersion in clove flower extract at concentrations of 1.6%, 1.8%, and 2.0%.

This comparative approach provides material-specific evidence on the susceptibility of different acrylic resin types to immersion in clove flower extract. Therefore, this study aimed to analyze changes in the surface roughness of heat- and cold-cured acrylic resins after immersion in clove flower extract.

METHODS

This study employed a true experimental design to evaluate the effect of clove flower extract immersion on the surface roughness of heat-cured and cold-cured acrylic resins. The design and reporting of the laboratory procedures followed the principles recommended by the checklist for reporting in vitro studies guidelines.[16]

After specimen fabrication and baseline evaluation, each specimen was assigned a unique identification code and randomly allocated to one of the eight experimental groups using a computer-generated random sequence. Random allocation was performed to minimize allocation bias and to ensure a balanced distribution of specimens across the treatment groups.16 Eight experimental groups were established, consisting of three extract concentrations (1.6%, 1.8%, and 2.0%) and one control group for each acrylic resin type, with distilled water serving as the control medium.

The calculation yielded a minimum requirement of four specimens per group, resulting in a total of 32 specimens across all experimental groups. This sample size determination was validated through pilot testing and aligned with established protocols for similar surface-roughness investigations of dental materials. The selection of clove flower extract concentrations was based on previous antimicrobial efficacy studies demonstrating optimal *Candida albicans* inhibition at 1.6% and maximum in vitro antimicrobial effectiveness at 2.0%. The 1.8% concentration was selected as an intermediate level to establish dose–response relationships.

Acrylic resin specimens were fabricated using standardized protocols to ensure dimensional consistency and surface uniformity across all experimental groups. Metal molds measuring 65 mm × 10 mm × 2.5 mm were used to ensure uniform specimen dimensions, with mold preparation involving dental stone investment and the application of appropriate separators to prevent adhesion. For heat-cured acrylic resin preparation, the powder-to-liquid ratio was maintained at 3:1 (w/v), and materials were mixed in porcelain containers using cement spatulas until a homogeneous consistency without air entrapment was achieved.

The polymerization process involved closing the flask under controlled pressure with a hydraulic press, followed by thermal processing at 100°C for 30 minutes in a water bath, ensuring complete monomer conversion and optimal mechanical properties.[17] cold-cured acrylic resin specimens were prepared using identical powder-to-liquid ratios, with polymerization occurring at ambient temperature (23 ± 2°C) for 45 minutes to achieve complete curing without thermal activation. Surface standardization was accomplished through sequential polishing using silicon carbide abrasive papers of progressively finer grits (120, 600, and 1200 grit), followed by mechanical polishing with felt wheels and pumice suspension to achieve clinically relevant surface finishes.

All specimens underwent 24-hour hydration in distilled water before baseline measurements to eliminate residual monomer effects and ensure dimensional stability. Surface roughness measurements were performed using a calibrated profilometer (Mitutoyo SJ-210) with a 0.25 mm cutoff length, ensuring that baseline values remained below 0.2 μm to meet clinical acceptability criteria. Each specimen surface was divided into three measurement zones to provide triplicate readings and enhance measurement reliability, and the arithmetic mean roughness (Ra) value was calculated for statistical analysis.

Clove flower extract was prepared using a standardized maceration method to ensure reproducibility and consistent bioactive compound concentrations. Dried clove flowers were mechanically ground to obtain a uniform particle size, thereby enhancing solvent penetration during extraction. The powdered material was then macerated in 96% ethanol, selected for its established efficiency in dissolving phenolic and eugenol-rich compounds present in clove flowers. Maceration was carried out for 72 hours at room temperature, with periodic agitation to optimize extraction yield.

Following maceration, the extract was filtered using Whatman No. 1 filter paper to remove particulate matter. The filtrate was subsequently concentrated under reduced pressure on a rotary evaporator at 40°C, yielding a 100% (w/v) crude clove flower extract after complete solvent removal. To prepare immersion solutions, the concentrated extract was dissolved in dimethyl sulfoxide (DMSO), which was used as a biocompatible solvent due to its high solubility capacity and minimal interaction with polymethyl methacrylate (PMMA). Final extract concentrations of 1.6%, 1.8%, and 2.0% (w/v) were prepared by dissolving 0.8 g, 0.9 g, and 1.0 g of clove flower extract, respectively, in 50 mL of DMSO, corresponding to concentrations of 16 mg/mL, 18 mg/mL, and 20 mg/mL.

The 23-day immersion period was determined using accelerated aging principles and was designed to simulate approximately 3 months of clinical denture cleanser use, assuming daily immersion for 6-8 hours during patient rest periods. This protocol was consistent with established aging methodologies in dental materials research and provided a clinically relevant simulation of prolonged chemical exposure.

Throughout the immersion process, all specimens were maintained at 37 ± 1°C in a calibrated incubator to replicate physiological oral temperature. Immersion solutions were renewed every 48 hours to preserve chemical stability and to prevent degradation of active compounds. Upon completion of the immersion period, specimens were rinsed thoroughly with distilled water and air-dried before post-immersion surface roughness evaluation to eliminate residual extract interference with measurement accuracy.

Post-immersion surface roughness measurements were conducted using identical protocols and equipment calibration as baseline assessments to ensure measurement consistency and reliability. Data collection involved triplicate measurements at predetermined surface locations, and the arithmetic mean was calculated for each specimen to minimize measurement variability.

Statistical analysis commenced with a normality assessment using the Shapiro–Wilk test to determine the appropriate parametric or non-parametric testing procedures. For normally distributed data, paired-samples t-tests were used to evaluate within-group changes from baseline to post-immersion measurements. At the same time, between-group comparisons were performed using analysis of variance (ANOVA) with appropriate post hoc tests.

Non-parametric data were analyzed using the Kruskal-Wallis test for multiple-group comparisons, followed by Mann-Whitney U tests for pairwise comparisons, with Bonferroni correction for multiple testing. Statistical significance was defined as $p < 0.05$, and effect sizes were calculated to assess the clinical significance of the observed changes. All statistical analyses were performed using SPSS version 28.0, with data management protocols ensuring complete-case analysis and appropriate handling of missing values through sensitivity analyses.

RESULTS

The differences in surface roughness of heat-cured acrylic resin before and after immersion in clove flower extract at concentrations of 1.6%, 1.8%, 2%, and distilled water were determined by conducting a normality test using the Shapiro-Wilk test, followed by a paired-samples t-test. The results are presented in Figure 1.

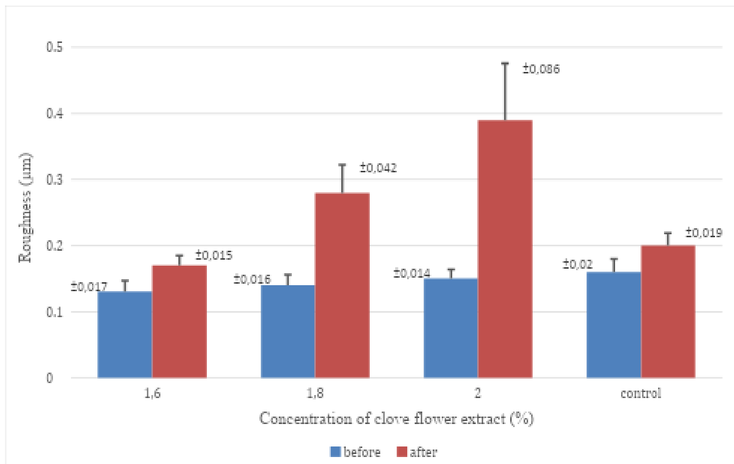

Figure 1. Differences in surface roughness values of heat polymerized acrylic resin before and after immersion in clove flower extract ($p < 0.05$, indicating a statistically significant difference).

Based on Figure 1, the p-value for the surface roughness of heat-cured acrylic resin before and after immersion in clove flower extract at concentrations of 1.6%, 1.8%, and 2% was less than 0.05 ($p < 0.05$), indicating a statistically significant difference. This indicates a mean difference in the surface roughness of heat-cured acrylic resin before and after immersion in clove flower extract at concentrations of 1.6%, 1.8%, and 2%.

Meanwhile, the p-value for the surface roughness of heat-cured acrylic resin immersed in distilled water, used as a control, was greater than 0.05 ($p > 0.05$), indicating no statistically significant difference. Therefore, there was no mean difference in the surface roughness of heat-cured acrylic resin before and after immersion in distilled water.

The differences in surface roughness of cold-cured acrylic resin before and after immersion in clove flower extract at concentrations of 1.6%, 1.8%, and 2%, as well as distilled water, were determined by conducting a normality test using the Shapiro–Wilk test, followed by a paired sample t-test. The results are presented in Figure 2.

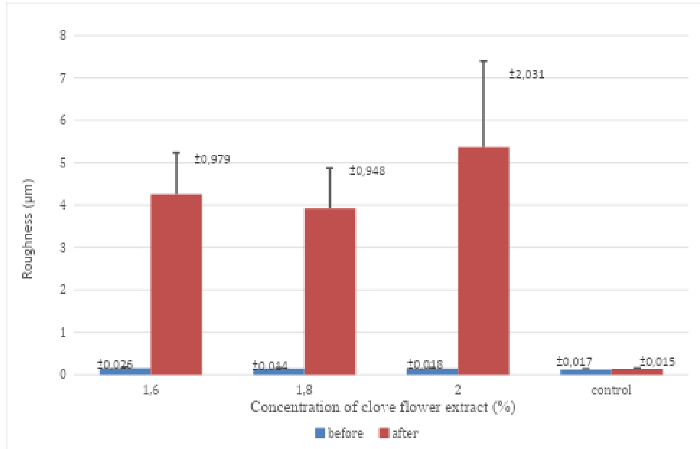

Figure 2. Differences in surface roughness values of cold-cured acrylic resin before and after immersion in clove flower extract (p <0.05, indicating a statistically significant difference)

Based on Figure 2, the results of the statistical tests for clove flower extract concentrations in the study groups are shown by the obtained p-values. The p-values for the surface roughness of cold-cured acrylic resin before and after immersion in clove flower extract at concentrations of 1.6%, 1.8%, and 2% were less than 0.05 ($p < 0.05$), indicating statistically significant differences. Thus, there was a difference in the mean surface roughness of cold-cured acrylic resin before and after immersion in clove flower extract at concentrations of 1.6%, 1.8%, and 2%.

Meanwhile, the p-value for the surface roughness of cold-cured acrylic resin immersed in distilled water, used as a control, was greater than 0.05 ($p > 0.05$), indicating no statistically significant difference. Therefore, there was no significant difference in the mean surface roughness of cold-cured acrylic resin before and after immersion in distilled water.

The differences in surface roughness changes between heat-cured and cold-cured acrylic resins before and after immersion in clove flower extract at concentrations of 1.6%, 1.8%, and 2% (eight treatment groups) were assessed using the Kruskal-Wallis test. The calculation results are presented in Table 1.

Table 1. Differences in acrylic resin surface roughness values before and after immersion across eight Treatment Groups

Group		p value
The difference between the increase surface roughness of the heat polymerized acrylic resin before and after immersion	clove flower extract 1.6%	0.001*
	clove flower extract 1.8%	
	clove flower extract 2%	
	distilled water	
The difference between the increase surface roughness of the self- polymerized acrylic resin before and after immersion	clove flower extract 1.6%	……
	clove flower extract 1.8%	
	clove flower extract 2%	
	distilled water	

* = the value of p <0.05, it means that there is a significant difference.

Based on Table 1, the p-value was less than 0.001 ($p < 0.01$), indicating significant changes in the surface roughness of acrylic resin across the eight treatment groups. Furthermore, to determine differences in surface roughness changes between heat-cured and cold-cured acrylic resins at each concentration, a post hoc Mann-Whitney test was conducted; the results are presented in Figure 3.

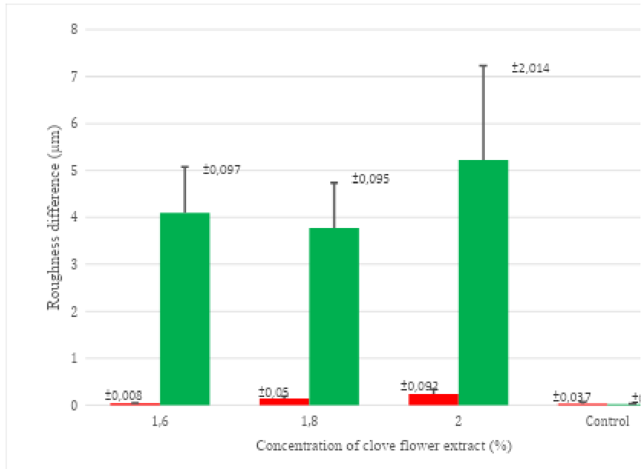

Figure 3. Differences in surface roughness between heat polymerized and self- polymerized acrylic resin at each concentration ($p < 0.05$, indicating a statistically significant difference)

Based on Figure 3, statistical analysis revealed significant differences in surface roughness between heat-cured and cold-cured acrylic resins when immersed in clove flower extract at concentrations of 1.6%, 1.8%, and 2.0% ($p < 0.05$). These findings indicate that clove flower extract induced differential changes in surface roughness between the two polymerization methods at all tested concentrations. Conversely, the control group using distilled water immersion showed no significant difference in surface roughness between heat-cured and cold-cured acrylic resins ($p > 0.05$).

DISCUSSION

The randomized complete block experimental design implemented in this study provided a rigorous methodological framework for evaluating the effects of clove flower extract immersion on surface roughness alterations in both heat-cured and cold-cured acrylic resins. A comparable controlled experimental approach was used by Sharma et al., who evaluated the effects of different denture cleansers on heat-cured acrylic resin and reported that daily immersion in 1% sodium hypochlorite for three months significantly increased surface roughness. In contrast, the comparison groups showed less pronounced changes. This supports the importance of using well-controlled treatment and control groups to distinguish material changes caused by immersion media from those related to storage conditions alone.[18]

This design enabled effective control of confounding variables while ensuring a balanced distribution of specimens across treatment groups, thereby supporting valid statistical inference.[19] The establishment of eight experimental groups allowed comprehensive evaluation of concentration-dependent effects and direct comparison between polymerization methods.

The findings presented in Figures 1 and 2 demonstrate that immersion in clove flower extract at concentrations of 1.6%, 1.8%, and 2.0% resulted in statistically significant increases in surface roughness for both heat-cured and cold-cured acrylic resins ($p<0.05$). In contrast, immersion in distilled water did not produce significant changes. These results are consistent with previous studies reporting that exposure to ethanol-based or plant-derived solutions can induce changes in surface roughness in acrylic resins due to solvent-polymer interactions and partial plasticization.19 However, unlike synthetic chemical cleansers, clove flower extract offers the additional benefit of antimicrobial activity, which may offset moderate surface alterations within clinically acceptable limits.

The selection of extract concentrations was guided by earlier investigations demonstrating effective inhibition of *Candida albicans* at concentrations ranging from 1.6% to 2.0%.[20] This approach aligns with previous dental materials research emphasizing the importance of balancing antimicrobial efficacy with the preservation of material integrity.

The intermediate concentration of 1.8% provided valuable insight into dose–response behavior, supporting the identification of an optimal concentration range for clinical application. The clinical relevance of this correlation is well established, as increased surface roughness facilitates microbial adhesion and biofilm formation, potentially compromising denture hygiene and oral health outcomes.[21] The accelerated aging protocol of 23 days was designed to simulate three months of routine denture cleanser use and is consistent with established aging methodologies reported in prior acrylic resin studies.

Standardized specimen preparation and surface-finishing protocols ensured uniform baseline conditions, minimizing variability that could affect post-immersion surface-roughness outcomes. Baseline Ra values for all specimens were maintained below 0.2 µm, which is widely accepted as the clinical threshold for minimizing plaque accumulation. This ensured that any statistically significant changes observed following immersion could be attributed primarily to the chemical effects of the clove flower extract rather than pre-existing surface irregularities.

The significant increases in surface roughness observed after clove extract immersion (Figures 1 and 2) are in agreement with previous reports indicating that acrylic resins may undergo surface degradation when exposed to solutions containing organic solvents or phenolic compounds.[22] Kavda et al. similarly reported that prolonged exposure of PMMA to selected solvents may promote solvent penetration into the polymer matrix, extraction of soluble components, plasticization, and physical surface deterioration, such as crazing or increased susceptibility to abrasion. Their findings support the mechanism by which solvent-containing or phenolic solutions can weaken the PMMA surface structure and contribute to roughness alterations after immersion.[23]

Ethanol-based extracts and phenolic constituents such as eugenol have been shown to penetrate the PMMA matrix, potentially leading to polymer chain relaxation, increased porosity, and surface microcracking. These mechanisms are more pronounced in cold-cured acrylic resins, which generally exhibit higher residual monomer content and lower cross-link density compared to heat-cured resins.

This material-dependent response is further supported by the comparative analysis shown in Figure 3, which reveals significant differences in surface roughness changes between heat-cured and cold-cured acrylic resins across all clove extract concentrations ($p<0.05$). Similar findings have been reported in previous studies comparing the chemical resistance of acrylic resins processed by different polymerization techniques, in which cold-cured materials exhibited greater susceptibility to chemically induced surface alterations.[24]

Clove flower extract contains high concentrations of phenolic compounds, particularly eugenol, which possess well-documented antimicrobial properties against oral pathogens such as *Candida albicans*.[25,26] The immersion-induced changes in surface roughness observed in this study may be attributed to interactions between these phenolic compounds and the PMMA matrix. Eugenol has been reported to act as a plasticizing agent, facilitating solvent penetration and localized surface softening, which may explain the statistically significant increases in roughness observed across all extract concentrations.

Despite these changes, the absence of significant alterations in roughness in the distilled water control groups confirms that the observed effects are attributable to the chemical composition of the clove flower extract rather than to immersion duration alone (Figures 1–3).

This finding is consistent with previous investigations demonstrating that neutral aqueous solutions do not significantly affect acrylic resin surface topography under comparable aging conditions.[27]

The statistical outcomes summarized in Table 1 indicate significant differences in surface roughness changes across all eight treatment groups ($p<0.01$), confirming that both resin type and immersion medium contribute to surface modification behavior. This is supported by Kyathappa et al., who evaluated the influence of three different denture cleansers on heat-polymerizing acrylic resin and found significant differences in surface roughness among treatment groups after immersion. Their post hoc analysis demonstrated that the type of cleansing solution significantly affected acrylic resin surface characteristics, reinforcing the present finding that the composition of the immersion medium is an important determinant of surface modification behavior.[28]

Post hoc Mann-Whitney analysis (Figure 3) further demonstrated that heat-cured acrylic resin exhibited significantly smaller changes in surface roughness than cold-cured resin across all clove extract concentrations. These results align with prior studies attributing the greater chemical stability of heat-cured resins to higher degrees of polymerization and reduced residual monomer content.[29]

From a clinical perspective, alterations in surface roughness must be interpreted in relation to established thresholds for microbial adhesion. While increased roughness may promote biofilm formation, the concurrent antimicrobial activity of clove flower extract may mitigate this effect by inhibiting microbial colonization on the denture surface.[30-34] Therefore, the findings suggest that clove flower extract, when used at appropriate concentrations, may offer a favorable balance between antimicrobial efficacy and acceptable material performance.

Overall, this study extends previous research by directly comparing the effects of clove flower extract on different acrylic resin polymerization methods and by integrating surface roughness evaluation with clinically relevant antimicrobial considerations. These findings support the potential application of clove flower extract as a natural denture cleansing agent, provided that concentration and exposure protocols are carefully optimized to preserve long-term material integrity.

This suggests that the polymerization method alone does not significantly influence changes in surface roughness under neutral conditions. The significant differences observed with clove flower extract immersion demonstrate that the chemical composition and concentration of the immersion medium interact differently with heat-cured and cold-cured acrylic resins. This differential response may be attributed to varying degrees of cross-linking, residual monomer content, and material density between the two polymerization techniques, which affect the materials' susceptibility to chemical-induced surface alterations.

The limitation of this study is that it was conducted under controlled in vitro conditions, which may not fully replicate the oral cavity's complex biological, mechanical, and chemical environment. Factors such as salivary flow, enzymatic activity, masticatory forces, temperature fluctuations, and continuous microbial challenges were not simulated. They may influence surface roughness behavior and material-extract interactions in clinical settings. Additionally, the accelerated aging protocol, although designed to represent three months of clinical denture cleanser use, may not precisely reflect the long-term cumulative effects of repeated immersion over extended periods.

Another limitation is that only surface roughness was evaluated as a material outcome. At the same time, other clinically relevant properties of acrylic resin, such as hardness, flexural strength, color stability, and residual monomer release, were not assessed. These parameters may also be affected by prolonged exposure to plant-derived extracts and should be considered when interpreting the overall impact of clove flower extract on denture base materials. Furthermore, the antimicrobial efficacy of the clove flower extract was inferred from previous studies rather than directly evaluated alongside changes in surface roughness in the present investigation.

The study was also limited to three extract concentrations and a single solvent system (DMSO), which may restrict the generalizability of the findings to other concentration ranges or to alternative solvent formulations commonly used in clinical denture-cleansing products. Finally, only two polymerization techniques were examined, and the results may not be directly applicable to other denture base materials or processing methods. Future studies incorporating in vivo models, extended immersion periods, broader evaluations of material properties, and direct microbiological assessments are recommended to validate and expand upon the present findings.

Previous investigations have demonstrated that the composition of denture cleansing solutions and the duration of exposure can affect the surface characteristics of acrylic resin materials.[18,30] In the present study, the increase in surface roughness was substantially greater in cold-cured acrylic resin than in heat-cured acrylic resin, indicating that the polymerization method should be considered when selecting a cleansing solution. Increased surface irregularity may provide additional retention sites for microbial adhesion and biofilm formation on denture resin surfaces.[32,33]

Therefore, despite the reported antimicrobial potential of clove-derived compounds, the formulation evaluated in this study cannot yet be recommended for routine clinical use. Further optimization of extract concentration, solvent composition, and immersion duration is required to achieve antimicrobial effectiveness without compromising the surface integrity of the denture base material.

Nevertheless, several limitations should be acknowledged, including the exclusive evaluation of surface roughness without a comprehensive assessment of other mechanical or aesthetic properties, the limited range of concentrations examined, and the absence of long-term clinical validation. Future studies should focus on identifying optimal concentration ranges that maximize antimicrobial effectiveness while minimizing surface degradation, exploring additional bioactive compounds to achieve synergistic effects, and conducting longitudinal clinical trials to confirm laboratory findings under real-world denture-care conditions.

CONCLUSION

Clove flower extract immersion significantly increased the surface roughness of both heat-cured and cold-cured acrylic resins, particularly at concentrations of 1.6%, 1.8%, and 2.0%. The effect was more pronounced in cold-cured acrylic resin, which may be attributed to its higher residual monomer content and greater capacity to absorb the extract. These findings indicate that clove flower extract can influence the surface durability of acrylic resin denture base materials. Therefore, although clove flower extract has potential as a natural denture cleansing agent, its concentration and immersion duration should be carefully controlled to minimize adverse effects on acrylic resin surfaces. The findings of this study have implications for both clinical denture care and the development of plant-based denture cleansing formulations.

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