

Article

Antifungal Effect of Alum Solution as a Natural Disinfectant and Its Impact on Surface Properties of 3D-Printed Denture Base Resin

Sarah Jaleel Mohan ¹, Abdalbseet A. Fatalla ^{1,*}, Matheel AL-Rawas ^{2,3,*} and Johari Yap Abdullah ^{4,5}

¹ Department of Prosthodontics, College of Dentistry, University of Baghdad, Baghdad 10071, Iraq; sarah.muhan2401@codental.uobaghdad.edu.iq

² Prosthodontic Unit, School of Dental Sciences, Universiti Sains Malaysia, Kota Bharu 16150, Malaysia

³ Department of Prosthodontics, Saveetha Dental College and Hospital, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai 602105, India

⁴ Craniofacial Imaging Laboratory, School of Dental Sciences, Health Campus, Universiti Sains Malaysia, Kubang Kerian, Kota Bharu 16150, Malaysia; johariyap@usm.my

⁵ Dental Research Unit, Center for Transdisciplinary Research (CFTR), Saveetha Dental College, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai 602105, India

* Correspondence: abdalbasit@codental.uobaghdad.edu.iq (A.A.F.); matheel@usm.my (M.A.-R.)

Abstract

Objectives: Disinfection of 3D-printed acrylic resin is essential to reduce fungal colonization and improve the clinical performance of dentures. This in vitro study assessed the antifungal activity of aluminum potassium sulfate (alum) solutions against *Candida albicans* in 3D-printed acrylic resin at different concentrations, while also illustrating their effects on the material's surface roughness and wettability. **Materials and methods:** The study included 120 specimens prepared from 3D-printed acrylic resin and then randomly assigned to four groups: distilled water as the negative control, a CHX 2% as the positive control, and two concentrations (10% and 15%) of alum solution. A total of 40 specimens were used for each of the three tests, with 10 specimens per group. An additional 16 specimens were fabricated for microstructural characterization, with 3 specimens per group for SEM and 1 specimen per group for AFM, bringing the total number of specimens to 136. The antifungal activity against *Candida albicans* was evaluated using a colony-forming unit (CFU) method. Surface roughness was evaluated utilizing a profilometer, while wettability was assessed by a contact angle goniometer. Before surface roughness, wettability, SEM, and AFM testing, the specimens in the alum (10% and 15%) and 2% chlorhexidine (CHX) groups were immersed for 5 min per cycle, completing 90 immersion cycles over 10 days to simulate approximately 3 months of clinical denture use. In contrast, the specimens used for the colony-forming unit (CFU) test against *Candida albicans* were immersed only once for 5 min. The negative control specimens were not subjected to any disinfection. Statistical assessments were conducted out by employing one-way ANOVA with Games–Howell post hoc for CFU, as well as one-way ANOVA with Bonferroni post hoc were chosen for wettability and roughness data. In all statistical assessments, the significance was determined at $p < 0.05$. **Results:** Number of CFU of *Candida albicans* was significantly reduced ($p < 0.0001$) in all tested groups relative to the negative control group, along with a significant rise in surface roughness. Chlorhexidine revealed higher wettability (decreased contact angle), though no significant change was found between either the 10% or 15% alum groups and the negative control ($p > 0.05$). **Conclusions:** Alum solutions at concentrations of 10% and 15% for 5 min revealed antifungal activity against *Candida albicans* in 3D-printed acrylic denture base resin. There was no statistical change in wettability for any concentration compared to the negative control, while surface roughness increased after treatment.



Academic Editor: Marco Cicciu

Received: 18 August 2026

Revised: 25 September 2026

Accepted: 26 September 2026

Published: 29 September 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and

conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

Keywords: alum; 3D printed resin material; disinfection; immersion; antifungal agent; denture base; Surface properties

1. Introduction

The fabrication of dentures underwent a revolution with the development of acrylic resin [1]. A polymethyl methacrylate substance was brought in 1936 [2]. PMMA and its copolymers have been used to fabricate 98% of dentures since 1948 [3], and PMMA is the best choice of material for denture base fabrication due to its good esthetic properties, biological compatibility with oral tissues, inexpensiveness, lightweight, ease of manufacturing, and handling [1]. However, dimensional inaccuracy; mechanical qualities like as flexural and impact strength are inadequate, and polymerization shrinkage are among the drawbacks that should be addressed [4]. Technological innovation has the power to transform the traditional denture manufacturing process. Particularly, 3-dimensional printing, initially developed in 1983, is swiftly developing. This computer-controlled digital production method relies on 3D model data to produce both basic and sophisticated products. Its working concept, sometimes referred to as additive manufacturing or rapid prototyping, can be understood as the opposite of subtractive manufacturing [5,6]. Building up a layer-by-layer technique, 3D printing technology generates precise models [7]. Also, 3D-printing can precisely build items or components at a reasonable cost yet reduce material waste [8], and these gains, together with shorter chairside time and fewer appointments, explain why the technique is being adopted more widely in clinics [9]. That said, 3D-printed denture base resins are not without drawbacks; they also have some limitations that should be considered. Prior research reported that residual monomer can remain in the material after printing and post-curing, and this has been linked to cytotoxic effects [10]. The layer-by-layer build process and the resulting surface features can also make these materials more susceptible to the adhesion of microbes, *Candida albicans* in particular [11], while interlayer defects, orientation-related imperfections, and incomplete polymerization may all influence how the material performs clinically over time [12]. An example of why this is crucial is denture stomatitis, which affects in excess of 70% of humans wearing complete dentures. Its causes are multifactorial, yet *Candida albicans* biofilms sticking to and growing on denture surfaces play a major role [13]. Denture bases at times behave as reservoirs where biofilm can build up because of the irregularities and porosity of the tissue surfaces [14,15]. The most popular control method is mechanical cleansing, like brushing with soap or toothpaste, though it is often not enough by its own, especially for seniors with declined manual dexterity [15–17]. Chemical disinfection closes that gap for traditional dentures, yet there are still little clinical guidance and proof for 3D-printed materials [15]. Chlorhexidine di-gluconate and sodium hypochlorite are well-known chemical cleansers due to their antifungal and antibiofilm action [18,19]. Prolonged use of these cleansers has been linked to issues such as a change in color of the acrylic foundation, cytotoxic effects, lower flexural strength, and corrosion of metallic parts [15,20]. This is part of why naturally derived solutions are gaining attention as less expensive alternatives, with prior work revealing antimicrobial effects and potential advantages over some traditional harsher agents [21,22]. However, their performance for a period of time on 3D-produced resins is yet unknown. Aluminum potassium sulfate (alum) is a naturally occurring substance that has been used for centuries in healthcare; it has therapeutic value. Natural products are inexpensive, environmentally favorable, and readily available [23]. In the food and medical industries, this solution shows promise as a disinfectant. The chemical formula of aluminum potassium sulfate (alum) is $KAl(SO_4)_2 \cdot 12H_2O$, which is normally without

color or smell crystal-like solid that becomes white in air and can be applied to purify water and preserve food. The OTC (Over-the-Counter) Advisory Panel of the U.S. Food and Drug Administration (FDA) recommended the use of alum as an active ingredient in mouthwash [24]. Aluminum potassium sulfate has revealed low toxicity in laboratory animals [25]. A previous dental study has shown that the treatment of potassium aluminum sulfate did not significantly alter the vitality of fibroblasts before or after thermocycling to feldspathic ceramic [26]. The current study, however, did not specifically assess cytotoxicity. Several investigations have found that alum has antimicrobial capabilities against a wide variety of fungal and bacterial species and uses other advantageous attributes [27]. Because of the favorable properties of aluminum potassium sulfate, particularly the antifungal properties, and since there is no study evaluating the effect of alum as a disinfectant for 3D printing resin material, this in vitro investigation was executed to measure the antifungal activity of alum on 3D-printed resin using an immersion technique in different concentrations while evaluating its impact on the wettability and surface roughness.

While the mechanical performance of 3D-printed resins has been widely studied, their surface and biological behavior after disinfection remain less explored, even though it carries direct clinical consequences. CFU counts of *Candida albicans* gave a direct measure of alum's antifungal activity to control the organism most frequently responsible for denture-related illnesses. Surface roughness was evaluated because rougher surfaces give bacteria and fungi more places to reside, which makes them harder to remove with routine cleaning and urges plaque buildup, food debris retention, and staining over time; past a roughness of about 0.2 μm , microbial adhesion has been shown to increase noticeably [28]. A more hydrophilic surface allows saliva to spread and wet the denture more readily, which has been linked in the literature to enhanced retention and less adhesion of *Candida albicans* and other microbes; for these reasons, wettability was incorporated [29]. In order to examine surface changes structurally and at the nanoscale, SEM and AFM were used, providing a more complete image.

Together, these biological and surface analyses were intended to build a clear picture of how the material behaves after alum disinfection.

The null hypothesis for our investigation was that alum solution has no antifungal effect and does not impact the wettability or surface roughness of 3D printed resin, with no surface alteration detectable by SEM or AFM.

2. Materials and Methods

2.1. Specimen Preparation and Grouping

120 specimens were made following guidelines for each experimental evaluation. For the antifungal activity against *Candida albicans* (CFU counts), 40 disks measuring $2 \times 10 \text{ mm}$ were prepared [30]. Surface roughness and wettability were each assessed on a separate set of 40 rectangular specimens of $65 \times 10 \times 2.5 \text{ mm}$ (L $\times$ W $\times$ T). These dimensions closely adhered to American Dental Association Specification No. 12 [31]. The sample size was evenly divided to include 10 specimens per experimental group (comprising the control group, 2% CHX group, 10% alum group, and 15% alum group). An a priori sample size computation was done by G*Power (version 3.1.9.6) using an effect size (f) of 0.6, $\alpha = 0.05$, a statistical power of 0.80, and four study groups. The effect size was chosen based on a recent comparable in vitro study assessing the surface roughness of 3D-printed denture resin [19]. Surface roughness was the output for the sample size calculation. The calculation resulted in a total sample size needed of 36 specimens (9 for each group); hence, 10 specimens per group were selected to consider potential loss or exclusion of specimens. Randomization was done using Research Randomizer, version 4.0 (www.randomizer.org) to produce a random sequence, and the specimens were allocated to the study groups

using this sequence. A further 16 specimens were included in the study for microstructural characterization (3 per group for SEM, 1 specimen per group for AFM), raising the total number of specimens to 136 (Table 1).

Table 1. Specimen distribution across tests and groups.

Group	Roughness	Wettability	Antifungal (CFU)	SEM	AFM	Total
Control	10	10	10	3	1	34
CHX 2%	10	10	10	3	1	34
Alum 10%	10	10	10	3	1	34
Alum 15%	10	10	10	3	1	34
Total	40	40	40	12	4	136

The chosen denture base resin (DentaBase, Asiga, Sydney, Australia), manufactured under ISO 13485:2016 [32] & EN ISO 13485:2016 [33], was employed to fabricate the tested specimens via additive 3D-printing techniques. This material naturally shows high mechanical performance and a natural pink appearance. The material (a methacrylate-based resin) is used in its pure form without any fillers or nanoparticle reinforcements. The first specimen dimensions were digitally designed via FreeCAD version 1.0.2 (open-source CAD software) and then converted to STL file formats; this is the standard file format utilized for 3D printing. Printing was then performed by Asiga MAX UV385 (Asiga, Sydney, Australia), operating on Digital Light Processing (DLP) technology in addition to a dedicated UV light source. The standard setup involved a layer thickness of 50 µm and 0° build orientation [34], whereby each specimen was positioned flat on the build platform, with its largest surface facing the platform. The build-platform-facing surface represented the intaglio (tissue-contacting) surface of the denture base. This surface is formed during the 3D-printing method and corresponds to the tissue-contacting surface of the final prosthesis; therefore, it was selected for the surface-related tests. No support structures were used during the printing. This applied to both disc-shaped specimens, oriented with their circular surface parallel to the platform, and rectangular specimens, whose long axis ran parallel to the platform surface (Figure 1). To achieve full polymerization, each printed layer was exposed to ultraviolet (UV) radiation of a 405 nm wavelength in accordance with manufacturer's recommendations. The procedure continued until the 3D-printed structures were completely created. Post-printing, specimens were cleansed by isopropyl alcohol (99.9%) (Scharlau, Barcelona, Spain), immersed in glycerol (Alpha Chemika, Mumbai, India), and left in a UV light curing chamber for ten minutes to guarantee complete polymerization conversion. All specimens were evaluated in their as-printed (no finishing or polishing steps were carried out).

To keep consistent preparation conditions, the whole procedure was conducted by one operator. Prior to testing, a 48 h storage period in distilled water at 37 °C was allowed for the specimens [35].

2.2. Preparation of Disinfectants and Immersion Procedure

Two categories of disinfectants were evaluated: alum at two concentrations (10% and 15%) and 2% chlorhexidine, which serves as the positive control. Commercially available 2% chlorhexidine (CHX) (National Health Factory for the Production of Disinfectants, M.P.C., Baghdad, Iraq) was utilized without dilution or further preparation.

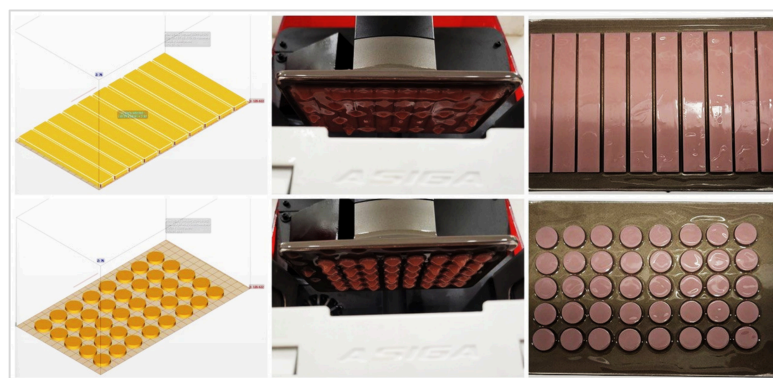


Figure 1. Specimen placement during 3D-printing of rectangular (**top row**) and disc-shaped (**bottom row**) specimens. Left to right: the build design in the printing software, the specimens on the build platform during fabrication, and the final printed specimens.

The alum solutions were prepared at 10% and 15% (*w/v*) concentrations by dissolving 10 g and 15 g, respectively, of alum powder (HiMedia Laboratories, Mumbai, India) in distilled water (Al-Rafidain, Baghdad, Iraq). The alum powder was initially mixed with approximately 80 mL of distilled water. A magnetic stirrer was utilized at room temperature until complete dissolution. Once the solution turned clear after dissolution, distilled water was then added to the solution in a graduated cylinder until a final volume of 100 mL was obtained. Before each test, the alum solutions (10% and 15%) were made fresh to maintain their chemical stability. To prevent photodegradation, these solutions were stored in amber glass containers.

Two different immersion protocols were used. The CFU test of *Candida albicans* was performed after one immersion cycle to evaluate the immediate antifungal effect of the disinfectant after a single application, reflecting routine daily denture cleansing. Surface roughness, wettability, SEM, and AFM were evaluated after 90 immersion cycles to evaluate the cumulative impact of repeated disinfection on the material surface. The specimens were soaked for each immersion cycle for five min in the respective disinfection solution. One immersion cycle represented one day of denture cleansing, so 90 cycles were used to represent three months of daily use. The cycles were completed over 10 days, with a 1 h interval between successive immersions (during the rest period between those 90 cycles, then the specimens were preserved at 37 °C in distilled water to maintain them at a temperature similar to that of the oral cavity). No disinfection treatment was applied to the negative control specimens, which were kept in distilled water during the experimental period. After the immersion process in the disinfectant solutions, the specimens were taken out, cleaned with distilled water, and then blotted dry with filter paper (Jiao Jie, Fushun, China) [36]. Within 24 h, these specimens were tested for colony-forming units, surface roughness, wettability, SEM, and AFM. The surface assessments were performed on the surface of the specimens (facing the build platform during printing).

2.3. Antifungal Efficiency Test

This test was conducted to determine antifungal activity using the colony-forming unit (CFU) approach to evaluate the immediate effect of alum solution against *Candida albicans* fungi on 3D-printed acrylic resin specimens after 5 min of immersion for each group. A single clinical isolate of *Candida albicans* collected from a patient attending the Basic Sciences Branch, College of Dentistry, University of Baghdad, Iraq, was used in this study. *Candida albicans* was identified by standard microbiological procedures, including germ tube test, Gram stain, and VITEK 2 Compact system (bioMérieux, Marcy-L'Etoile, France).

The lab report revealed that the analysis identified the strain as *Candida albicans* with a 98% probability of identification and a bionumber of 6542546075325771 (Figure 2) [37].

Organism Quantity:						
Selected Organism : <i>Candida albicans</i>						
Source:	Collected:					
Comments:						
Identification Information	Analysis Time: 18.23 hours Status: Final					
Selected Organism	98% Probability <i>Candida albicans</i>					
ID Analysis Messages	Bionumber: 6542546075325771					
Biochemical Details						
3	LysA - 4	IMLTa + 5	LeuA + 7	ARG + 10	ERYa - 12	GLYLa -
13	TyrA + 14	BNAG - 15	ARBa - 18	AMYa - 19	dGALa + 20	GENa -
21	dGLUa + 23	LACa - 24	MAdGa + 26	dCELa - 27	GGT - 28	dMALa +
29	dRAFa - 30	NAGA1 + 32	dMNEa + 33	dMELa - 34	dMLZa - 38	ISBEa -
39	IRHAa - 40	XLTa + 42	dSORa + 44	SACa + 45	URE - 46	AGLU +
47	dTURa + 48	dTREa + 49	NO3a - 51	lARaA - 52	dGATa + 53	ESC -
54	IGLTa + 55	dXYLa + 56	LATa + 58	ACEa + 59	CITa + 60	GRTas +
61	IPROa + 62	2KGa + 63	NAGa + 64	dGNTa +		

Figure 2. VITEK laboratory report.

The research protocol was reviewed and approved by the Institutional Ethical Committee, College of Dentistry, University of Baghdad (Reference No. 1191, Project No. 1191226; approval date: 6 April 2026).

During the initial 24 h, a limited aliquot of isolated *Candida albicans* colonies was transferred into tubes with 10 mL of Tryptic Soy Broth (TSB). Then, these tubes incubated for 24 h at 37 °C.

By 48 h, the microbial density of the tubes was then adjusted to match the No. 5 McFarland standard, $\sim 1 \times 10^7$ CFU/mL. Thereafter, under aseptic conditions, 100 µL taken from each prepared test tube was utilized to inoculate 10 mL of fresh TSB.

All specimens were autoclaved at 121 °C and 15 psi for 15 min on the day of microbiological testing to eliminate any microorganisms and ensure that any subsequent fungal growth resulted solely from the inoculated *Candida albicans* [38]. The sterilized specimens were given time to cool to normal room temperature. Each specimen was then placed separately into a tube containing the prepared *Candida albicans* suspension and incubated for 24 h at 37 °C under aerobic condition to permit *Candida albicans* to adhere to the specimen surface before disinfection. After biofilm maturation, the specimens were disinfected according to their respective test groups, whereas the control specimens received no disinfection treatment. The specimens were then cleaned with water and transferred into tubes filled with 10 mL of distilled water, followed by a brief 20 s vortex agitation at 10 W [39]. Then, the tenfold serial dilution method was performed to quantify the viable microorganisms. This step was done by taking 1 mL of the initial suspension (with the specimen) into sterile normal saline of 9 mL to achieve a volume of 10 mL, that represented the primary dilution 10^{-1} . The serial dilutions were generated using the same procedure. A 100 µL sample from the third dilution was then seeded onto Sabouraud Dextrose Agar (SDA) plates in triplicate, and the mean CFU count of the three plates was used to represent each specimen. These culture plates were subsequently aerobically incubated for 48 h at 37 °C [40]. Following incubation, the number of CFU visible on the agar media were quantified using the equation below [41]:

$$\text{CFU/mL} = \frac{\text{Number of colonies} \times \text{Dilution factor}}{\text{Volume plated (mL)}} \quad (1)$$

2.4. Surface Roughness Test

A portable digital profilometer (TR200, Beijing Time High Technology Ltd., Beijing, China) was employed to assess the surface roughness. The portable profilometer had a diamond stylus. Measurements were made on the specimen surfaces that were in contact with the build platform during 3D-printing. The stylus was calibrated as specified by the manufacturer prior to the roughness measurement. Each specimen surface was placed on a solid, non-vibrating stage to provide continuous and uniform contact between the stylus and the specimen surface. The measurements were made using a cutoff value of 0.25 mm with a Gaussian filter. The stylus tracing was done parallel to the orientation of the printing layers. The Ra was measured for each specimen, with three different readings for each specimen. The stylus traces an 11 mm length on the surface of the specimen. Ra is the mean of the absolute values of the deviations of the surface profile from the mean line across a specific length of the specimen. The average of the three readings was computed as the Ra value for each specimen and used for statistical analysis.

2.5. Wettability Test

An Attension Theta goniometer (Biolin Scientific, Espoo, Finland) was employed to assess surface wettability. To prevent the transfer of oily substances and pollutants from the skin to the specimens, the specimens were handled with tweezers and gloved hands [39]. The assessment of contact angle was undertaken via the sessile drop technique. A tiny distilled-water droplet (volume approximately 10 μ L) was placed on the surface of the specimen that was being examined. A picture was captured with a digital camera 10 s following deposition of the droplet onto the specimen surface [42]. To determine the contact angle, evaluation was performed on the intersection formed between the baseline reference of the water droplet and the line of convergence at the three-phase contact lines: the liquid (water), the solid (the specimen), and the air. The angle was automatically calculated by the goniometer's software (OneAttension software, version 3.2) (via profile fitting of the droplet contour using the Young-Laplace method). The measurements were conducted at room temperature [43]. Three independent readings were acquired from each sample at three distinct spots. The contact angle of that specimen was taken to be the average of all three readings.

2.6. SEM-Based Surface Examination

The surface features were assessed by utilizing scanning electron microscopy (FEI S50, FEI Company, Eindhoven, The Netherlands). 3 specimens were set up for every group and examined after immersion. The specimens were sectioned into a 3 $\times$ 3 mm square using a diamond disc under continuous water irrigation to minimize heat generation during cutting. Before cutting, the specimen was stabilized to minimize movement and vibration during cutting. Gentle pressure was applied throughout the cutting procedure to minimize the risk of introducing surface damage. The sectioned specimens were cleaned with distilled water to remove cutting debris and left to dry. Then, each specimen was coated with 40–60 nm of gold prior to imaging. The original as-printed surface was used for SEM imaging, and the cut edges were excluded from examination. The examination of the specimens was conducted at magnification levels of 200 $\times$ and 500 $\times$ using an accelerating voltage of 30 kV.

2.7. AFM-Based Surface Topography Analysis

AFM imaging was carried out utilizing a CoreAFM system (Nanosurf AG, Liestal, Switzerland) operating in tapping mode, with a scan area of 10 $\times$ 10 μ m² for each specimen. The sample-holder was mounted on a magnetic disk, and the specimen was loaded on the

sample-holder. A gold-coated silicon cantilever probe (Tap190-G series, BudgetSensors, Sofia, Bulgaria) was employed, having a 48 N/m spring constant and a tip radius of less than 10 nm. The system's integrated vibration isolation mechanism ensures stable imaging conditions and minimal environmental noise. Prior to roughness calculation, surface images were flattened using a third-order polynomial correction, and roughness parameters, including Sq, Sa, Sp, Sv, Sku, Ssk, and Sz, were subsequently calculated using Mountains SPIP software, version 8.2.9537 (Digital Surf, Besançon, France). AFM imaging was used for representative qualitative assessment of surface morphology.

2.8. Statistical Methods

Data analysis was carried out in GraphPad Prism, version 9. Data distribution was tested with the Shapiro–Wilk test, while the Brown–Forsythe test was used for testing the equality of variances. The differences in mean values of the experimental groups were calculated by one-way ANOVA. In the case of data for CFU, the Games–Howell post hoc test was used because of heterogeneous variances, whereas the Bonferroni post hoc evaluation was performed on the wettability and surface roughness data, which had homogeneous variances. For all statistical evaluations the threshold for statistical significance was set at $p < 0.05$.

3. Results

3.1. Antifungal Efficiency Test (CFU/mL)

In descriptive statistics, the control group showed the highest mean ($M = 110.4 \pm 19.91 \times 10^3$ CFU/mL), while the minimum value was found in the alum 15% group ($M = 5.8 \pm 2.86 \times 10^3$ CFU/mL) (Table 2 and Figure 3). A significant overall difference was found by one-way ANOVA ($p = 0.0001$) among the experimental groups (Table 3). Figure 4 shows CFU counts/mL $\times 10^3$.

Table 2. Descriptive statistics for the CFU counts/mL $\times 10^3$.

Groups	N	Mean ($\times 10^3$ CFU/mL)	Std. Deviation	95% Confidence Interval for Mean		Min.	Max.
				Lower Bound	Upper Bound		
Control	10	110.40	19.91	96.16	124.60	73.00	131.00
CHX 2%	10	10.10	6.54	5.42	14.78	5.00	26.00
10% alum	10	26.90	6.69	22.11	31.69	16.00	35.00
15% alum	10	5.80	2.86	3.75	7.85	3.00	12.00

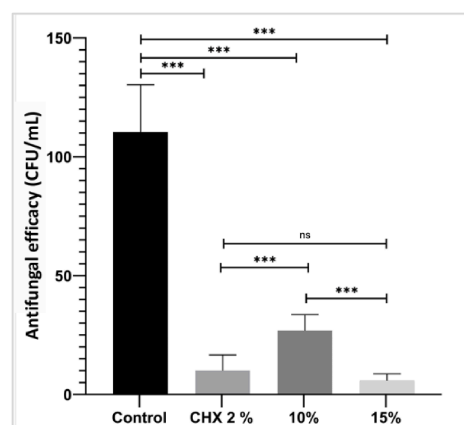
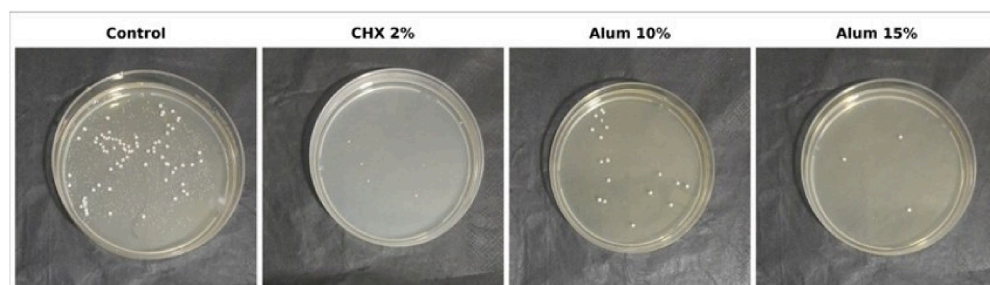


Figure 3. Bar chart for the *C. albicans* CFU test. *** $p < 0.001$; ns: not significant ($p > 0.05$).

Table 3. One-way ANOVA results for *C. albicans* colony-forming unit (CFU).

Source of Variation	SS	DF	MS	F	<i>p</i> -Value
Between groups	71,799	3	23,933	194.60	0.0001
Within groups	4428	36	123.00		
Total	76,226	39			

**Figure 4.** CFU of *Candida albicans*.

According to the Games-Howell post hoc analysis (Table 4), each of the experimental groups demonstrated a significant difference ($p < 0.05$) from the control group. Alum 15% gave a non-significant change compared to the CHX test group ($p = 0.2753$), and the Alum 10% test group revealed a significant variation ($p = 0.0001$).

Table 4. Games–Howell multiple comparison for the CFU test.

Study Groups		Mean Diff.	Summary	Adjusted <i>p</i> -Value
Control	CHX 2%	100.30	***	<0.0001
	10% alum	83.50	***	<0.0001
	15% alum	104.60	***	<0.0001
CHX 2%	10% alum	−16.80	***	0.0001
	15% alum	4.30	ns	0.2753
10% alum	15% alum	21.10	***	<0.0001

*** $p < 0.001$; ns: not significant ($p > 0.05$).

3.2. Surface Roughness Test

In descriptive statistics the maximum mean was determined in 2% CHX group ($M = 0.7531 \pm 0.0143 \mu\text{m}$), and the smallest mean was found in control group ($M = 0.4657 \pm 0.0051 \mu\text{m}$) (Tables 5 and S1 of the Supplemental Materials, and Figure 5). One-way ANOVA of the experimental groups found a significant difference between the groups ($p = 0.0001$) (Table 6). All the test groups were significantly different from the control and CHX groups by Bonferroni's multiple comparisons test (Table 7) ($p < 0.05$).

Table 5. Descriptive statistics for surface roughness results (Ra).

Groups	N	Mean (μm)	Std. Deviation	95% Confidence Interval for Mean		Min.	Max.
				Lower Bound	Upper Bound		
Control	10	0.4657	0.0051	0.4620	0.4694	0.4593	0.4726
CHX 2%	10	0.7531	0.0143	0.7429	0.7633	0.7220	0.7630
10% alum	10	0.5202	0.0029	0.5181	0.5223	0.5153	0.5250
15% alum	10	0.6195	0.0049	0.6160	0.6230	0.6086	0.6260

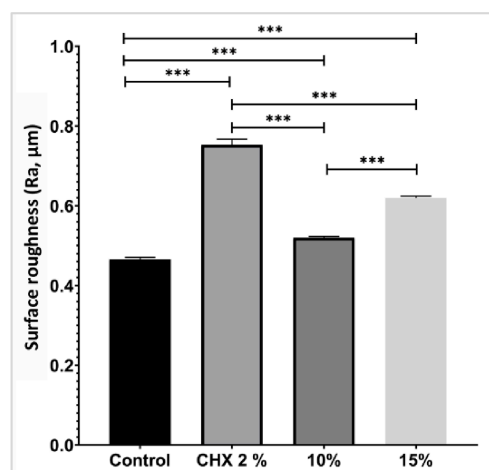


Figure 5. Bar chart for the surface roughness (Ra) means and standard deviations for all test groups. *** $p < 0.001$.

Table 6. One-way ANOVA results for surface roughness (Ra).

Source of Variation	SS	DF	MS	F	<i>p</i> -Value
Between groups	0.4778	3	0.1593	2430	0.0001
Within groups	0.002360	36	0.00006556		
Total	0.4802	39			

Table 7. Bonferroni multiple comparison for the surface roughness test.

Study Groups		Mean Diff.	Summary	Adjusted <i>p</i> -Value
Control	CHX 2%	−0.2874	***	<0.0001
	10% alum	−0.0545	***	<0.0001
	15% alum	−0.1538	***	<0.0001
CHX 2%	10% alum	0.2329	***	<0.0001
	15% alum	0.1336	***	<0.0001
10% alum	15% alum	−0.0993	***	<0.0001

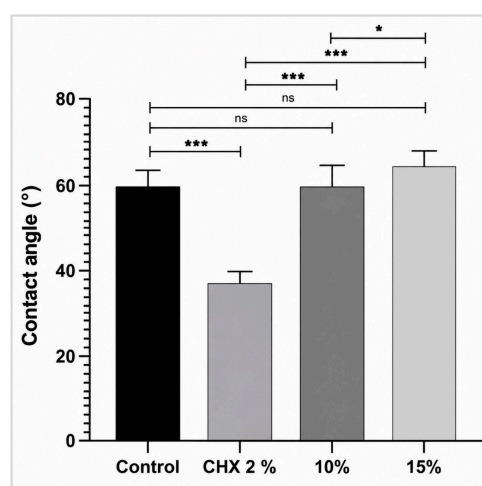
*** $p < 0.001$.

3.3. Wettability Test

In descriptive statistics, the lowest value was for the CHX group ($M = 36.54 \pm 2.58^\circ$), followed by the 10% alum group ($M = 59.33 \pm 5.41^\circ$), then the control group ($M = 59.42 \pm 3.58^\circ$), while 15% alum had the highest contact angle ($M = 64.25 \pm 3.41^\circ$) (Tables 8 and S2 of the Supplementary Materials, Figures 6 and S1 of the Supplementary Materials). One-way ANOVA demonstrated a significant overall variance ($p < 0.0001$) among the experimental groups (Table 9). Bonferroni's multiple comparisons test revealed that all test groups revealed nonsignificant differences ($p > 0.05$) relative to the control group, except for the CHX group, which revealed a significant variation ($p < 0.0001$), while every test group showed significant differences ($p < 0.05$) in comparison with the CHX test group, and a notable difference was also observed between the alum concentrations (Table 10).

Table 8. Descriptive statistics for contact angle (°).

Groups	N	Mean (°)	Std. Deviation	95% Confidence Interval for Mean		Min.	Max.
				Lower Bound	Upper Bound		
Control	10	59.42	3.58	56.86	61.98	54.77	65.75
CHX 2%	10	36.54	2.58	34.70	38.39	32.82	39.97
10% alum	10	59.33	5.41	55.45	63.20	50.70	66.92
15% alum	10	64.25	3.41	61.81	66.69	58.87	70.93

**Figure 6.** Means and standard deviations for the wettability (contact angle)/degrees for all test groups. *** $p < 0.001$; * $p < 0.05$; ns: not significant ($p > 0.05$).**Table 9.** One-way ANOVA results for contact angle (°).

Source of Variation	SS	DF	MS	F	p-Value
Between groups	4645	3	1548	102.6	<0.0001
Within groups	543.2	36	15.09		
Total	5188	39			

Table 10. Bonferroni multiple comparison for contact angle (°).

Study Groups		Mean Diff.	Summary	Adjusted p-Value
Control	CHX 2%	22.88	***	<0.0001
	10% alum	0.097	ns	>0.9999
	15% alum	−4.828	ns	0.0516
CHX 2%	10% alum	−22.78	***	<0.0001
	15% alum	−27.71	***	<0.0001
10% alum	15% alum	−4.925	*	0.0448

*** $p < 0.001$; * $p < 0.05$; ns: not significant ($p > 0.05$).

3.4. Scanning Electron Microscope (SEM)

The CHX 2% group showed localized surface abnormalities and morphological changes relative to the control group. By contrast, the first control group revealed a relatively uniform surface topography. Following immersion in alum solutions, no substantial morphological alterations were observed relative to the control group, except for the appearance of surface precipitate in the 15% group (Figures 7 and 8).

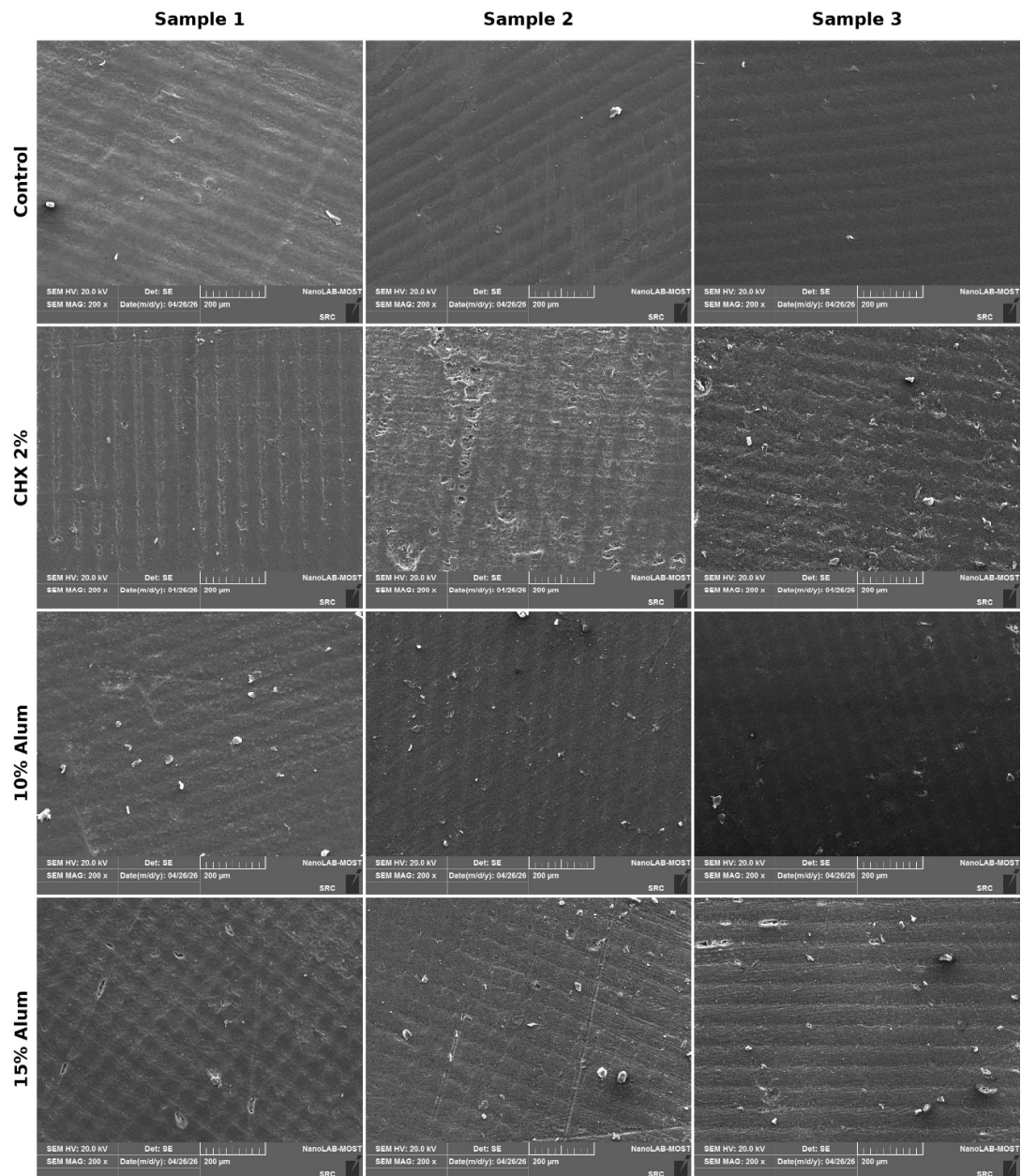


Figure 7. SEM images of the 3D-printed acrylic resin surface at 200× magnification.

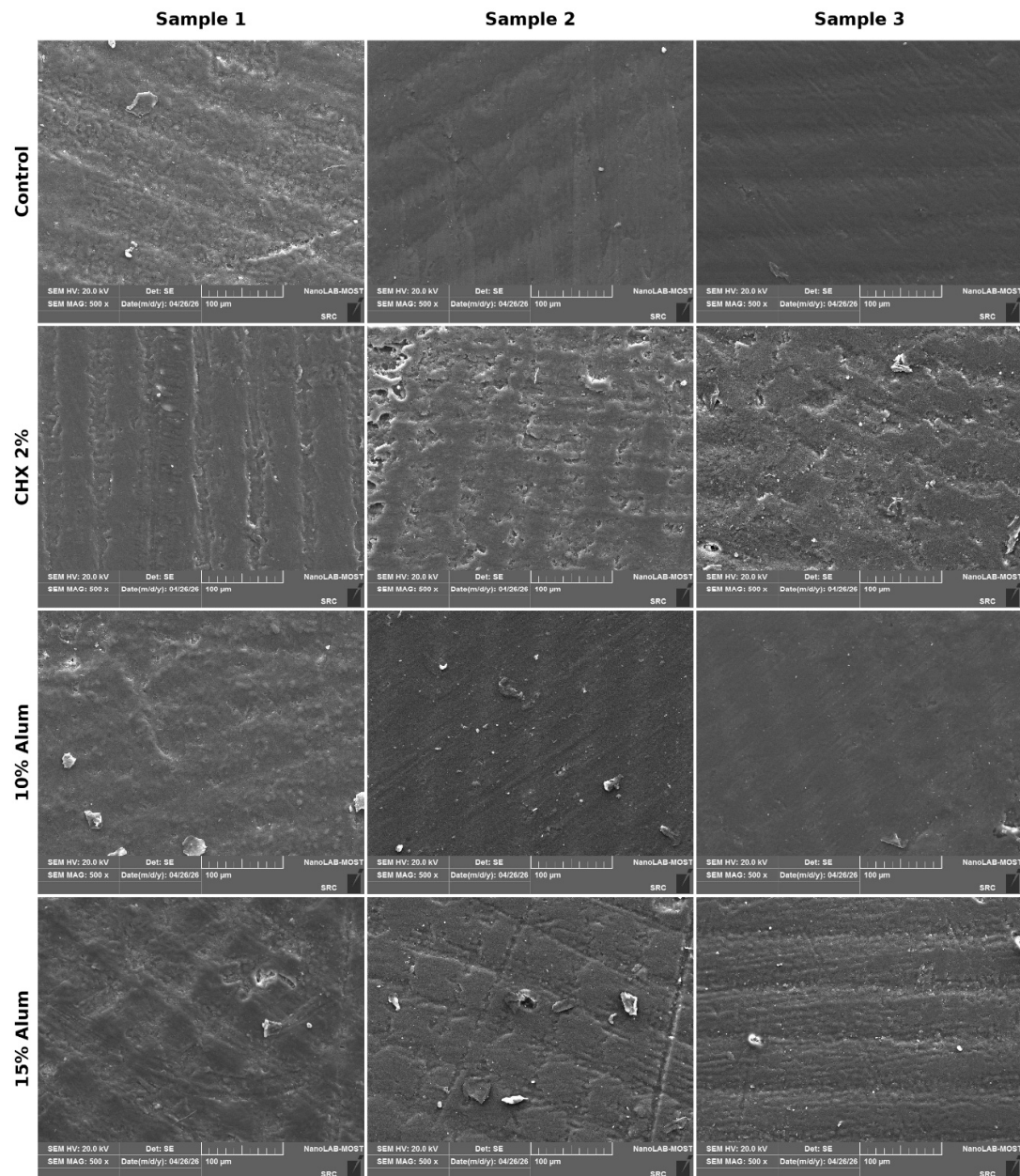
3.5. Atomic Force Microscopy (AFM)

The topography of the specimens is shown in Figure 9. The roughness of the specimens increased with increasing alum solution concentration but remained lower than that of chlorhexidine. The 10% alum specimen exhibited a roughness of 3.88 nm, while the 15% alum specimen displayed a roughness of 7.98 nm. The CHX 2% specimen exhibited a roughness of 24.30 nm (Table 11).

Table 11. AFM surface roughness parameters (nm) for each tested group—descriptive, single representative scan per group.

Group	Sa (nm)	Sq (nm)	Sp (nm)	Sv (nm)	Sz (nm)	Sku	Ssk
Control	2.98	4.94	82.44	80.51	163.00	41.64	0.36
CHX 2%	24.30	29.63	43.79	103.30	147.10	3.38	−1.17
Alum 10%	3.88	7.37	116.80	7.81	124.60	100.30	7.88
Alum 15%	7.98	11.09	75.28	19.56	94.84	8.39	1.95

Sa: arithmetic mean height; Sq: root mean square height; Sp: maximum peak height; Sv: maximum valley depth; Sz: maximum height; Sku: kurtosis; Ssk: skewness.

**Figure 8.** SEM images of the 3D-printed acrylic resin surface at 500× magnification.

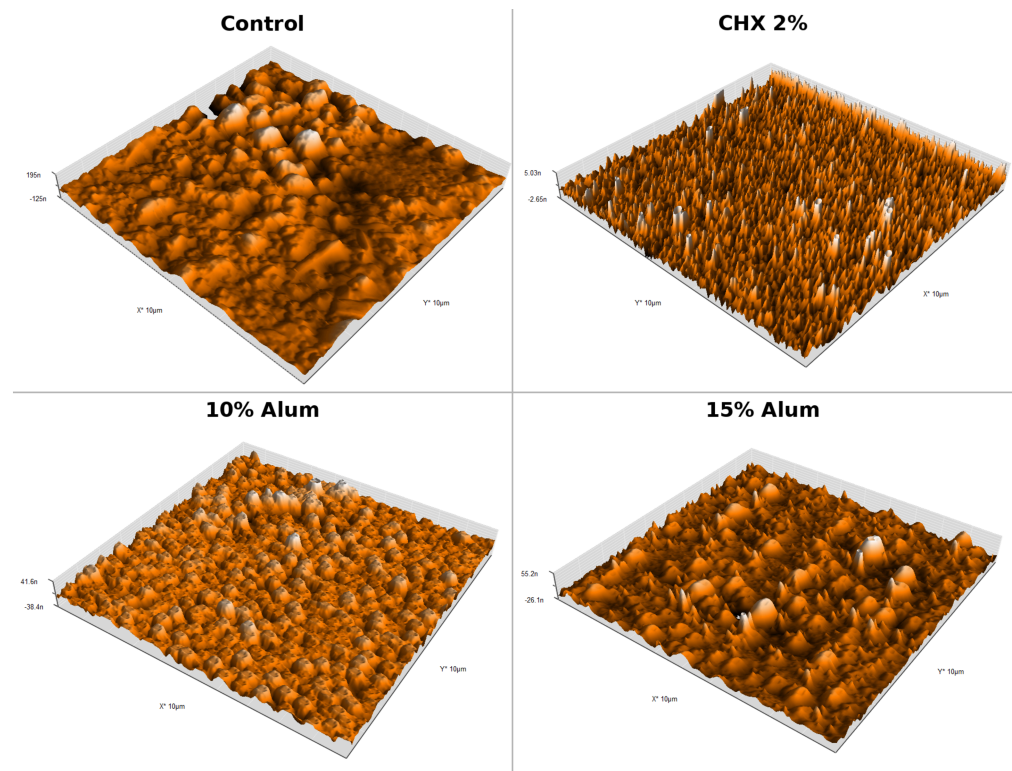


Figure 9. AFM analysis of the 3D-printed acrylic resin surface (scan area $10 \times 10 \mu\text{m}$).

4. Discussion

Candida albicans is a prevalent oral yeast that remains harmless until host conditions change, resulting in oral candidiasis. In denture wearers, this change is facilitated by the yeast's ability to adhere to acrylic resin surfaces. At its core, microbial build-up on the prosthesis is the primary cause of *Candida*-associated denture stomatitis [44]. Numerous previous studies [31,45–47] have explored techniques to address denture stomatitis, including surface coatings, immersion in denture cleansers, and the incorporation of antimicrobial fillers. While prior research aimed to eradicate or minimize the presence of the causative microorganism (*C. albicans*), the purpose of this research was to assess the influence of immersion of 3D-printed acrylic resin in alum solutions on surface roughness, wettability, and *C. albicans* biofilm. The statistical results indicated that the null hypothesis was rejected, demonstrating that the immersion process significantly impacted both the *Candida* count and the surface roughness.

Regarding *Candida* counts, the alum solution exerted an immediate antifungal effect against *C. albicans* following 5 min of exposure, with the effect rising proportionally with concentration. The primary cause of the antifungal activity is alum's capacity to change the fungal cell's environment by producing an acidic microenvironment. The localized rise in acidity induces cytotoxicity, which impairs spore germination and interferes with normal fungal development [48]. Likewise, aluminum potassium sulfate's action against fungi can be linked to direct action on the fungal architecture, causing massive plasma membrane damage. This is a necrotic event that causes immediate loss of cellular integrity and subsequent leakage of intracellular components. Fungal survival is strongly impeded by such physical damage to the membrane, giving a clear explanation for the significant decrease in fungal viability within the experimental groups [25,45]. These results support the idea of a dose-dependent effect and agree with earlier research that addressed the antimicrobial and antifungal actions of alum [45,48–50]. Regarding the biological safety of alum, in a prior dental study the effect of potassium aluminum sulfate on fibroblast

viability was evaluated, and no significant effect on cell viability was identified in the tested settings [26].

Soaking 3D-printed acrylic resin specimens in alum (10% and 15%) and CHX 2% solutions notably increased their roughness compared to the control (with the 10% and 15% alum groups exhibiting lower surface roughness than the CHX 2% group) as detected by Bonferroni post hoc analysis. In the case of alum, its ionic nature can contribute to the precipitation of mineral salts on the acrylic surface. Such deposition can form micro-crystalline layers on the material surface, causing increased roughness [51]. On the other hand, it is known that chlorhexidine gluconate, a commonly employed antimicrobial agent, can interact with acrylic resin surfaces through adsorption and penetration into the polymer network. With time, this action may cause a plasticization effect and soften the surface, making it more vulnerable to abrasion and surface damage. Multiple studies showed that recurrent exposure to chlorhexidine raises the surface roughness of denture bases because of chemical degradation and alterations in surface microstructure [52,53]. The 10% alum group exhibited a marginal increase of 0.05 μm , and the 15% alum group showed an increase of 0.15 μm . These results indicated higher surface roughness following alum treatment, with the increase being greater at the 15% concentration. These outcomes align with earlier studies that showed increased surface roughness [43,54–56]; yet, these outcomes are contrasted to those of Jasim et al. [36], who documented no significant increase in surface roughness.

Evaluating wettability by one-way ANOVA revealed that the overall change in wettability was significant. However, Bonferroni post hoc comparisons showed that this significant rise in wettability was primarily attributable to the CHX 2% group relative to the control group, while the alum (10% and 15%) groups showed no significant variation from the control. This increase in wettability noted in the CHX 2% group could be related to surface roughness and surface chemical composition changes caused by chlorhexidine adsorption onto the acrylic surface, which change surface energy, causing enhanced hydrophilicity and wettability, yielding lower contact angles [57]. The result of alum agrees with Tawfeeq et al. [58] and Kim et al. [59], who stated no change in wettability, and conflicts with Abed et al. [42].

As for SEM, surface morphological variations among the experimental groups were clear at both 200 $\times$ and 500 $\times$ magnifications. The control group presented a relatively smooth surface feature with uniform parallel lines owing to the 3D printing technique, and no sign of surface deterioration was found. This result matches the findings that submersion in water exerts a very limited influence on the surface damage of acrylics [60]. Specimens subjected to the 10% alum solution showed surface qualities resembling the control, pointing to good integrity without considerable material deterioration or precipitation [19]. In contrast, chlorhexidine 2% specimens exhibited marked surface irregularities at 200 $\times$ magnification, which became more notable at 500 $\times$. These morphological traits may be related to the loss of surface material or polymer dissolution; however, the SEM data alone are not sufficient to demonstrate the existence of a chemical reaction or polymer degradation. Also, the observed surface alterations could be due to the higher reported surface roughness following treatment [61]. At both magnifications, specimens submerged in the 15% alum solution showed localized deposits on the surface and particle remnants adhering to the surface of the resin. Still, no underlying structural damage was evident [31], suggesting that these deposits can represent crystallization of alum rather than resin deterioration.

For AFM, atomic force microscopic evaluation exhibited similar patterns to those observed by the profilometer. A relatively smooth nanoscale texture was exhibited in the control group, reflecting the lowest surface irregularities. Immersion in a 10% alum solution caused a slight rise in the nanoscale surface roughness, but immersion in a 15%

alum solution produced more surface changes, suggesting a concentration-dependent effect on the resin surface. Of the examined groups, the chlorhexidine group exhibited the most pronounced nanoscale surface roughness, suggesting that CHX immersion caused the greatest degree of nanoscale surface damage. The AFM results gave representative qualitative support for the measured changes in surface roughness.

This study also has some limitations. Baseline surface roughness, wettability, SEM, and AFM measurements were not taken before immersion (the comparisons in this work were made between groups rather than on the same specimen over time, with the control group serving as the reference point), representative roughness profiles were not generated, only one type of resin was tested, and the immersion period was relatively short. Longer studies, simulating 6 months to 1 year of clinical denture use and testing additional resin types, are suggested to confirm these findings in future studies.

5. Clinical Implications

The results suggest that alum solution could be considered as a candidate disinfectant for 3D-printed acrylic resin dentures. Immersion in 15% alum solution for 5 min exhibited an immediate antifungal activity against *C. albicans* under the investigated in vitro conditions. These findings are limited to the immediate effect observed after a single 5 min exposure, and further studies are needed to evaluate a sustained antifungal effect and clinical applicability before any suggestion for routine usage in dentistry practice.

6. Conclusions

Alum solutions at concentrations of 10% and 15% for 5 min revealed antifungal activity against *Candida albicans* in 3D-printed acrylic denture base resin. There was no statistical change in wettability for any concentration compared to the negative control, while surface roughness increased after treatment.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/prosthesis8100100/s1>, Figure S1: Representative water droplet images used for contact angle measurements in the control, 2% CHX, Alum 10%, and Alum 15% groups; Table S1: Individual surface roughness (Ra) measurements (μm); Table S2: Individual contact angle measurements ($^\circ$).

Author Contributions: Conceptualization, S.J.M. and A.A.F.; methodology, S.J.M. and A.A.F.; software, S.J.M. and J.Y.A.; validation, A.A.F. and M.A.-R.; formal analysis, S.J.M., A.A.F., J.Y.A., and M.A.-R.; investigation, S.J.M. and A.A.F.; resources, S.J.M. and A.A.F.; data curation, A.A.F. and M.A.-R.; writing—original draft preparation, S.J.M.; writing—review and editing, S.J.M., A.A.F., J.Y.A., and M.A.-R.; visualization, S.J.M.; supervision, A.A.F. and M.A.-R.; project administration, A.A.F., J.Y.A., and M.A.-R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: On 6 April 2026, the Research Ethics Committee of the University of Baghdad, College of Dentistry, approved this study (Reference No. 1191, Project No. 1191226). The patient information sheet and informed consent form were reviewed as part of the ethical approval procedure.

Informed Consent Statement: The patient was informed and gave his consent before the saliva sample collection, which was used only for isolation of the *Candida albicans* strain used in this study.

Data Availability Statement: All original contributions offered in the investigation are contained in the publication. The signed informed consent form, containing identifiable participant information, is omitted and maintained in the department's records and can be sent to the editor or ethics committee on formal request.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The manuscript uses the following abbreviations:

CFU	Colony-forming unit
CHX	Chlorhexidine
alum	aluminum potassium sulfate
3D	three-dimensional
DS	Denture stomatitis
PMMA	polymethyl methacrylate
UV	ultraviolet
DLP	Digital Light Processing
TSB	Tryptic Soy Broth
SDA	Sabouraud Dextrose Agar
SEM	Scanning electron microscopy
AFM	Atomic force microscopy

References

1. Bilgin, M.S.; Erdem, A.; Aglarci, O.S.; Dilber, E. Fabricating complete dentures with CAD/CAM and RP technologies. *J. Prosthodont.* **2015**, *24*, 576–579. [[CrossRef](#)]
2. Murray, M.D.; Darvell, B.W. The evolution of the complete denture base. Theories of complete denture retention—A review. Part 1. *Aust. Dent. J.* **1993**, *38*, 216–219. [[CrossRef](#)]
3. Tasaka, A.; Matsunaga, S.; Odaka, K.; Ishizaki, K.; Ueda, T.; Abe, S.; Yoshinari, M.; Yamashita, S.; Sakurai, K. Accuracy and retention of denture base fabricated by heat curing and additive manufacturing. *J. Prosthodont. Res.* **2019**, *63*, 85–89. [[CrossRef](#)]
4. Gad, M.M.; Abualsaud, R. Behavior of PMMA denture base materials containing titanium dioxide nanoparticles: A literature review. *Int. J. Biomater.* **2019**, *2019*, 6190610. [[CrossRef](#)]
5. Ngo, T.D.; Kashani, A.; Imbalzano, G.; Nguyen, K.T.; Hui, D. Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. *Compos. Part B Eng.* **2018**, *143*, 172–196. [[CrossRef](#)]
6. Bilgin, M.S.; Baytaroglu, E.N.; Erdem, A.; Dilber, E. A review of computer-aided design/computer-aided manufacture techniques for removable denture fabrication. *Eur. J. Dent.* **2016**, *10*, 286–291. [[CrossRef](#)]
7. Palaganas, N.B.; Mangadiao, J.D.; de Leon, A.C.C.; Palaganas, J.O.; Pangilinan, K.D.; Lee, Y.J.; Advincula, R.C. 3D printing of photocurable cellulose nanocrystal composite for fabrication of complex architectures via stereolithography. *ACS Appl. Mater. Interfaces* **2017**, *9*, 34314–34324. [[CrossRef](#)]
8. Altarazi, A.; Haider, J.; Alhotan, A.; Silikas, N.; Devlin, H. Assessing the physical and mechanical properties of 3D printed acrylic material for denture base application. *Dent. Mater.* **2022**, *38*, 1841–1854. [[CrossRef](#)]
9. Alghazzawi, T.F. Advancements in CAD/CAM technology: Options for practical implementation. *J. Prosthodont. Res.* **2016**, *60*, 72–84. [[CrossRef](#)]
10. Chander, N.G.; Prakash, H.G.; Deshmukh, A.S.; Swetha, T.V.S. Effect of glycerol-assisted ultraviolet postcuring duration on residual monomer release from 3D-printed denture base resins. *J. Indian Prosthodont. Soc.* **2026**, *26*, 245–251. [[CrossRef](#)]
11. Alqarawi, F.K.; Gad, M.M. Tendency of microbial adhesion to denture base resins: A systematic review. *Front. Oral Health* **2024**, *5*, 1375186. [[CrossRef](#)]
12. Azab, A.; Abdelhady, W.A.; Elwakeel, E.; Ashraf, M.; Wally, R.; Soliman, A.; Mohamed, M.A.; Abozaid, D. Systematic review and meta analysis of mechanical properties of 3D printed denture bases compared to milled and conventional materials. *Sci. Rep.* **2025**, *15*, 29207. [[CrossRef](#)]
13. Gendreau, L.; Loewy, Z.G. Epidemiology and etiology of denture stomatitis. *J. Prosthodont.* **2011**, *20*, 251–260. [[CrossRef](#)]
14. Mayahara, M.; Kataoka, R.; Arimoto, T.; Tamaki, Y.; Yamaguchi, N.; Watanabe, Y.; Yamasaki, Y.; Miyazaki, T. Effects of surface roughness and dimorphism on the adhesion of *Candida albicans* to the surface of resins: Scanning electron microscope analyses of mode and number of adhesions. *J. Investig. Clin. Dent.* **2014**, *5*, 307–312. [[CrossRef](#)]
15. Ferro, A.C.; de Oliveira, C.C.; Morais, B.L.; de Oliveira, J.S.; Piazza, R.D.; Marques, R.F.; Mota, C.; Baker, M.B.; Jorge, J.H. Long-term disinfection of 3D-printed denture resin: Physical and biological in vitro assessments. *J. Mater. Sci. Mater. Med.* **2026**, *37*, 72. [[CrossRef](#)]
16. Radford, D.R.; Sweet, S.; Challacombe, S.; Walter, J. Adherence of *Candida albicans* to denture-base materials with different surface finishes. *J. Dent.* **1998**, *26*, 577–583. [[CrossRef](#)]

17. Kulak-Ozkan, Y.; Kazazoglu, E.; Arian, A. Oral hygiene habits, denture cleanliness, presence of yeasts and stomatitis in elderly people. *J. Oral Rehabil.* **2002**, *29*, 300–304. [\[CrossRef\]](#)
18. Noori, Z.S.; Al-Khafaji, A.M.; Dabaghi, F. Effect of tea tree oil on candida adherence and surface roughness of heat cure acrylic resin. *J. Baghdad Coll. Dent.* **2023**, *35*, 46–54. [\[CrossRef\]](#)
19. Abass, E.F.; Fatalla, A.A.; Matheel, A.-R.; Abdullah, J.Y. Impact of Mouthwash Immersion on 3D-Printed Resin Material: A Comprehensive Evaluation of Surface Hardness, Surface Roughness, Wettability, and Characterization Using FTIR and FE-SEM Techniques. *J. Clin. Exp. Dent.* **2026**, *18*, e199. [\[CrossRef\]](#)
20. Pavarina, A.C.; Pizzolitto, A.; Machado, A.L.; Vergani, C.E.; Giampaolo, E. An infection control protocol: Effectiveness of immersion solutions to reduce the microbial growth on dental prostheses. *J. Oral Rehabil.* **2003**, *30*, 532–536. [\[CrossRef\]](#)
21. Zoccolotti, J.d.O.; Tasso, C.O.; Arbeláez, M.I.A.; Malavolta, I.F.; Pereira, E.C.d.S.; Esteves, C.S.G.; Jorge, J.H. Properties of an acrylic resin after immersion in antiseptic soaps: Low-cost, easy-access procedure for the prevention of denture stomatitis. *PLoS ONE* **2018**, *13*, e0203187. [\[CrossRef\]](#)
22. Olga Tasso, C.; de Oliveira Zoccolotti, J.; Morandim Ferrisse, T.; Ferreira Malavolta, I.; Habib Jorge, J.; Tasso, C.O.; Ferrisse, T.M.; Malavolta, I.F.; Jorge, J.H. Effectiveness of Disinfectant Liquid Soaps in the Reduction of Candida spp Present in Complete Dentures: A Crossover Randomized Clinical Trial. *Int. J. Prosthodont.* **2020**, *33*, 620. [\[CrossRef\]](#)
23. Osuala, F.; Ibidapo-obe, M.; Okoh, H.; Aina, O.; Igbasi, U.; Nshio, M.; Onubogu, C.; Egbuna, K.; Ajibaye, O.; Orok, A. Evaluation of the efficacy and safety of Potassium Aluminium Tetraoxosulphate (Vi)(ALUM) in the Treatment of tuberculosis. *Eur. J. Biol. Sci.* **2009**, *1*, 10–15.
24. Olmez, A.; Can, H.; Ayhan, H.; Okur, H. Effect of an alum-containing mouthrinse in children for plaque and salivary levels of selected oral microflora. *J. Clin. Pediatr. Dent.* **1998**, *22*, 335–340.
25. Bryan, I.; Alta'ee, A.; Kadhum, N. Antibacterial activity of aluminum potassium sulfate and Syzygium aromaticum extract against pathogenic microorganisms. *J. Nat. Sci. Res.* **2014**, *4*, 11–14.
26. Çakmak, G.; Akay, C.; Donmez, M.B.; Mumcu, E.; Akan, H.S.; Sasany, R.; Abou-Ayash, S.; Yilmaz, B. Effect of Potassium Aluminum Sulfate Application on the Viability of Fibroblasts on a CAD-CAM Feldspathic Ceramic before and after Thermocycling. *Materials* **2022**, *15*, 4232. [\[CrossRef\]](#)
27. Alhusayni, A.A.; AL-Khikani, F.H.O. Efficacy of aluminum potassium sulfate against Staphylococcus species in wound infections compared to meropenem and amoxycylav. *Microbes Infect. Dis.* **2026**, *7*, 530–535.
28. Bollenl, C.M.; Lambrechts, P.; Quirynen, M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: A review of the literature. *Dent. Mater.* **1997**, *13*, 258–269. [\[CrossRef\]](#)
29. Hanno, K.I.; Metwally, N.A. The wettability of complete denture base materials constructed by conventional versus digital techniques: An in-vitro study. *BMC Oral Health* **2024**, *24*, 1081. [\[CrossRef\]](#)
30. Aslanimehr, M.; Rezvani, S.; Mahmoudi, A.; Moosavi, N. Comparison of Candida Albicans adherence to conventional acrylic denture base materials and injection molding acrylic materials. *J. Dent.* **2017**, *18*, 61.
31. Taha, N.R.; Abass, S.M. Cordia Myxa Fruit Extract Antibacterial Efficacy and Its Effect on the Surface Roughness of Heat-Cured Acrylic Denture Base Material. *Prosthesis* **2025**, *7*, 48. [\[CrossRef\]](#)
32. ISO 13485:2016; Medical Devices—Quality Management Systems—Requirements for Regulatory Purposes. International Organization for Standardization: Geneva, Switzerland, 2016.
33. EN ISO 13485:2016; Medical Devices—Quality Management Systems—Requirements for Regulatory Purposes. European Committee for Standardization: Brussels, Belgium, 2016.
34. Al-Dulaijan, Y.A.; Alsulaimi, L.; Alotaibi, R.; Alboainain, A.; Akhtar, S.; Khan, S.Q.; Al-Ghamdi, M.; Gad, M.M. Effect of printing orientation and postcuring time on the flexural strength of 3D-printed resins. *J. Prosthodont.* **2023**, *32*, 45–52. [\[CrossRef\]](#)
35. Iwaki, M.; Kanazawa, M.; Arakida, T.; Minakuchi, S. Mechanical properties of a polymethyl methacrylate block for CAD/CAM dentures. *J. Oral Sci.* **2020**, *62*, 420–422. [\[CrossRef\]](#)
36. Jasim, S.; Abass, S.M. Effect of alum disinfectant solutions on some properties of a heat-cured acrylic resin. *J. Res. Med. Dent. Sci.* **2021**, *9*, 42–47.
37. Han, Y.-Y.; Huang, Y.-T.; Li, D.-F.; Chen, K.-L.; Chi, Y.; Tsai, H.-M.; Cheng, H.-W.; Wang, J.-K.; Wang, Y.-L. SERS-Based Universal AST: Rapid Treatment Guidance for Blood-Culture Bacteria before Species Identification. *Anal. Chem.* **2026**, *98*, 5989–6002. [\[CrossRef\]](#)
38. Mahmood, M.A.; Khalaf, B.S.; Abass, S.M. Efficiency of different denture disinfection methods. *Glob. J. Biosci. Biotech.* **2017**, *6*, 439–444.
39. Pourhajibagher, M.; Noroozian, M.; Ahmad Akhoundi, M.S.; Bahador, A. Antimicrobial effects and mechanical properties of poly (methyl methacrylate) as an orthodontic acrylic resin containing Curcumin-Nisin-poly (L-lactic acid) nanoparticle: An in vitro study. *BMC Oral Health* **2022**, *22*, 158. [\[CrossRef\]](#)
40. Khalaf, B.S.; Abass, S.M.; Al-Khafaji, A.M.; Issa, M.I. Antimicrobial efficiency of hypochlorous acid and its effect on some properties of alginate impression material. *Int. J. Dent.* **2023**, *2023*, 8584875. [\[CrossRef\]](#)

41. Baron, E.J.; Peterson, L.R.; Finegold, S.M. *Bailey and Scott's Diagnostic Microbiology*, 9th ed.; Mosby: St. Louis, MO, USA, 1994; pp. 85–362.
42. Abed, A.A.; Al-Khafaji, A.M. Examining how PMMA and polyamide denture base materials' physical characteristics are affected by electrolyzed water used as a denture cleaner. *Bionatura* **2021**, *13*, 1–6.
43. Khairi, A.W.; Naji, G.A.-H. The effect of silica nano particle derived from natural rice on surface roughness and wettability of high impact heat cure resin. *Med. J. Babylon* **2023**, *20*, 308–314. [[CrossRef](#)]
44. Salerno, C.; Pascale, M.; Contaldo, M.; Esposito, V.; Busciolano, M.; Milillo, L.; Guida, A.; Petruzzi, M.; Serpico, R. Candida-associated denture stomatitis. *Med. Oral Patol. Oral Cir. Bucal* **2011**, *16*, e139–e143. [[CrossRef](#)]
45. Mohad, A.; Fatalla, A.A. The effectiveness of aluminum potassium sulfate micro-particles addition into soft denture lining material on tensile strength and peel bond strength of soft denture lining material. *J. Baghdad Coll. Dent.* **2019**, *31*, 51–58. [[CrossRef](#)]
46. Abass, I.F.; Fatalla, A.A.; AL-Rawas, M.; Abdullah, J.Y. Enhancement of 3D printed resin by incorporating nanofillers: A literature review. *Mustansiriya Dent. J.* **2026**, *22*, 88–105.
47. Ahmed, A.G.; Ismail, I.J. Evaluation the effect of addition of plasma treated polypropylene fiber and silanized silicon dioxide nanoparticles composite on some properties of heat-polymerized polymethylmethacrylate. *J. Bagh. Coll. Dent.* **2016**, *28*, 1–8. [[CrossRef](#)]
48. Amadi, L.O. A review of antimicrobial properties of alum and sundry applications. *Acta Sci. Microbiol.* **2020**, *3*, 109–117. [[CrossRef](#)]
49. Salman, A.M.; Al-Saedi, F.; Karim, H.A. Detection of Inhibitory Effect of Aluminium Potassium Sulfate Against Some Bacterial and Fungal Strains. *Al-Mustansiriyah J. Pharm. Sci.* **2025**, *25*, 854–861. [[CrossRef](#)]
50. Irshad, M.; Younas, M.; Shabir, H.; Alam, M.S.; Rehman, Z.U.; Aleem, S. In vitro antifungal activity of potash alum against *Candida albicans* on acrylic resin. *Pak. Armed Forces Med. J.* **2020**, *70*, 1460–1464.
51. Strathdee, G.L.; Klein, M.; Melis, L. *Crystallization and Precipitation: Proceedings of the International Symposium, Saskatoon, Saskatchewan, Canada, 5–7 October 1987*; Elsevier: Amsterdam, The Netherlands, 2016.
52. Moreno, A.; Goiato, M.C.; dos Santos, D.M.; Haddad, M.F.; Pesqueira, A.A.; Bannwart, L.C. Effect of different disinfectants on the microhardness and roughness of acrylic resins for ocular prosthesis. *Gerodontology* **2013**, *30*, 32–39. [[CrossRef](#)]
53. Carvalho, C.F.; Vanderlei, A.D.; Salazar Marocho, S.M.; Pereira, S.; Nogueira, L.; Arruda Paes-Junior, T.J. Effect of disinfectant solutions on a denture base acrylic resin. *Acta Odontol. Latinoam.* **2012**, *25*, 255–260.
54. Abualsaud, R.; Aleraky, D.M.; Akhtar, S.; Khan, S.Q.; Gad, M.M. Antifungal activity of denture base resin containing nanozirconia: In vitro assessment of candida albicans biofilm. *Sci. World J.* **2021**, *2021*, 5556413. [[CrossRef](#)]
55. Zaidan, N.M.; Jassim, R.K. The Impact of Adding Silanized Microcrystalline Cellulose on Some Properties of Heat-Cured Acrylic Denture Base Material. *J. Res. Med. Dent. Sci.* **2022**, *10*, 11–18.
56. Porwal, A.; Khandelwal, M.; Punia, V.; Sharma, V. Effect of denture cleansers on color stability, surface roughness, and hardness of different denture base resins. *J. Indian Prosthodont. Soc.* **2017**, *17*, 61–67. [[CrossRef](#)]
57. Choudhary, A.; Ganesh, S.B. Comparative Contact Angle Analysis of 1% Chlorhexidine and 2% Metronidazole Mouthgel-An In Vitro Study. *J. Pharm. Res. Int.* **2022**, *34*, 56–61. [[CrossRef](#)]
58. Tawfeeq, S.A.; Al-Khafaji, A.M. Wettability, UV Absorption, and SEM Investigation of PMMA after Immersion in Ozone Water. *Front. Biomed. Technol.* **2025**, *12*, 882–889. [[CrossRef](#)]
59. Kim, M.-C.; Byeon, D.-J.; Jeong, E.-J.; Go, H.-B.; Yang, S.-Y. Color stability, surface, and physicochemical properties of three-dimensional printed denture base resin reinforced with different nanofillers. *Sci. Rep.* **2024**, *14*, 1842. [[CrossRef](#)]
60. Costa, R.T.F.; Pellizzer, E.P.; Vasconcelos, B.C.d.E.; Gomes, J.M.L.; Lemos, C.A.A.; de Moraes, S.L.D. Surface roughness of acrylic resins used for denture base after chemical disinfection: A systematic review and meta-analysis. *Gerodontology* **2021**, *38*, 242–251. [[CrossRef](#)]
61. Arbelaez, M.I.A.; Vergani, C.E.; Barbugli, P.A.; Pavarina, A.C.; Sanita, P.V.; Jorge, J.H. Long-term effect of daily chemical disinfection on surface topography and *Candida albicans* biofilm formation on denture base and relined acrylic resins. *Oral Health Prev. Dent.* **2020**, *18*, a45521. [[CrossRef](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.