

Surface roughness of conventional and 3D-printed resins as a function of different cleaning processes: a scanning electron microscopy approach

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ABSTRACT

Aims: This study aimed to investigate the effect of different cleaning methods on the surface roughness of conventional polymethyl methacrylate (PMMA) and three-dimensional printed (3D) acrylic resin material.

Methods: Eighty disc-shaped specimens of conventional PMMA and 3D-printed resin were prepared and divided into four subgroups based on cleaning methods. The specimens of the control group (group C) were immersed in distilled water, the second group (group T) was immersed in Corega tablet solution. The third group (group B) was subjected with liquid soap in a toothbrush simulator. The specimens in the fourth group (group BT) were brushed in the same way with liquid soap and immersed in Corega tablet solution. Surface roughness (Ra) was measured before and after cleaning, using a contact profilometer. Surface morphology was evaluated by scanning electron microscopy (SEM). Kolmogorov-Smirnov, repeated-measures ANOVA, and post-hoc tests were done to analyze the data ($p < 0.05$).

Results: Initial surface roughness values were not significantly differed between PMMA and 3D-printed resins. After cleaning, the highest roughness was observed in group BT (PMMA: 0.25 μm ; 3D resin: 0.21 μm), and the lowest in group C (PMMA: 0.15 μm ; 3D resin: 0.12 μm). Brushing alone or in combination significantly increased surface roughness for both materials ($p < 0.001$). There was no statistically significant difference among the material groups for each type of cleaning procedure.

Conclusion: The surface roughness of denture bases are affected by different cleaning procedures. Brushing alone had a greater abrasive effect than tablet immersion. Although surface roughness increased within groups, no significant differences were found among the materials. Clinical recommendations should consider that denture cleaning methods may influence the surface integrity of the prosthesis.

Keywords: 3D-printed resin, additive manufacturing, denture cleanser, PMMA, surface roughness

INTRODUCTION

Polymethyl methacrylate (PMMA) is a widely used material in various branches of dentistry. It is commonly preferred for the fabrication of total dentures due to its ease of fabrication and repair, acceptable aesthetic properties, and biocompatibility.¹ However, it has several limitations, including low compressive and tensile strength, hypersensitivity, and allergic reactions. In addition, polymerization shrinkage, susceptibility to microbial colonization due to its porous structure, color change, and low wear resistance have also been reported. Various techniques have been introduced to overcome these drawbacks in the manufacturing process. However, it is not always possible to eliminate the negative characteristics of the material and limitations of traditional production methods.²

Digital design and manufacturing techniques have been widely adopted in routine clinical practice due to their advantages such as increased production speed and accuracy

compared with traditional methods, prevention of cross-infection risk, predictable results, and savings in material consumption.³ Computer aided design-computer aided manufacturing (CAD-CAM) can be used with two main types of manufacturing processes: subtractive and additive. In the subtractive manufacturing method, the final product is obtained by milling the pre-polymerized acrylic resin disc in a milling unit, while the additive method uses three-dimensional (3D) printing. This layer-by-layer manufacturing reduces material wastage compared with subtractive manufacturing.⁴ The mechanical and surface properties of complete prostheses fabricated by both methods are well established. 3D printing has gained increasing attention due to its ability to fabricate highly complex and customized geometries with excellent surface detail and dimensional accuracy. This technique achieves high resolution, precise detail, and surface smoothness.⁵ It allows for chairside fabrication in a cost-effective and time-efficient

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manner using affordable and compact equipment. Depending on the technology used (e.g., DLP or SLA), different levels of resolution, surface texture, and material properties can be achieved, making it a versatile tool in prosthetic dentistry.⁶

Cleaning and caring for dentures are essential for maintaining a healthy oral mucosa. Inadequate denture cleaning leads to the proliferation of various microorganisms and causes disorders such as denture stomatitis and halitosis.⁷ To prevent this problem, various mechanical and chemical cleaning methods can be used. Mechanical methods include brushing dentures, ultrasonic cleaning baths, and microwave ovens, while chemical methods include the use of various disinfectants, enzymes, and alkaline peroxide-based denture cleansers (e.g., Corega). Brushing is a simple and effective method that is often used to remove plaque deposits from prosthetic surfaces. However, due to the low abrasion resistance of denture base materials, an increase in surface roughness is observed after brushing. Chemical methods should be recommended as an alternative for geriatric patients with reduced manual ability.^{8,9}

Due to their alkaline peroxide content, effervescent tablets provide both chemical and mechanical cleaning by releasing oxygen bubbles on contact with water. The use of prosthesis cleaners such as Corega is becoming more widespread to minimize the effect of reduced manipulation ability on prosthesis cleaning, particularly in geriatric patients. Alkaline peroxide provides effective cleaning by dissolving stains on the denture base. Despite routine use, denture cleaners can have an adverse effect on the surface hardness, color stability, and surface roughness of these materials.^{10,11} Abrasion of prosthesis surfaces facilitates the attachment of microorganisms, leading to bacterial colonization and discoloration. According to previous studies, surface roughness (Ra) exceeding 0.2 µm is considered a critical threshold that promotes microbial colonization and biofilm formation on dental materials.¹²⁻¹⁴

The aim of this study is to evaluate the effect of different cleaning methods, including brushing, tablet immersion, and their combined use, on the surface roughness of two different acrylic resin materials: conventionally fabricated PMMA and 3D-printed resin. The null hypotheses of the study are;

- There would be no statistically significant difference in surface roughness among the control, tablet, brushing, and combined cleaning methods for both materials.
- There would be no statistically significant difference in surface roughness changes between PMMA and 3D-printed resin materials when the same cleaning procedures are applied.

METHODS

Ethics committee approval was not required for this study, as it involved only in vitro testing of dental materials and did not include human or animal subjects. All procedures were carried out in accordance with the ethical rules and the principles.

The materials, manufacturers, and compositions examined in this study are presented in **Table 1**. Conventional heat polymerisation technique was used to produce the PMMA samples. Wax samples with dimensions of Ø10x3 mm³ were prepared, embedded in the dental stone which is placed in the lower part of the muffle and waited for setting of dental stone. Then the upper part of the muffle settled and pressed in a hydraulic press at 20 psi for 5 minutes. After the wax removal, the acrylic powder and the liquid were mixed according to the manufacturers' recommendations (powder/liquid ratio of 2.34 g/ml) and packed into the mold. PMMA samples were produced by using conventional heat polymerization technique (100°C for 45 min.).¹⁵ The design of the 3D-printed specimens was done in a software programme (Mashmixer, Autodesk) as a virtual Ø10x3 mm³ circular disc shape. Then printed using a digital light processing (DLP)-based 3D-printer (Dentafab Sega, 3Bfab Technologies, İstanbul, Türkiye) using a biocompatible acrylic resin (PowerResins Denture, İstanbul, Türkiye) with a 90-degree structural orientation as shown in **Figure 1**. After completion of specimen fabrication, the cylinder discs were immersed in isopropyl alcohol, then dried with air spray and post-cured at 405 nanometres for 10 minutes. To ensure surface standardization, the surface of all specimens was grounded with 800-1200 grit abrasive papers and polished with polishing paste (Ivoclar Vivadent, Liechtenstein, Germany). After surface preparation, the

Table 1. Materials used in the study

Materials	Brand name/manufacturer	Composition	Immersion/ brushing procedure
Distilled water	Distilled water	-----	Immersion throughout the experiment at room temperature
Effervescent tablet (Corega)	GlaxoSmithKline Healthcare, İstanbul, Türkiye	Potassium monopersulfate; sodium bicarbonate; sodium lauryl sulfoacetate; sodium perborate monohydrate; sodium polyphosphate	One tablet dissolved in 200 ml water, 1 hour each for 9 days
Antiseptic soap	Evyap Tic AS., Levent, İstanbul, Türkiye	Aqua, sodium laureth sulfate, cocamidopropyl betaine, salicylic acid, chloroxylenol, glycerin, polyquaternium-7, tetrasodium EDTA, methylchloroisothiazolinone & methylisothiazolinone, acrylates/PEG-10 maleate, styrene copolymer, parfum, sodium hydroxide, citric acid, sodium chloride	5.000 cycles in a brushing simulator, equivalent to 6 months of brushing
PMMA	SR Triplex Hot™, Ivoclar Vivadent Inc. Schaan, Liechtenstein	Polymethyl methacrylate, catalyst, pigments	-----
3D-printed resin	PowerResins Denture™, İstanbul, Türkiye	4,4'-isopropylidenediphenol, ethoxylated and 2-methylprop-2-enoic acid, 7,7,9 (or 7,9,9)-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate, titanium dioxide, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide	-----

EDTA: Etilen diamin tetra asetik asit, PEG: Polyethylene glycol, PMMA: Polymethyl methacrylate

specimens were sterilized with ethylene oxide at 37°C for 4 hours, followed by a 12-hour aeration period to prevent microbial contamination and stored in distilled water prior to testing.

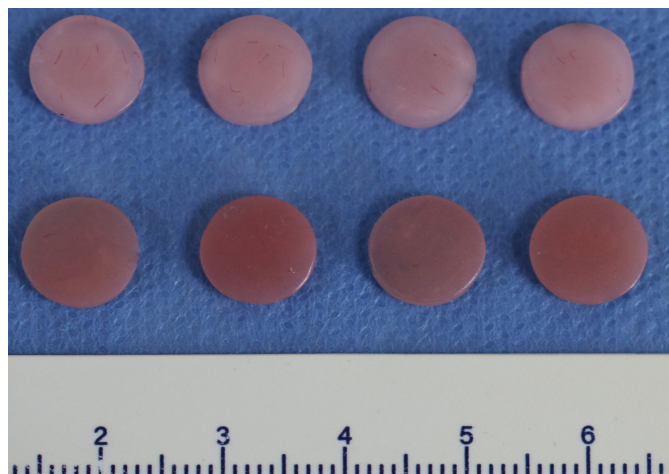


Figure 1. First row, PMMA samples; second row, 3D-printed acrylic resin samples. Control group, tablet group, brushing group, brushing and tablet group, respectively

PMMA: Polymethyl methacrylate

Baseline roughness values of samples were recorded using a profilometer (Surtronic 25, Taylor Hobson, UK) with a measuring length of 4 mm and a speed of 1 mm/sec. Prior to conducting each measurement, a thorough instrument calibration was performed. The measurement process was replicated in three distinct regions of the sample surfaces, the mean values were calculated, and the mean was recorded as the baseline surface roughness (Ra0). The final surface roughness values (Ra1) were recorded by means of the same approach.¹⁶

All samples of each material were divided into 4 groups according to the cleaning procedure (n=10). The samples of the control group (group C) were kept in distilled water and did not take any cleaning procedure. The samples of the second group (group T) were immersed in Corega (GlaxoSmithKline, Brentford, UK) tablet solution. The third group (group B) was brushed with liquid soap (Evyap, İstanbul, Türkiye). Specimens in the fourth group (group BT) were kept in Corega tablet solution after brushing with liquid soap in the same way.

Group T was immersed in the tablet solution, which was prepared according to the manufacturer's instructions. To simulate 180 days of daily cleaning, specimens were immersed 20 times per day for 9 consecutive days, with each immersion lasting 3 minutes using a fresh tablet for each cycle. Upon completion of the cleaning procedures, all samples were washed in an ultrasonic bath and dried for 24 hours.¹⁰

The brushing process was performed using a simulator (DentArGe TB-6.1 Brushing Simulator, Analitik Medikal, Türkiye). Each sample was fixed with silicone in one of the six independent plastic containers of the simulator, as illustrated in **Figure 2**. FDA-certified toothbrushes of medium hardness (Dipadent, Difaş, İstanbul, Türkiye) were fixed to the plastic toothbrush holder arms of the brushing

simulator by screwing them parallel to each other. For the study groups including the brushing process, liquid soap was mixed with distilled water (Hygasonic, Dürr Dental AG, Bietigheim-Bissingen, Germany) in a 1:1 ratio and placed in plastic containers to cover the samples. All samples were brushed in 5,000 cycles, which is equivalent to 6 months of brushing.¹² To ensure standardization, a new toothbrush was used for each sample and a new liquid soap-water mixture was prepared. Each sample was brushed in diluted liquid soap at room temperature (25°C) with a constant vertical force of 350 g, with a stroke length of 10 mm and a reciprocating motion at a rotational speed of 40 mm/sec.¹⁶



Figure 2. Brushing of the samples

The specimens in the BT group were brushed and then immersed in tablet solution as previously described methods. Once the cleaning process was complete, the specimens were stored in distilled water until the surface roughness measurements were taken.

Scanning electron microscopy (SEM) (Quanta FEG 450, Oxford Instruments, The Netherlands) was used under low vacuum, at x1000 magnification to analyze the surface morphology. Images were obtained at an accelerating voltage ranging from 15 to 18 kV. SEM image of one sample for each group is presented in **Figure 3**.

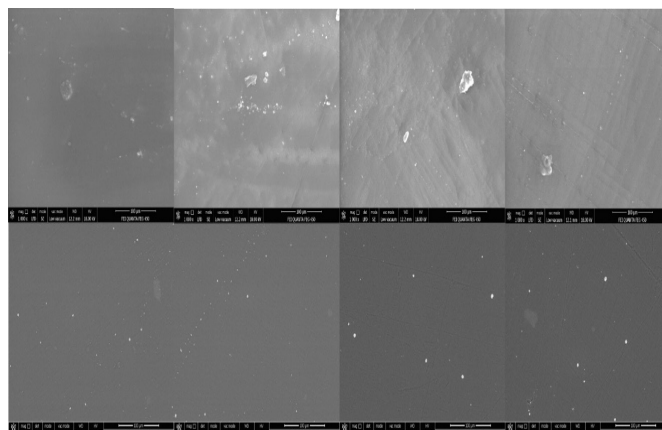


Figure 3. SEM images, group C, group T, group B, and group BT respectively, the first row indicates PMMA; the second row indicates 3D-printed resin samples

SEM: Scanning electron microscope, PMMA: Polymethyl methacrylate

Statistical Analysis

Data analysis was done in the software programme (IBM SPSS Statistics v23, IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed as mean, standard deviation (SD), minimum and maximum values (min-max). The normality of variables was determined by the Kolmogorov-Smirnov test and parametric test methods were used. While the T test was used for group comparisons of normally distributed variables, repeated measures ANOVA was used for repeated measurements. The post hoc test (Bonferroni method) was used in pairwise comparisons. Statistical significance was assessed at $p < 0.05$.

RESULTS

The mean, standard deviation, minimum, and maximum roughness values of the groups before and after cleaning procedures are presented in Table 2. According to the ANOVA results, initial surface roughness values were not significantly different for both material groups (PMMA, $p = 0.422$; 3D-printed resin, $p = 0.673$), whereas final roughness values were significantly different ($p < 0.001$). The highest roughness values before the cleaning procedures were achieved in group C and T ($Ra_0 = 0.14 \mu m$ for both), lowest values were seen in group B ($Ra_0 = 0.11 \mu m$) for PMMA. For 3D-printed resins, highest values were found in group C and T ($Ra_0 = 0.11 \mu m$ for both), lowest values were obtained in group B and BT ($Ra_0 = 0.10 \mu m$ for both). The highest values were found in the BT group for both PMMA and 3D-printed resin samples ($Ra_1 = 0.25 \mu m$, $0.21 \mu m$ respectively) for final roughness values. The lowest roughness values were recorded in both the control and tablet treated group of the PMMA ($Ra_1 = 0.15 \mu m$ for both) with no statistically significant difference and control specimens of 3D-printed resin ($Ra_1 = 0.12 \mu m$). In pair group comparisons (T test) both group B and BT in the PMMA material exhibited statistically significant increases in surface roughness from baseline to final value ($p < 0.001$). Similarly, analysis of the differences between the initial and final surface roughness values in the 3D-printed resin groups also revealed a statistically significant increase in surface roughness in groups T, B, and BT ($p < 0.001$), indicating that all three treatments resulted in rougher surfaces compared to

baseline (Table 2). Unlike the PMMA material, a significant increase in surface roughness was also observed in group T, suggesting that the chemical tablet alone may have affected the surface properties of the 3D-printed resin. For final surface roughness values, there was no statistically significant difference in terms of type of treatment among the material groups (Table 3).

Table 3. Difference of final surface roughness values among the material groups

		Mean	SD	t	p*
Group C	PMMA	0.15	0.04	-1.833	.100
	3D-printed resin	0.12	0.02		
Group T	PMMA	0.15	0.04	-.476	.645
	3D-printed resin	0.15	0.01		
Group B	PMMA	0.22	0.04	-.563	.587
	3D-printed resin	0.20	0.04		
Group BT	PMMA	0.25	0.05	-2.181	.057
	3D-printed resin	0.21	0.03		

*T test, SD: Standard deviation, PMMA: Polymethyl methacrylate

Scanning electron microscopy images of all groups are presented in Figure 3. In the PMMA specimens, group B and BT exhibited clear surface abrasions and linear striations consistent with mechanical brushing, which were absent in the group C and T. The tablet-treated surfaces appeared relatively smooth and similar to the control. 3D-printed resin samples in groups B and BT showed visible surface alterations, including brush marks and surface irregularities. Compared to PMMA, the topography of 3D-printed samples revealed a more uniform texture, suggesting a higher resistance to surface abrasion. Overall, brushing led to the most evident surface deterioration in both material types, with PMMA showing a more pronounced effect.

DISCUSSION

The first hypothesis tested in this study was rejected as there was a statistically significant difference in the surface roughness for both PMMA and 3D-printed resin samples

Table 2. Descriptive analysis for the groups (μm)

		Initial (Ra_0)			Final (Ra_1)			p**
		Min-max	Mean	SD	min-max	Mean	SD	
PMMA	Group C	0.08-0.24	0.14	0.05	0.10-0.20	0.15	0.04	0.591
	Group T	0.06-0.23	0.14	0.06	0.10-0.23	0.15	0.04	0.406
	Group B	0.10-0.12	0.11	0.01	0.15-0.29	0.22	0.04	<0.001
	Group BT	0.07-0.19	0.13	0.05	0.14-0.30	0.25	0.05	<0.001
	p*		0.422			<0.001		
3D-printed resin	Group C	0.07-0.13	0.11	0.02	0.09-0.15	0.12	0.02	0.089
	Group T	0.06-0.13	0.11	0.02	0.11-0.16	0.15	0.01	<0.001
	Group B	0.08-0.12	0.10	0.01	0.13-0.26	0.20	0.04	<0.001
	Group BT	0.05-0.12	0.10	0.02	0.13-0.24	0.21	0.03	<0.001
	p*		0.673			<0.001		

*Surface roughness differences between the groups, repeated measures ANOVA, $p < 0.05$. **Initial and final surface roughness differences among each group, T test, $p < 0.05$, Min: Minimum, Max: Maximum, SD: Standard deviation, Ra_0 : Roughness, Ra_1 : Roughness values, PMMA: Polymethyl methacrylate

among different cleaning methods. The second hypothesis was accepted since the difference in surface roughness values was not statistically significant when the same cleaning method applied to the different materials.

The traditional production method involves multi-stage and complicated laboratory steps that take a long time in the production process of prostheses. The high number and difficulty of these laboratory steps leads to a significant number of technician errors, increased costs and longer production times. The use of digital techniques makes it possible to reduce such problems, costs and production times.¹⁷

The heat polymerisation of PMMA produces a linear polymer structure with minimal crosslinking and residual monomers. The polar nature of the polymer means it easily absorbs water and cleaning agents, which can soften the material and reduce its surface hardness. Additionally, its low filler content makes it more susceptible to abrasion, resulting in increased roughness after cleaning.¹⁸ 3D-printed resin consists of cross-linked methacrylate oligomers and photoinitiators, and it is cured layer by layer. Unpolymerised areas can exist between layers, reducing the material's overall strength and trapping debris during brushing.¹⁹

With advances in digital dentistry, 3D printers are increasingly being used to produce various types of prostheses. These production systems offer low technical sensitivity, reduced manufacturing errors, patient comfort, high accuracy and more predictable laboratory operations, as well as reduced production time.²⁰ Although there are many studies in the literature evaluating the roughness levels of different base materials after cleaning, there is no study that examines the changes in surface roughness of 3D-printed base materials compared with PMMA, as a result of soaking in the cleaning tablet, brushing with antiseptic soap and using a combination of these two methods.

Dentists recommend various mechanical (e.g., brushing, ultrasonic cleaning) and chemical (e.g., cleansing tablets, mouthwash, liquid disinfectants) methods for maintaining denture hygiene. Individuals also use household products such as soap and vinegar to clean their dentures. In developed countries, denture cleaning tablets are often recommended as the primary method. In our study, the most common cleaning protocols, tablets and brushing, were used to clean resin samples.²¹

It is recommended to use anatomically shaped special brushes with small diameter, soft, long bristles, and appropriate technique for mechanical denture cleaning.²² In this study, standardization was achieved by using an FDA-certified medium-hardness toothbrush in accordance with recommendations for brushing resin surfaces. Many studies in the literature have used soap brushing and immersion in tablet solution to clean prostheses.^{23,24} Soap was chosen for brushing due to its non-abrasive nature, ease of access, affordability, and neutral pH, which minimizes the risk of allergic reactions or unpleasant taste. A liquid formulation was preferred for ease of application, and no antiseptics or drugs were added to allow objective assessment of cleaning performance.²⁵

Low pH cleaning solutions (between 3 and 6) can soften the resin matrix of the material by removing inorganic molecules such as Ca^{2+} , Al^{3+} and Sr^{2+} . When the effervescent tablet dissolves in water, it can decompose sodium perborate, resulting in the degradation of poorly cured areas of the material over time, a decrease in the hardness of the material and an increase in surface roughness.²⁶ Corega tablets are a popular choice for cleaning dentures and are able to remove light stains and deposits from the denture base.²⁷ Immersion of removable dentures overnight in an alkaline peroxide-based effervescent solution has been reported as an effective chemical method for reducing bacterial plaque.²⁸

Several studies have demonstrated that immersion in denture cleansing tablets such as Corega does not significantly alter the surface roughness of heat-polymerised acrylic resins, which is consistent with the findings of the present study.²⁹⁻³¹ However, contrasting evidence exists. Peracini et al.,³² Durkan et al.,³³ and a long-term evaluation by another study³⁴ reported increased surface roughness following prolonged exposure to tablet solutions. These differences may be attributed to variations in immersion time, chemical concentration, or differences in the composition of the acrylic resin used. The present study employed a shorter immersion duration, possibly explaining the absence of surface degradation.

Another study compared the durability and surface properties of prosthesis bases produced by three-dimensional printing and heat-polymerised PMMA. The CAD group was found to be significantly more durable than the other groups. While the heat-cured and 3D-printed bases had similar mechanical properties, it was reported that all the bases tested had similar surface roughness after polishing.³⁵

Alqanas et al.¹⁰ showed that there were no significant differences in surface roughness when acrylic resins produced with different 3D printers were immersed in denture cleanser tablets for 180 days; after immersion for 360 days, there was a significant increase in surface roughness for all samples compared to initial measurements. The results were consistent with the present study that all denture cleaning methods produced higher surface roughness values when compared to the control group which is only immersed in distilled water. However, in this study, there was a significant difference in the samples stored in tablets for 180 days when compared to the initial roughness values. The difference can be due to using different 3D-printed resin materials and immersion procedures. Also, Moussa et al.³⁶ compared the surface roughness of 3D-printed denture resins after different cleaning protocols, and the results showed that the use of Corega tablet cleanser led to higher roughness values when compared to the control group which was immersed in distilled water. In this aspect, the results were similar to the present study.

Exposure of denture base materials to various cleaning agents, monomer release, and binding with free oxygen causing continuous polymerization reactions have been shown to alter surface microhardness.³⁷ 3D-printed denture base materials may exhibit reduced microhardness compared to conventional acrylic resins because of reduced double bond formation.³⁸ The adhesion of microorganisms to the surface has been shown to result in a compromise of hardness and

an increased surface roughness. It has been observed that denture-cleaning solvents can expand the microcavities by penetrating the polymer network of the prosthesis. Since the production stage of 3D resins takes place layer by layer, this leads to the formation of pores and grooves on the surface of the final product. Surface hardness is not evaluated in this study, however, it is an indicator of the wear resistance and surface roughness of the material.^{32,39}

Brushing with antiseptic soap may be an alternative for cleaning removable dentures, as it is non-cytotoxic and does not alter the physical and mechanical properties of acrylic resins after application of the solution.²⁵ Zoccolotti et al.⁴⁰ reported that some disinfectant liquid soaps reduced bacterial accumulation on the surface of acrylic resin samples. In addition, the same study concluded that no change was observed in the roughness of the soap solution-treated specimens. As brushing was combined with soap solution in the present study, it is thought that an increase in surface roughness values was observed in the soap-applied group compared to control, but there were no difference in roughness depending on the type of material.

As the surface roughness increases, the adhesion of microorganisms on the surface of the dentures becomes easier and plaque accumulation, fungal and bacterial infections, stomatitis and angular cheilitis may occur. To prevent the attachment of microorganisms, the surface roughness of polished dentures should be kept below 0.2 μm .¹² A study evaluated the surface roughness of CAD-CAM and conventional PMMA showed that the roughness values were increased after brushing with soap.¹² Similarly, Alfouzan et al.⁴¹ investigated the surface roughness of conventionally and 3D-printed manufactured resins after thermocycling, brushing, and staining with various colourants. The conclusion drawn by the authors of the study was that the brushing process resulted in a greater degree of roughness in comparison with the initial. In this study, surface roughness measurements were obtained before and after exposure to cleaning agents. Although a significant increase in roughness was observed in all samples after the cleaning process, the surface roughness of brushed specimens both for PMMA and 3D-printed resin materials were above the clinically acceptable threshold (0.2 μm).¹²

Limitations

This study has several limitations. Because of the in vitro nature of the study, clinical conditions such as the presence of microorganisms, temperature, and pH changes can not be presented. In addition, the samples used have a flat, disc-shaped surface and are unable to mimic the anatomical shape of the prosthesis. In addition, other surface roughness and topographic imaging methods (such as atomic force microscopy or non-contact profilometry) can be used to enable larger areas of the materials to be analysed which is a limitation of the measurement methods used in the study. Future studies should focus on the effect of changes in surface properties on microbial adhesion, the effect of intraoral constraints (temperature, pH, etc.) on denture base materials, and the effect of wear on surface hardness and color stability.

CONCLUSION

The surface properties of denture bases produced by the conventional and 3D manufacturing methods is affected by different cleaning procedures. Brushing and use of cleanser tablet together lead to an increase in the roughness of resins. The brushing method was found to have a greater increase in surface roughness than the tablet cleaning method. The application of different cleaning methods does not lead to significant results in terms of affecting the surface roughness between PMMA and 3D-printed resins. Individuals using PMMA or 3D printed resin denture prostheses should be informed that various cleaning methods can affect the smoothness of the surface of the prostheses.

ETHICAL DECLARATIONS

Ethics Committee Approval

Ethics committee approval was not required for this study, as it involved only in vitro testing of dental materials and did not include human or animal subjects.

Informed Consent

Since this study only included in vitro tests of dental materials, no consent form was obtained.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

REFERENCES

- Salama F, Al-khunaini N, Al-Rashed S, Abou-Obaid AA, Elsharawy M. Effect of different denture cleansers on surface roughness of acrylic denture base materials. *Int J Contemp Res Rev*. 2017;35(2):14-20. doi:10.15520/ijcrr/2017/8/11/359
- Ratanajanchai M, Kanchanavasita W, Suputtamongkol K, Wonglamsam A, Thamapipol S, Sae-Khow O. Heat-cured poly (methyl methacrylate) resin incorporated with different food preservatives as an anti-microbial denture base material. *J Dent Sci*. 2021;16(2):706-712. doi: 10.1016/j.jds.2020.09.006
- Schweiger J, Stumbaum J, Edelhoft D, Güth JF. Systematics and concepts for the digital production of complete dentures: risks and opportunities. *Int J Comput Dent*. 2018;21(1):41-56.
- Gutiérrez TJ. 3D Printing of Biopolymers: Trends and Opportunities for Medical Applications. In *Handbook of Biopolymers: Advances and Multifaceted Applications*; Jenny Stanford Publishing. 2018:45-74.
- Limírio JPJ, Gomes JML, Rezende MCR, et al. Mechanical properties of polymethyl methacrylate as a denture base: conventional versus CAD-CAM resin-a systematic review and meta-analysis of in vitro Studies. *J Prosthet. Dent*. 2022;128(6):1221-1229. doi:10.1016/j.prosdent.2021.03.018
- Javaid M, Haleem A. Current status and applications of additive manufacturing in dentistry: a literature-based review. *J Oral Biol Craniofac Res*. 2019;9(3):179-185. doi:10.1016/j.jobcr.2019.04.004

7. Salerno C, Pascale M, Contaldo M, et al. *Candida*-associated denture stomatitis. *Med Oral Patol Oral Cir Bucal*. 2011;16:139-143. doi:10.4317/medoral.16.e139
8. Gornitsky M, Paradis J, Zandaverde G, Malo AM, Velly AM. A clinical and microbiological evaluation of denture cleansers for geriatric patients in long-term care institutions. *J Can Dent Assoc*. 2002;68(1):39-45.
9. Panariello BH, Izumida FE, Moffa EB, Pavarina AC, Jorge JH, Giampaolo ET. Effects of short-term immersion and brushing with different denture cleansers on the roughness, hardness, and color of two types of acrylic resin. *Am J Dent*. 2015;28(3):150-156.
10. Alqanas SS, Alfuhaid RA, Alghamdi SF, Al-Qarni FD, Gad MM. Effect of denture cleansers on the surface properties and color stability of 3D printed denture base materials. *J Dent*. 2022;120:104089. doi:10.1016/j.jdent.2022.104089
11. Al-Thobity AM, Gad M, ArRejaie A, Alnassar T, Al-Khalifa KS. Impact of denture cleansing solution immersion on some properties of different denture base materials: an in vitro study. *J Prosthodont*. 2019;28(8):913-919. doi:10.1111/jopr.12649
12. Çakmak G, Donmez MB, Atalay S, et al. Surface roughness and stainability of CAD-CAM denture base materials after simulated brushing and coffee thermocycling. *J Prosthet Dent*. 2024;132(1):260-266. doi:10.1016/j.prosdent.2022.06.006
13. Yu P, Wang C, Zhou J, Jiang L, Xue J, Li W. Influence of surface properties on adhesion forces and attachment of *Streptococcus mutans* to zirconia in vitro. *Biomed Res Int*. 2016;2016:8901253. doi:10.1155/2016/8901253
14. Andreotti AM, Sousa CA, Goiato MC, et al. In vitro evaluation of microbial adhesion on the different surface roughness of acrylic resin specific for ocular prosthesis. *Eur J Dent*. 2018;12(2):176-183. doi:10.4103/ejd.ejd_50_18
15. Nakhaei M, Dashti H, Sasannejad S, Mohammadipour HS. Bonding the titanium attachment matrix housing to acrylic overdentures using different primers, adhesives, and resin materials: an in vitro study. *Int J Dent*. 2025;2025(1):9702318. doi:10.1155/ijod/9702318
16. Halis G, Köroğlu A, Şahin O, Dede DÖ, Yılmaz B. Effect of simulated toothbrushing on surface roughness of sealant agent coupled nanohybrid composite resins. *J Esthet Restor Dent*. 2022;34(6):907-914. doi:10.1111/jerd.12871
17. Davidowitz G, Kotick PG. The use of CAD/CAM in dentistry. *Dent Clin North Am*. 2011;55(3):559-ix. doi:10.1016/j.cden.2011.02.011
18. Zafar MS. Prosthodontic applications of polymethyl methacrylate (PMMA): an update. *Polymers (Basel)*. 2020;12(10):2299. doi:10.3390/polym12102299.
19. Penzenstadler M, Intarak N, Kamnoedboon P, et al. In vitro analysis of composition profiles of resins for 3D printing of dentures. *J Dent*. 2025;154:105565. doi:10.1016/j.jdent.2025.105565
20. Fotovat F, Abbasi S, Nikanjam S, Alafchi B, Baghiat M. Effects of various disinfectants on surface roughness and color stability of thermoset and 3D-printed acrylic resin. *Eur J Transl Myol*. 2024;34(1):11701. doi:10.4081/ejtm.2024.11701
21. Fouda SM, Gad MM, Ellakany P, et al. Influence of denture brushing on the surface properties and color stability of CAD-CAM, thermoformed, and conventionally fabricated denture base resins. *J Prosthodont*. 2025;34(1):91-100. doi:10.1111/jopr.13801
22. Rossato MB, Unfer B, May LG, Braun KO. Analysis of the effectiveness of different hygiene procedures used in dental prostheses. *Oral Health Prev Dent*. 2011;9(3):221-227.
23. Costa MS, Lovato da Silva CH, de Cássia Oliveira V, et al. Effects of different forms of denture adhesives on biofilm formation, adhesive strength and hygiene of complete dentures. *Int J Prosthodont*. 2022;35(6):784-792. doi:10.11607/ijp.7188
24. Yuzugullu B, Acar O, Cetinsahin C, Celik C. Effect of different denture cleansers on surface roughness and microhardness of artificial denture teeth. *J Adv Prosthodont*. 2016;8(5):333-338. doi:10.4047/jap.2016.8.5.333
25. Paranhos HF, Salles AE, Macedo LD, Silva-Lovato CH, Pagnano VO, Watanabe E. Complete denture biofilm after brushing with specific denture paste, neutral soap and artificial saliva. *Braz Dent J*. 2013;24(1):47-52. doi:10.1590/0103-6440201301946
26. Santi MR, Khodor N, Sekula M, Donatelli D, De Souza GM. Effect of cleaning solution on surface properties of 3D-printed denture materials. *J Prosthodont*. 2024. doi:10.1111/jopr.13936
27. Gad MM, Khattar A, Alramadan DM, et al. Nanoparticle-modified 3D-printed denture base resins: influence of denture cleansers on the color stability and surface roughness in vitro. *Nanomaterials*. 2024;14(10):891. doi:10.3390/nano14100891
28. Coelho SRG, da Silva MDD, Nunes TSBS, Viotto HEC, Marin DOM, Pero AC. Effect of immersion in disinfectants on the color stability of denture base resins and artificial teeth obtained by 3D printing. *J Prosthodont*. 2024;33(2):157-163. doi:10.1111/jopr.13663
29. Paranhos Hde F, Peracini A, Pisani MX, Oliveira Vde C, de Souza RF, Silva-Lovato CH. Color stability, surface roughness and flexural strength of an acrylic resin submitted to simulated overnight immersion in denture cleansers. *Braz Dent J*. 2013;24(2):152-156. doi:10.1590/0103-6440201302151
30. Ural C, Sanal FA, Cengiz S. Effect of different denture cleansers on surface roughness of denture base materials. *Clin Dent Res*. 2011;35(2):14-20.
31. Felipucci DN, Davi LR, Paranhos HF, Bezzon OL, Silva RF, Pagnano VO. Effect of different cleansers on the surface of removable partial denture. *Braz Dent J*. 2011;22(5):392-397. doi:10.1590/s0103-64402011000500008
32. Peracini A, Davi LR, de Queiroz Ribeiro N, de Souza RF, Lovato da Silva CH, de Freitas Oliveira Paranhos H. Effect of denture cleansers on physical properties of heat-polymerized acrylic resin. *J Prosthodont Res*. 2010;54(2):78-83. doi:10.1016/j.jpjor.2009.11.004
33. Durkan R, Ayaz EA, Bagis B, Gurbuz A, Ozturk N, Korkmaz FM. Comparative effects of denture cleansers on physical properties of polyamide and polymethyl methacrylate base polymers. *Dent Mater J*. 2013;32(3):367-375. doi:10.4012/dmj.2012-110
34. Ozyilmaz OY, Akin C. Effect of cleansers on denture base resins' structural properties. *J Appl Biomater Funct*. 2019;17:2280800019827797. doi:10.1177/2280800019827797
35. Di Fiore A, Meneghello R, Brun P, et al. Comparison of the flexural and surface properties of milled, 3D-printed, and heat polymerized PMMA resins for denture bases: an in vitro study. *J Prosthodont Res*. 2022;66(3):502-508. doi:10.2186/jpr.JPR_D_21_00116
36. Moussa R, Ellakany P, Fouda SM, El-Din MS. Comparative evaluation of the effects of laser and chemical denture disinfectants on the surface characteristics of CAD-CAM and conventional denture resins: an in vitro experimental study. *J Prosthodont*. 2024. doi:10.1111/jopr.13952
37. Kassab NH, Mustafa EA, Hasan RH. Antifungal effect: comparison of commercial denture cleansers and microwave energy. *Al-Rafidain Dent J*. 2009;9(1):24-31. doi:10.33899/rden.2009.8990
38. Alifui-Segbaya F, Bowman J, White AR, George R, Fidan I. Characterization of the double bond conversion of acrylic resins for 3D printing of dental prostheses. *Compend Contin Educ Dent*. 2019;40(10):7-11.
39. Nunes TSBS, Silva MDDD, Coelho SRG, Viotto HEDC, Pero AC. Effectiveness of disinfectant solutions associated or not with brushing on the biofilm control of a 3D printed-denture base resin. *J Appl Oral Sci*. 2023;31:e20230104. doi:10.1590/1678-7757-2023-0104
40. Zoccolotti JO, Tasso CO, Arbelaez MIA, et al. 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(8):e0203187. doi:10.1371/journal.pone.0203187
41. Alfouzan AF, Alotiabi HM, Labban N, Al-Otaibi HN, Al Taweel SM, AlShehri HA. Effect of aging and mechanical brushing on surface roughness of 3D printed denture resins: a profilometer and scanning electron microscopy analysis. *Technol Health Care*. 2022;30(1):161-173. doi:10.3233/THC-212974