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BASIC RESEARCH:

Effect of Desensitizing Mouth Rinses on Surface Properties of 3D-Printed Crowns: An *In Vitro* Study

Efecto de los enjuagues bucales desensibilizantes sobre las propiedades superficiales de coronas impresas en 3D: un estudio *in vitro*

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ABSTRACT: This study evaluates the effect of desensitizing mouth rinses on the surface properties of 3D-printed crowns compared to heat-cured and cold-cured crowns. Thirty dental crowns were fabricated and divided into three groups: 3D-printed crowns, heat-cured crowns, and cold-cured crowns (n=10 each). All samples underwent daily immersion in a desensitizing mouth rinse (Senquel AD) for four weeks. Surface roughness, hardness, and color stability were analyzed pre- and post-treatment using a profilometer, Vickers hardness tester, and spectrophotometer. Statistical analyses were performed using ANOVA and post-hoc tests. 3D-printed crowns showed a significant increase in surface roughness and a reduction in hardness after exposure to the mouth rinse, while heat-cured crowns exhibited minimal changes. Cold-cured crowns demonstrated moderate alterations in surface properties. Color stability was unaffected in all groups. Desensitizing mouth rinses exert differential effects on dental crowns. While 3D-printed crowns are more susceptible to changes, heat-cured crowns retain superior surface stability. This underscores the importance of material-specific considerations when prescribing mouth rinses to patients.

KEYWORDS: 3D-printed crowns; Heat-cured crowns; Cold-cured crowns; Desensitizing mouth rinse; Surface roughness; Hardness; Color stability.

RESUMEN: Este estudio evalúa el efecto de los enjuagues bucales desensibilizantes sobre las propiedades superficiales de coronas dentales impresas en 3D en comparación con coronas polimerizadas por calor y por frío. Se fabricaron treinta coronas dentales, las cuales se dividieron en tres grupos: coronas impresas en 3D, coronas polimerizadas por calor y coronas polimerizadas por frío (n=10 en cada grupo). Todas las muestras fueron sometidas a inmersión diaria en un enjuague bucal desensibilizante (Senquel AD) durante cuatro semanas. Se analizaron la rugosidad superficial, la dureza y la estabilidad del color antes y después del tratamiento utilizando un perfilómetro, un durómetro Vickers y un espectrofotómetro. Los análisis estadísticos se realizaron mediante ANOVA y pruebas post hoc. Las coronas impresas en 3D mostraron un aumento significativo en la rugosidad superficial y una disminución en la dureza tras la exposición al enjuague bucal, mientras que las coronas polimerizadas por calor presentaron cambios mínimos. Las coronas polimerizadas por frío exhibieron alteraciones moderadas en sus propiedades superficiales. La estabilidad del color no se vio afectada en ninguno de los grupos. Los enjuagues bucales desensibilizantes ejercen efectos diferenciales sobre las coronas dentales. Las coronas impresas en 3D son más susceptibles a modificaciones en sus propiedades superficiales, mientras que las coronas polimerizadas por calor mantienen una estabilidad superior. Estos hallazgos resaltan la importancia de considerar las características específicas del material al prescribir enjuagues bucales a los pacientes.

PALABRAS CLAVE: Coronas impresas en 3D; Coronas polimerizadas por calor; Coronas polimerizadas por frío; Enjuague bucal desensibilizante; Rugosidad superficial; Dureza; Estabilidad del color.

INTRODUCTION

The advent of 3D printing technology in dentistry has significantly transformed the fabrication of dental prostheses, offering unparalleled advantages in precision, efficiency, and customization. This innovative approach has enabled the creation of highly intricate designs that cater to individual patient needs, thereby improving clinical outcomes. Unlike traditional methods of crown fabrication, which involve multiple manual and laboratory steps prone to human error, 3D printing employs additive manufacturing. This technique builds structures layer by layer based on digital designs, minimizing inaccuracies and reducing fabrication time, thus revolutionizing restorative dentistry (1-3).

Beyond enhancing accuracy, 3D printing in dentistry facilitates the rapid prototyping of crowns, bridges, and other prosthetic components. This reduces the turnaround time for treatment, ensuring quicker restoration of dental function and aesthetics for patients. Furthermore, the digital workflows associated with 3D printing allow for seamless integration with other technologies such as intraoral scanners and CAD/CAM systems, streamlining the treatment process and minimizing the need for multiple adjustments. This efficiency makes 3D printing a cornerstone of modern restorative dentistry.

The materials utilized for 3D-printed crowns primarily comprise advanced resin composites. These materials, characterized by their distinct mechanical and aesthetic properties, differ substantially from conventional heat- and cold-cured acrylic resins. Heat-cured acrylics undergo polymerization under controlled thermal conditions, producing dense, durable structures with superior longevity. In contrast, cold-cured acrylics rely on self-polymerization at room temperature, which often results in higher residual monomer content. This compromises their mechanical strength and longevity compared to heat-cured alternatives (4-6).

Surface properties such as roughness and hardness play pivotal roles in determining the clinical success of dental crowns. Rough surfaces facilitate bacterial adhesion and biofilm formation, escalating the risk of periodontal disease, secondary caries, and premature crown failure (7-9). Hardness, which measures resistance to deformation, is critical for enduring masticatory forces and mitigating wear. Hence, ensuring optimal surface characteristics is crucial for the long-term functionality of crowns.

Desensitizing mouth rinses are widely recommended for managing dentinal hypersensitivity, a common dental condition. These rinses often contain active ingredients such as potassium nitrate and sodium fluoride, which effectively alleviate sensitivity by occluding dentinal tubules or reducing nerve excitability. While their clinical benefits are well-documented, the interactions between these chemical agents and dental restorative materials remain inadequately explored. Such interactions could potentially alter the physical properties of restorative materials, thereby affecting their durability and aesthetics. Moreover, given the widespread use of desensitizing mouth rinses, understanding their impact on various dental materials is vital for guiding clinical recommendations and ensuring optimal patient outcomes (11-13). Addressing this knowledge gap, the present study investigates the effects of a fluoride-based desensitizing mouth rinse (Senquel AD) on the surface properties of 3D-printed crowns compared to heat- and cold-cured crowns.

MATERIALS AND METHODS

SAMPLE PREPARATION

A total of thirty standardized full-coverage molar-shaped crowns were fabricated and divided into three groups (n=10 per group) according to the material used:

Group A. 3D-Printed Resin Crowns: Crowns were digitally designed using Exocad CAD software (Exocad GmbH, Germany) and fabricated via additive manufacturing using a Digital Light Processing (DLP) 3D printer (Anycubic Photon Mono X, Anycubic, China). The resin used was NextDent C&B MFH (Vertex Dental B.V., Netherlands; Lot #ND-MFH0923), a biocompatible Class IIa material approved for long-term intraoral use.

Group B.Heat-Cured Acrylic Resin Crowns: Conventional compression molding techniques were used to fabricate these crowns. Heat-cured acrylic resin (Lucitone 199, Dentsply Sirona, USA; Lot #L199-1023) was packed into a dental flask and polymerized at 74°C for 2 hours, followed by terminal boiling at 100°C for 30 minutes, in accordance with the manufacturer’s protocol.

Group C. Cold-Cured Acrylic Resin Crowns: Crowns were fabricated using self-polymerizing acrylic resin (DPI Self Cure, Dental Products of India, India; Lot #SC-091023) mixed in a 3:1 powder-to-liquid ratio and allowed to cure at ambient room temperature (25°C±1°C) under standard atmospheric pressure.

To ensure shape and dimensional consistency, all crowns were designed to a uniform size (10mm height × 8mm diameter) using CAD software. The digital design was used to generate silicone molds (Zhermack Elite Double, Lot #ZD-0923), which were used for both conventionally fabricated groups. This ensured that each crown, regardless of material or method, shared identical morphology and surface contours.

SAMPLE SIZE JUSTIFICATION

Sample size was calculated using G*Power 3.1 (Heinrich Heine University, Düsseldorf, Germany). Assuming a medium effect size (f=0.40), α=0.05, and power=0.80, 10 samples per group were required for statistically valid comparisons among the three groups.

IMMERSION PROTOCOL

Each crown was immersed in Senquel AD mouth rinse (Dr. Reddy's Laboratories Ltd., India; Lot #SAD1023), which contains 5% potassium nitrate and 0.2% sodium fluoride, known for desensitizing and remineralizing effects. Crowns were immersed in 10mL of the solution once daily for 5 minutes over 28 consecutive days, simulating clinical exposure. Between immersion cycles, samples were stored in sterile, sealed polypropylene containers at room temperature (25°C±1°C) and relative humidity of approximately 50%, away from direct light and contaminants to prevent evaporation and microbial growth.

TESTING PROCEDURES

All evaluations were conducted pre- and post-immersion, with the operator blinded to sample grouping to minimize observer bias.

Surface Roughness: Measured using a contact profilometer (Mitutoyo Surftest SJ-210, Japan; calibrated before each session). Ra values were obtained by averaging three linear scans per crown, taken at fixed intervals on the buccal surface.

Microhardness: Assessed using a Vickers hardness tester (Wilson VH1102, Buehler, USA) with a 100 g load and a 15-second dwell time. Three indentations per sample were made on the occlusal surface, and the mean value was reported.

Color Stability: Color change (ΔE) was calculated using a VITA Easyshade V spectrophotometer (VITA Zahnfabrik, Germany). Baseline and post-immersion readings of L*, a*, and b* values were recorded under standardized lighting conditions. The ΔE was computed using the CIELAB formula

STATISTICAL ANALYSIS

Statistical analysis was performed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY). Normality of data was confirmed using the Shapiro-Wilk test. One-way Analysis of Variance (ANOVA) was used to compare means across the three material groups. Tukey's post-hoc test was applied for pairwise comparisons. Statistical significance was set at $p<0.05$.

RESULTS

SURFACE ROUGHNESS (TABLE 1)

Table 1. Pre- and Post-Immersion Surface Roughness (Ra) Values of Different Crown Materials.

Crown Type	Pre-Immersion Ra (µm)	Post-Immersion Ra (µm)	p-value
3D-Printed Resin	12.5 ± 0.8	15.3 ± 0.9	< 0.05
Heat-Cured Acrylic	14.2 ± 1.0	14.4 ± 0.9	> 0.05
Cold-Cured Acrylic	13.8 ± 0.7	16.1 ± 1.1	< 0.05

3D-Printed Crowns: The surface roughness (Ra) values increased significantly from 12.5±0.8µm to 15.3±0.9 µm ($p<0.05$), as illustrated in the post-immersion surface roughness bar chart (Figure 2).

Heat-Cured Crowns: The Ra values remained stable, with minimal changes from 14.2 ± 1.0 μm to 14.4 ± 0.9 μm ($p>0.05$), as shown in Figure 2.

Cold-Cured Crowns: Moderate surface roughness was observed pre-immersion, as shown in the microscopic images (Figure 3). After immersion, Ra values increased from 13.8±0.7 μm to 16.1±1.1 μm ($p<0.05$), as depicted in Figure 1 and Figure 4.

HARDNESS (TABLE 2)

Table 2. Vickers Hardness Values of Crowns Pre- and Post-Immersion.

Crown Type	Pre-Immersion HV	Post-Immersion HV	p-value
3D-Printed Resin	110±5	92±4	<0.05
Heat-Cured Acrylic	125±3	124±2	>0.05
Cold-Cured Acrylic	95±4	88±3	<0.05

3D-Printed Crowns: The Vickers hardness decreased significantly, from 110±5 HV to 92±4 HV ($p<0.05$), supported by post-immersion surface degradation observed in microscopic images (Figure 6).

Heat-Cured Crowns: Hardness values remained stable, with only slight changes from 125±3 HV to 124±2 HV ($p>0.05$), confirming their chemical resistance (Figure 5).

Cold-Cured Crowns: A notable reduction in hardness was recorded, from 95±4 HV to 88±3 HV ($p< .05$), supported by post-immersion microscopic images showing surface variability (Figure 4).

COLOR STABILITY (TABLE 3)

Table 3. Color Stability of Crowns Based on ΔE Value.

Crown Type	Mean ΔE Value	Clinical Relevance	Interpretation
3D-Printed Resin	1.82±0.2	ΔE<2	No perceptible color change
Heat-Cured Acrylic	1.45±0.3	ΔE<2	Color stability maintained
Cold-Cured Acrylic	1.77±0.4	ΔE<2	No clinically relevant change

All groups exhibited minimal color changes ($\Delta E<2$), demonstrating excellent color stability regardless of crown type or treatment. This finding is supported by the spectrophotometric analysis (Figure 6).

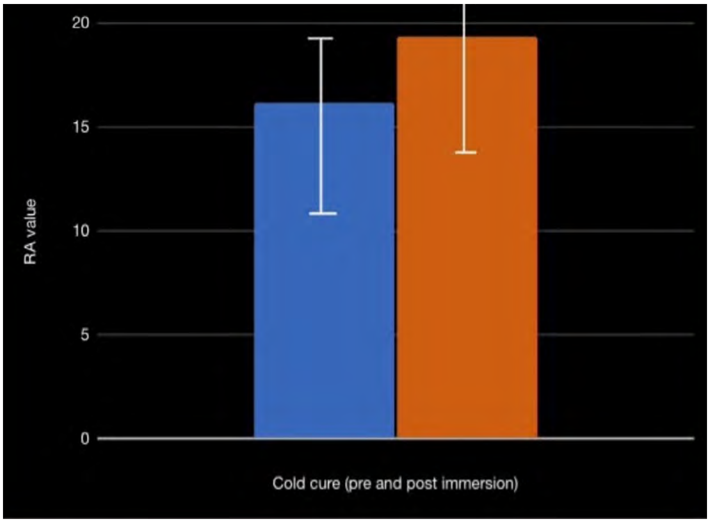

Figure 1. Pre-Immersion Surface Roughness: Bar chart showing Ra values of all crown types before immersion, clearly labeling the axes and including error bars to represent variability.

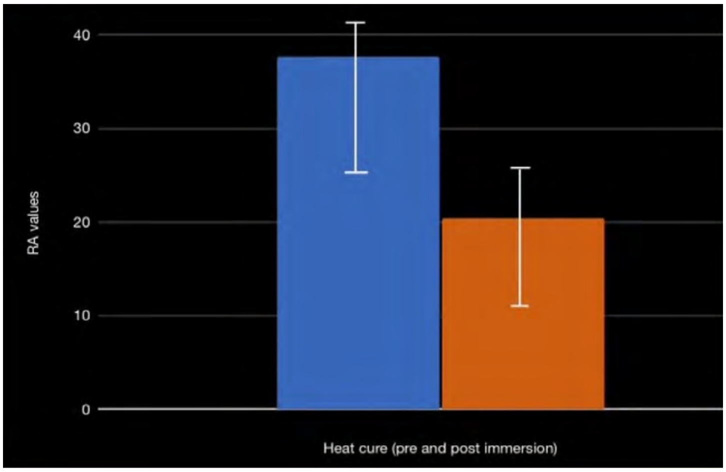

Figure 2. Post-Immersion Surface Roughness: Bar chart depicting Ra values of all crown types after immersion, highlighting statistically significant differences.

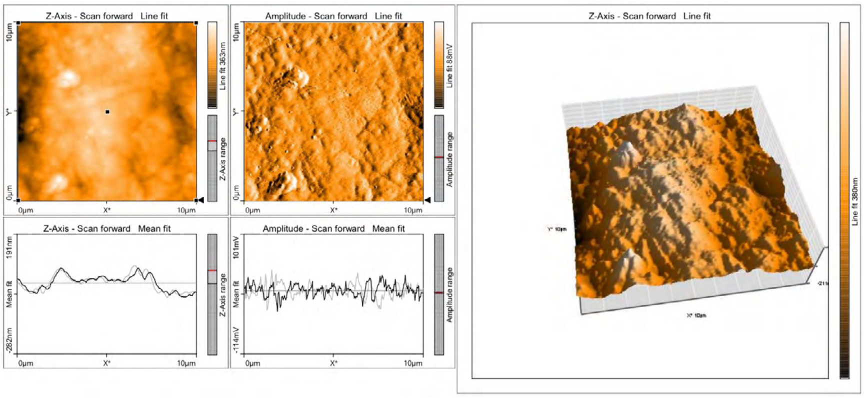

Figure 3. Pre-Immersion Cold-Cured Crowns: Microscopic images illustrating smooth, uniform surfaces of cold-cured crowns prior to immersion, serving as a baseline.

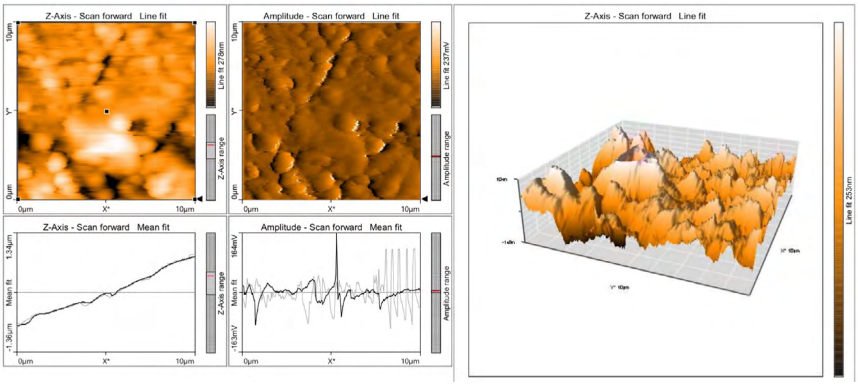

Figure 4. Post-Immersion Cold-Cured Crowns: Microscopic images illustrating surface variability in cold-cured crowns after immersion, highlighting changes such as increased roughness, minor pitting, and uneven texture.

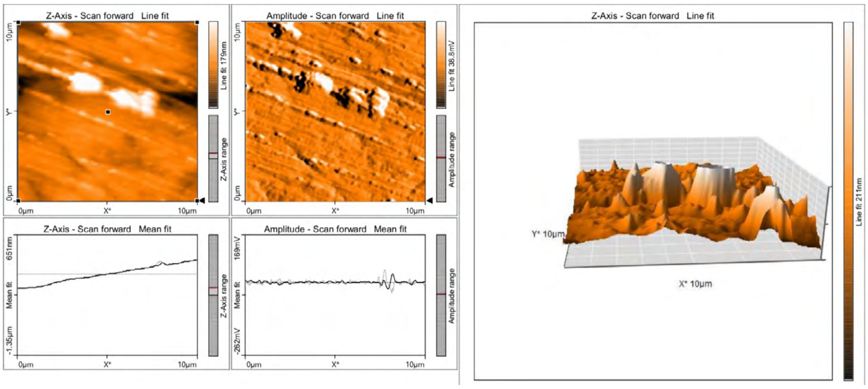

Figure 5. Post-Immersion Heat-Cured Crowns: Images confirming negligible changes in surface roughness and hardness of heat-cured crowns, validating their resistance to chemical agents in desensitizing mouth rinses

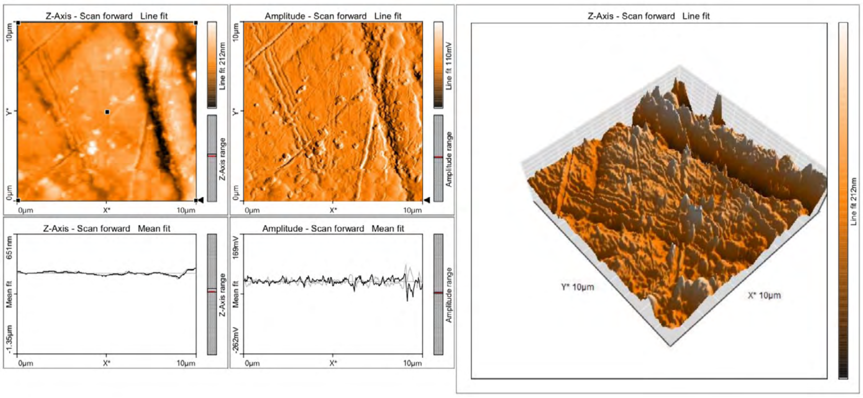

Figure 6. Color Stability Analysis: Spectrophotometric data illustrating ΔE values pre- and post-immersion for all crown types, demonstrating minimal clinically perceptible color changes (Δ<2).

DISCUSSION

The present study provides critical insights into the behavior of three distinct crown fabrication materials-3D-printed resin, heat-cured acrylic, and cold-cured acrylic-when exposed to a desensitizing mouth rinse containing potassium nitrate and sodium fluoride. The findings demonstrate that surface properties and mechanical resilience are strongly influenced by the type of material used, revealing both the advantages and limitations of each system under simulated clinical conditions.

The observed significant increase in surface roughness and reduction in Vickers hardness for the 3D-printed crowns suggests considerable susceptibility to chemical degradation. These findings are consistent with prior studies that reported reduced mechanical stability and increased water sorption in 3D-printed dental resins exposed to oral fluids and hygiene products (12, 14). The resin matrix in 3D-printed crowns may undergo plasticization or surface erosion due to the absorption of hydrophilic components from the mouth rinse, promoting leaching of unreacted monomers. This is concerning as surface roughness above the critical threshold (Ra>0.2 μm) facilitates bacterial adhesion and biofilm formation, thereby increasing the risk for secondary caries and periodontal inflammation (15).

In contrast, the heat-cured crowns exhibited superior chemical resistance, showing minimal changes in surface roughness and hardness. This aligns with previous investigations indicating that heat-polymerized acrylic resins exhibit higher cross-linking density, lower water sorption, and minimal residual monomer content due to the controlled heat and pressure curing process (16). These properties contribute to the material's mechanical durability and dimensional stability under long-term exposure to chemical agents. The negligible surface and mechanical alterations post-immersion further validate their suitability in clinical settings, especially in patients who require prolonged use of medicated mouth rinses.

Cold-cured crowns presented an intermediate response: they exhibited moderate surface roughness increases and a notable reduction in hardness, though to a lesser extent than 3D-printed crowns. These changes can be attributed to their lower polymerization efficiency and higher residual monomer content, making them more reactive to chemical exposure (17). Nonetheless, their performance suggests that cold-cured acrylics remain a viable option for provisional restorations or low-load bearing areas, particularly in situations where heat-curing equipment is unavailable or impractical. This finding is corroborated by earlier studies that have noted acceptable performance of cold-cured materials in short-term clinical applications, albeit with reduced mechanical endurance compared to their heat-cured counterparts (18, 19).

Despite the differences in mechanical and surface responses, all crown groups exhibited excellent color stability with ΔE values remaining below clinically perceptible thresholds (ΔE<2). This outcome agrees with previous literature demonstrating that fluoride- and nitrate-based rinses, while chemically active, tend to have limited interaction with polymer pigments at the concentrations commonly used in over-the-counter oral hygiene products (20). However, it must be noted that prolonged usage or variations in mouth rinse formulation-particularly those containing alcohol, chlorhexidine, or whitening agents-may yield different results, as reported in studies that observed pigment leaching or discoloration under such conditions (20).

From a methodological standpoint, the standardization of crown fabrication using CAD design and uniform immersion protocols is a strength of this study, as it minimizes variability and enhances reproducibility. Additionally, the inclusion of profilometric, hardness, and spectrophotometric assessments provides a comprehensive evaluation of clinically relevant parameters. However, the study's limitation lies in its *in vitro* design. Real-world conditions such as fluctuating pH, enzymatic activity, dietary factors, and mechanical stresses from mastication were not replicated, potentially limiting the extrapolation of results. This is a common limitation also acknowledged in previous studies investigating chemical aging of restorative materials (12, 14, 19).

Furthermore, while one-way ANOVA and Tukey's posthoc test are appropriate for intergroup comparisons, future studies might benefit from multifactorial analyses to explore the interaction effects of time, rinse composition, and material type. Studies incorporating longer immersion durations, thermocycling, or aging protocols may better simulate long-term clinical exposure and further elucidate material resilience.

Comparative literature supports the present findings, yet also suggests avenues for innovation. For instance, incorporation of nanofillers or cross-linking agents in 3D-printed resins has been shown to improve resistance to chemical and mechanical degradation, offering a potential pathway for enhancing current material formulations (14, 19). Similarly, experimental polymer blends with enhanced color stability and reduced sorption have been developed, particularly in the realm of CAD/CAM denture bases and temporary crowns, highlighting an ongoing evolution in material science.

Clinically, these findings underscore the importance of selecting restorative materials based not only on mechanical strength or esthetics but also on compatibility with the patient's oral hygiene regimen. In patients prescribed desensitizing mouth rinses, particularly over extended periods, heat-cured crowns may offer superior longevity and stability. Educating patients about the potential impact of oral care products on their restorations is equally vital to ensure informed decision-making and prolonged restoration lifespan (21, 22).

CONCLUSION

Desensitizing mouth rinses differentially affect the surface properties of dental crown materials, with 3D-printed crowns showing the greatest susceptibility to surface alterations. Heat-cured crowns demonstrated superior stability, making them the most durable option for long-term restorations. Cold-cured crowns, though moderately affected, remain viable alternatives under specific clinical conditions.

This study highlights the importance of material-specific considerations when selecting restorative materials for patients using desensitizing mouth rinses. Incorporating these findings into clinical practice can enhance the longevity and performance of dental crowns. Future research should explore the long-term effects of diverse mouth rinse formulations on a broader range of dental materials to provide comprehensive clinical guidelines.

AUTHOR CONTRIBUTION STATEMENT: Assisted in conducting the experiments, performed the statistical analysis, data visualization: B.G.S. and J.S.; Wrote the manuscript: B.G.S., J.S., G.R., V.P.V. and U.A.; Designed and conducted all of the experiments: G.R., V.P.V. and U.A.

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