Effects of various disinfectants on surface roughness and color stability of thermoset and 3D-printed acrylic resin

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Abstract

Denture cleansers are extensively utilized to inhibit the colonization of various *Candida* species. Currently, additive technology in denture fabrication has become more prevalent. This study aims to assess the impact of disinfectants on the surface roughness and color stability of distinct denture bases. Disc-shaped samples (N=66) were exposed to three different disinfectants: 0.5% sodium hypochlorite, 1% hydrogen peroxide, and 2% chlorhexidine. The samples underwent evaluation via spectrophotometry and profilometry, respectively. Data analysis was conducted utilizing analysis of variance (ANOVA) ($p < 0.05$). Within the heat-cured group, sodium hypochlorite resulted in the most notable change in surface roughness (0.2 µm), while chlorhexidine exhibited the least impact (0.001 µm), showing a significant difference ($p <0.008$). The color change (ΔE) for 3D-printed samples immersed in all disinfectants was higher compared to heat-cured samples. Among the heat-cured samples, chlorhexidine induced the highest ΔE (2.76), while sodium hypochlorite resulted in the lowest (ΔE = 1.44), and this difference was statistically significant ($p <0.008$). Chlorhexidine caused the most significant color alteration among the solutions, while sodium hypochlorite induced the most considerable changes in surface roughness.

Key Words: disinfectants; dentures; color; surface properties.

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Today, dentists encounter a rising need for prosthetic restorations, primarily attributed to the aging demographic and the heightened emphasis on enhancing the quality of life.[1,2] A significant number of patients necessitate the replacement of missing teeth and associated structures to enhance aesthetics chewing efficacy, avert undesired dental shifts, and refine pronunciation.[3] The selection among various treatment alternatives for replacing missing teeth is contingent upon clinical considerations, influenced by both patient-specific needs and the professional judgment of the dentist.[4-6] Over the years, diverse materials have been employed in the fabrication of denture bases. The attributes inherent in denture base resins hold pivotal significance in both the clinical functionality and aesthetic appeal of the prosthesis.[7] An exemplary denture base material demonstrates biocompatibility with oral tissues, showcases superior aesthetics, exhibits exceptional mechanical properties - particularly in compressive strength, bending strength, and hardness - maintains substantial bond strength with artificial teeth and liner materials, allows for potential repair or alteration, and ensures dimensional accuracy.[8] Polymethyl methacrylate (PMMA) stands as the most prevalent material employed in the construction of denture bases, primarily due to its affordability, ease of utilization, straightforward manufacturing process, and simplicity of repair relative to other available denture-making materials.[9] PMMAs are broadly categorized into two main groups based on their activation process: heat-activated or thermosetting PMMAs, processed in a powdered-liquid state, and chemically activated or self-curing PMMAs, employing chemical activators to initiate polymerization at ambient temperature.[10] In contemporary denture fabrication, beyond traditional heat-curing and self-curing techniques, additive technology tridimensional (3D) printing has emerged as an alternative method.[9] Additive 3D printing enables the creation of objects by depositing successive cross-sectional layers of materials and curing them.[11] Compared to traditional manufacturing methods, 3D-printed prostheses involve fewer steps within the production cycle, resulting in reduced errors and heightened precision. This approach also enhances the comfort of patients utilizing artificial teeth. Moreover, owing to digital data storage, the process of recreating dentures in case of necessity becomes notably more convenient. Furthermore, laboratory tasks can be accomplished with greater ease and cost-effectiveness compared to conventional methods.[9,10,12,13] Denture cleansers serve as common tools in preventing the colonization of *Candida albicans* and various *Candida* species, as well as in inhibiting plaque formation. The recognized approaches for denture cleaning encompass mechanical, chemical, and a combination of both. An effective disinfection regimen necessitates prior implementation of mechanical cleaning.[14] Nevertheless, in numerous elderly individuals experiencing compromised neuromuscular coordination owing to advanced age, the adoption of chemical denture cleaners has emerged as a dependable alternative.[15] Denture cleaners significantly impact several key characteristics, notably color, surface roughness, and hardness, all of which profoundly influence the long-term success of prosthetic treatments.[9,16-21] Among these attributes, surface roughness holds particular significance. Furthermore, color stability stands out as a crucial feature of a denture base, directly correlated with the success or potential failure of the prosthesis in the realm of aesthetics. Numerous studies have explored the impact of disinfectants on thermosetting denture bases, yielding varied outcomes.[19] However, investigations focusing on the influence of disinfectants on denture bases produced via 3D printing, as well as their comparison with thermosetting denture bases, remain scarce. Given the limited quantity of studies and conflicting findings, further research in this domain is warranted.

The present study was conducted to comparatively evaluate the impact of different disinfectants on the surface roughness and color stability of thermoset and 3D printed denture bases.

Materials and Methods

Sample size

This in-vitro study aimed to analyze the color change and surface roughness of acrylic resin denture bases produced via both heat curing and 3D printing methods. The investigation involved a three-month immersion of these bases in three distinct disinfectants: sodium hypochlorite, hydrogen peroxide, and chlorhexidine. The total sample size comprised 66 specimens, distributed among six groups with 11 samples each. The list of materials used in this study is outlined in Table 1.

Sample preparation

To create the thermoset samples, the cavity of the denture flasks was prepared by utilizing wax samples shaped as discs measuring 2 mm x 10 mm. Type 2 plaster, with a ratio of 100 grams of plaster to 30 milliliters of water, was employed for this purpose. Subsequently, once the plaster had set and the wax was removed, heat-setting acrylic powder and liquid (Acropars100, Tehran, Iran) were blended following the manufacturer's guidelines at a volume ratio of 3:1 until reaching the dough-like consistency. The mixture was then packed into the denture flasks, followed by acrylic additions. The final compression of the flasks was carried out under a pressure of 1.5 bar for 10 min. Next, the flasks were positioned in the cold water of the automatic curing machine (KAVO EWL type 5518, Warthausen, Germany). The machine was set to operate for 90 min at a temperature of 74 °C, followed by an additional 60 min at 95 °C. Following the completion of the curing process, the flasks were gradually cooled overnight.

Table 1. *Materials used in the research.*

Materials	Country of manufacturer	Seller company
Heat-cure acrylic resin	Iran	Acropars
pink resin FREEPRINT denture	Germany	Detax
Sodium hypochlorite 0.5%	Iran	Gol-Ben Lale Sepahan
hydrogen peroxide 1%	Iran	Kimia fam
Chlorhexidine 2%	Iran	Marva-Sept
self-cure acrylic resin	Iran	Acropars

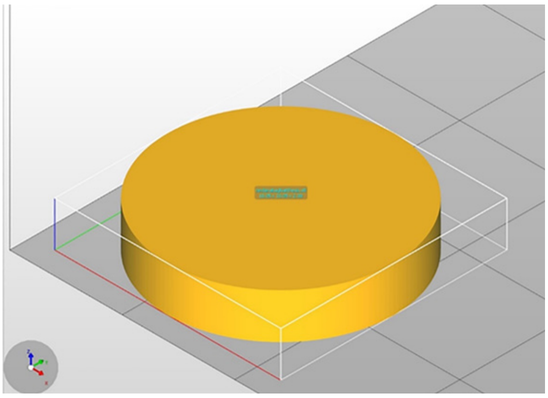

Fig 1. *STL file of the 3D printer group examples.*

Fig 2. *Spectrophotometer and positioning jig..*

Subsequently, the samples were extracted, and any porosities were carefully trimmed. Further refinement and polishing steps were executed on all samples using silicon carbide sandpaper (Soft FIEX, Sayeshparseh, Tehran, Iran) graded at 120, 200, 800, and 1000. The samples underwent thorough washing and drying under running water. A subsequent polishing stage involved the utilization of slurry water and pumice powder to enhance the surface finish. To fabricate samples via the 3D printing method, initially, a disk sample measuring 2 x 10 mm was designed using 3-matic13 software (Materialise, Belgium) and subsequently converted into Standard Tessellation Language (STL) format (Figure 1). This STL file was then transferred to an Asiga freeform two printer (Alexandria, Australia) employing digital light processing technology for sample production. The printed samples were prepared accordingly. Post-printing, finishing and polishing procedures for the 3D printer group were executed following the same process outlined for the heat-cured samples. Then, to ensure sample uniformity, the dimensions of all samples were measured using a digital caliper (Mitutoyo, Japan). Samples included in the study were required to be in the form of discs with a diameter of 10 mm and a thickness of 2 mm, manufactured through both thermosetting and 3D printing methods. Any samples deviating from these specified dimensions or exhibiting surface defects were excluded from the study based on predefined inclusion criteria. All samples were maintained in distilled water for 48 h before measurements of color and surface roughness were conducted and prior to initiating the disinfection process. Following this pre-treatment, the 66 samples were washed with distilled water and subsequently dried using absorbent paper.

Data collection

The initial surface roughness and standard color of each sample were assessed and documented. Surface roughness measurements were conducted using a profilometer (TR200 Plus, Testech, NDT, China). The device's probe tip traversed along the surface of the samples, measuring three distinct areas at intervals of 1 mm. The average roughness (Ra) was then calculated in micrometers (µm) based on the data obtained from these three areas. Color measurements were conducted utilizing a spectrophotometer (Easy Shade Advance/Vita Zahnfabric/Germany), adhering to the CIE Lab (Commission Internationale de l'Eclairage, L*, a*, b*) scale. A positioning jig crafted from self-cured acrylic resin was employed to facilitate this process (Figure 2). This positioning jig, designed with a recess matching the dimensions of the samples in the lower section and a hole matching the spectrophotometer aperture diameter in the upper part, ensured that color assessment was exclusively performed at the center of each sample.[22] Following the initial measurements of the prepared samples, the disinfection process was divided into three distinct categories for each manufacturing method,

Table 2. *National Bureau of Standards (NBS) ratings.*

NBS unit	Critical remarks of color difference	
0.0-0.5	Trace	Extremely slight change
0.5-1.5	Slight	Slight change
1.5-3.0	Noticeable	Perceivable
3.0-6.0	Appreciable	Marked change
6.0-12.0	Much	Extremely marked change
12.0 or more	Very much	Change to other color

corresponding to the use of the specified disinfectant materials.[17,18,23]

Disinfection procedure

To prepare a 0.5% sodium hypochlorite solution, 1 volume unit of Active 5% solution was combined with 9 volume units of distilled water. Subsequently, all samples underwent daily immersion in the disinfectant above solutions for 10 minutes at room temperature. Following each 10-minute interval, the samples were thoroughly washed with water and then stored in distilled water at room temperature. This immersion process was repeated over three months. The final assessment of color and surface roughness was conducted after the completion of this three-month immersion period. The calculation of color change (ΔE) before and after immersion among samples was performed using the subsequent formula, and the quantification was determined based on the National Bureau of Standards (NBS) scale (Table 2).[24]

The change in brightness (ΔL*) and the change in surface roughness (ΔR) were also obtained from the difference between their initial and final values.[21]

Color change measurement

The formula below was used to calculate the changes in the final color:[25]

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T \frac{\Delta C'}{K_C S_C}\frac{\Delta H'}{K_H S_H}}$$

$\Delta L' = L*_j - L*_i$, where K_L denotes unity and S_L represents compensation for lightness.

$\Delta C' = C'_j - C'_i$, $C'_{i,j} = \sqrt{a'^{\,2}_{i,j} + b*^{\,2}_{i,j}}$, where K_C denotes unity and S_C is compensation for Chroma.

$\Delta H' = 2\sqrt{C'_i C'_j}\sin(\frac{\Delta h'}{2})$, where K_H is unity and S_H denotes compensation for Hue.

where R_T denotes a Hue rotation term used to deal with the problematic blue region.

Statistical analysis

Following data collection using SPSS software (IBM SPSS Statistics 23.0), the distribution normality was assessed via the Shapiro-Wilks test. Parametric tests such as analysis of variance (ANOVA), Tukey, and independent t-tests were employed in cases where the data exhibited normal distribution. However, for non-normally distributed data, non-parametric tests, including Kruskal-Wallis and Mann-Whitney tests, were utilized. All statistical analyses were conducted at a 95% confidence level with a significance level set at 0.05.

Results

The primary objective of this research was to assess and compare the impact of various disinfectants on the surface roughness and color stability of heat-cured denture bases manufactured via 3D printing. The study involved measuring the alterations in surface roughness (ΔR), color change (ΔE), and brightness change (ΔL) before and after immersion in different disinfectants for samples produced through both manufacturing methods (Table 3). Subsequently, comparisons of these parameters were conducted specifically for thermosetting denture bases manufactured via 3D printing and immersed in three distinct disinfectants. Moreover, the study also included a comparative analysis of surface roughness change, color change, and brightness change

Table 3. *Comparison of average changes in surface roughness (ΔR) in terms of micrometers (µm) of heat curing samples made by the 3D printer in three types of disinfectants..*

Samples	Disinfectant	Mean ± standard deviation	P value	Pairwise comparisons	p value
Heat cure	sodium hypochlorite 0.5%	0.2 ± 0.13	0.001	sodium hypochlorite 0.5% - hydrogen peroxide 1%	0.01
	hydrogen peroxide 1%	0.08 ± 0.06		sodium hypochlorite 0.5% - chlorhexidine 2%	0.001
	chlorhexidine 2%	0.12 ± 0.001		hydrogen peroxide 1%-chlorhexidine 2%	0.43
3D print	sodium hypochlorite 0.5%	0.18 ± 0.1	0.05	sodium hypochlorite 0.5% - hydrogen peroxide 1%	0.69
	hydrogen peroxide 1%	0.15 ± 0.08		sodium hypochlorite 0.5% - chlorhexidine 2%	0.057
	chlorhexidine 2%	0.07 ± 0.04		hydrogen peroxide 1%-chlorhexidine 2%	0.02

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Table 4. *Comparison of average color change (ΔE) and ΔL of thermoset and 3D printer samples in three types of disinfectants.*

Methods of fabrication	Parameter	Disinfectant	Mean ± standard deviation	*P* value	Pairwise comparisons	*p* value
Heat cured	ΔE	sodium hypochlorite 0.5%	1.44 ± 0.54	0.002	sodium hypochlorite 0.5% - hydrogen peroxide 1%	0.83
		hydrogen peroxide 1%	1.64 ± 0.82		sodium hypochlorite 0.5% - chlorhexidine 2%	0.002
		chlorhexidine 2%	2.76 ± 1.04		hydrogen peroxide 1%- chlorhexidine 2%	0.01
	ΔL	sodium hypochlorite 0.5%	1.08 ±0.23	0.55	sodium hypochlorite 0.5% - hydrogen peroxide 1%	0.79
		hydrogen peroxide 1%	1.59 ± 0.53		sodium hypochlorite 0.5% - chlorhexidine 2%	0.25
		chlorhexidine 2%	1.82 ± 1.06		hydrogen peroxide 1%- chlorhexidine 2%	0.53
3D print	ΔE	sodium hypochlorite 0.5%	2.79 ± 0.38	<0.001	sodium hypochlorite 0.5% - hydrogen peroxide 1%	0.02
		hydrogen peroxide 1%	2.44 ± 0.34		sodium hypochlorite 0.5% - chlorhexidine 2%	<0.001
		chlorhexidine 2%	8.17 ± 1.51		hydrogen peroxide 1%- chlorhexidine 2%	<0.001
	ΔL	sodium hypochlorite 0.5%	0.9 ± 0.82	<0.001	sodium hypochlorite 0.5% - hydrogen peroxide 1%	0.43
		hydrogen peroxide 1%	0.41 ± 0.73		sodium hypochlorite 0.5% - chlorhexidine 2%	0.004
		chlorhexidine 2%	2.28 ± 1.15		hydrogen peroxide 1%- chlorhexidine 2%	<0.001

within each of the three types of disinfectants. This analysis was performed across two groups of materials: one fabricated through thermosetting methods and the other through 3D printing techniques. To compare the means of the variables across the three disinfectant groups, the Kruskal-Wallis test, a non-parametric equivalent of the analysis of variance, was employed for variables that did not exhibit a normal distribution within one or more of the three groups. The significance level was set at 0.05. In cases where analysis of variance (ANOVA) was utilized to determine differences in the means of the desired parameters across the three groups if a significant difference was identified among the three groups, Tukey's post hoc test was conducted to assess the specific differences between the pairs of groups. Conversely, when the Kruskal-Wallis test was applied to examine differences in the means of the desired parameters across the three groups and a significant difference was observed, the Mann-Whitney post hoc test with Bonferroni adjustment was used for pairwise comparisons between the two groups. For these follow-up tests, a more stringent significance level of 0.008 was considered to account for multiple comparisons. Based on the outcomes derived from both the analysis of variance (ANOVA) and Kruskal-Wallis tests, there was no significant difference observed in the mean changes of surface roughness among the samples manufactured by the 3D printer across the three disinfectants ($p<0.05$).

Table 5. *Comparison of the averages of investigated variables in two groups of heat-cured resin and 3D printer resin.*

Parameter	**Disinfectant**	**Studied groups**		**The difference of the averages**	**P-value**
		Heat cured Mean ± Standard deviation	3D print Mean ± Standard deviation		
ΔR	Sodium hypochlorite 0.5%	0.2 ± 0.13	0.18 ± 0.1	0.17	0.2
	Hydrogen peroxide 1%	0.08 ± 0.06	0.15 ± 0.08	-0.39	0.97
	Chlorhexidine 2%	0.12 ± 0.001	0.07 ± 0.04	0.04	0.53
ΔE	Sodium hypochlorite 0.5%	1.44 ± 0.54	2.79 ± 0.38	-1.36	<0.001
	Hydrogen peroxide 1%	1.64 ± 0.82	2.44 ± 0.34	-0.8	0.01
	Chlorhexidine 2%	2.76 ± 1.04	8.17 ± 1.51	-5.4	<0.001
ΔL	Sodium hypochlorite 0.5%	1.08 ± 0.23	0.9 ± 0.82	-0.67	0.11
	Hydrogen peroxide 1%	1.59 ± 0.53	0.41 ± 0.73	0.11	0.51
	Chlorhexidine 2%	1.82 ± 1.06	2.28 ± 1.15	-1.21	0.07

However, contrasting results were observed in the heat-cured samples, indicating a noteworthy disparity in surface roughness changes among the three disinfectant groups (p =0.001).

Upon conducting Tukey's test among the thermoset samples, the analysis revealed a statistically significant difference in the average change of surface roughness between the thermoset samples treated with 0.5% sodium hypochlorite (0.2) and those treated with 2% chlorhexidine (0.001) (p=0.001). The statistical analysis from Table 4 revealed a significant difference in the average ΔL among the 3D printer samples across the three disinfectant groups, as determined by both the analysis of variance and the Kruskal-Wallis test (p < 0.001).

Subsequent Tukey's test results indicated a significant disparity in the average ΔL between the sodium hypochlorite 0.5% and chlorhexidine 2% disinfectants (p=0.004). Furthermore, a statistically significant difference was observed in the average ΔL between the 1% hydrogen peroxide and 2% chlorhexidine disinfectants (p < 0.001).

Based on the findings presented in Table 4, a statistically significant difference was identified in the average color change (ΔE) among the three disinfectant groups for both thermosetting material and 3D printer samples. This was determined through the analysis of variance (p=0.002) and Kruskal-Wallis test (p<0.001). Specifically, among the thermoset samples, a significant discrepancy was observed in the average color change between the sodium hypochlorite 0.5% (1.44) and chlorhexidine 2% (2.76) disinfectant groups (P=0.002).

Additionally, according to the post hoc test (Mann-Whitney) results for the 3D printer samples, significant differences were evident in the average color change between sodium hypochlorite 0.5% (2.79) compared with chlorhexidine 2% (8.17) and hydrogen peroxide 1% (2.44) compared with chlorhexidine 2% (p<0.001). The outcomes obtained from both the independent t-parametric test and the non-parametric Mann-Whitney test, with a significance level of 0.05, are presented in Table 5.

Based on the results outlined in Table 5, a statistically significant difference was observed between the average color change (ΔE) in the thermosetting and 3D printer groups across all disinfectants (p < 0.05).

Notably, in each disinfectant, the average color change was consistently higher in the 3D printer group compared to the thermosetting group.

Discussion

Heat-cured polymethyl methacrylate (PMMA) acrylic resins are widely used in denture bases due to their affordability, ease of manipulation, and repair capabilities.[26]

With the advancements in digital dentistry, the utilization of 3D printers for prosthesis fabrication has gained prominence. This method offers several advantages, including reduced fabrication errors, enhanced precision and fit, improved patient comfort, and the flexibility of refabrication owing to data backup.[27]

However, there remains a scarcity of information regarding how detergents affect the properties of 3D-printed polymers. More comprehensive data in this area is imperative. Thus, this study aimed to assess the impact of various detergents on the surface roughness and color stability of both heat-cured and 3D-printed denture bases.[12] Considering the limited studies specifically using hydrogen peroxide solution, this research also draws comparisons with studies on alkaline peroxides due to their similar mechanisms of action. Alkaline peroxides, containing oxygen-releasing components like sodium perborate and sodium bicarbonate, function by dissolving in water, producing hydrogen peroxide solutions, and releasing oxygen. This released oxygen plays a pivotal role in cleansing the denture through chemical and physical effects.[19,24] Polymerized acrylic resin is susceptible to hydrolysis and decomposition when exposed to denture cleaners.[18] In the current study, all tested groups exhibited an elevation in surface roughness subsequent to immersion in disinfectants.

Significantly different increases in surface roughness were observed among the samples of thermosetting acrylic resin, where sodium hypochlorite 0.5% and chlorhexidine 2% notably caused the least increase in surface roughness. This finding aligns with earlier research investigating the impact of sodium hypochlorite and effervescent solutions on the surface roughness of thermoset denture bases.[15,19] Notably, Carvalho et al. (2012) investigated the effect of disinfectants on denture base acrylic resins. They found that sodium hypochlorite solution led to a greater increase in material roughness compared to chlorhexidine,[28] which concurs with the observations from our study. In our study, the observed level of color change in samples produced by the 3D printer and immersed in all three disinfectants notably surpassed that of the thermoset samples.

This finding concurs with the outcomes reported in a systematic review and meta-analysis conducted by Srinivasan et al. (2021)[29] and in Gruber et al.'s (2020) study.[30] However, Alqanas et al. (2022) investigated the impact of denture cleaners on denture base materials, noting a disparity in the discoloration observed between conventional and 3D printed bases after immersion in effervescent solutions and sodium hypochlorite, differing from our observations.[31] Similarly, Jain et al. (2021) observed that thermosetting bases exhibited more pronounced color changes following immersion in effervescent solutions, presenting a discrepancy in comparison to our findings.[31]

The observed discrepancy in color changes between the studies might be attributed to differences in the types of resins utilized. In Jain's study, the samples produced by the 3D printer were based on dimethacrylate resins.[32] In contrast, our study employed 3D printer resin based on 2-hydroxyethyl methacrylate (HEMA), while the thermosetting resin was based on methyl methacrylate (MMA).[21]

Studies by Iazetti and Hersek have indicated that hydrophilic materials tend to exhibit more pronounced color changes compared to hydrophobic materials. Acrylic resins, being hydrophilic, can absorb water and solvents, leading to hydrolysis and the creation of acrylic areas with distinct optical properties due to the diffusion of absorbed liquids into the polymer network.[33] Notably, the HEMA monomer demonstrates greater hydrophilicity compared to MMA.[34] Therefore, this difference in hydrophilicity could potentially account for the increased color changes observed in our study in the samples produced by the 3D printer. Another significant factor impacting color stability is the surface erosion characteristic of 3D printer resins, which correlates with the filler content within the resin. Typically, 3D printer resins contain fewer inorganic filler particles, a requisite to maintain low viscosity during the printing process. This low viscosity ensures seamless material flow throughout production, contributing to a smooth and refined final surface. However, the reduction in filler content compromises the wear resistance of the resin material, rendering it more prone to surface erosion over time. Furthermore, the deposition of filler particles during storage exacerbates this effect. Non-uniform layers of filler particles during the printing process might lead to irregular polymerization, consequently intensifying surface erosion.[35] This factor could significantly contribute to the observed increase in color change, specifically within the group of 3D printing resins.

The necessity for reduced filler content, fundamental for 3D printing, profoundly impacts surface attributes, wear resistance, and, ultimately, the color stability of the resin material. In our investigation, we noted the highest color change in the groups immersed in chlorhexidine and the lowest in those subjected to sodium hypochlorite. Referring to the thresholds established in the study by Perez et al.,[34,] the color change observed in all three groups was deemed clinically acceptable. However, according to the NBS classification, while the color alteration in the groups immersed in sodium hypochlorite was slight, it was noticeably evident in those treated with hydrogen peroxide and chlorhexidine. Our findings align with the outcomes reported in the studies conducted by Rocha et al.[36] and Hong et al., indicating a consistent trend. However, there is contrastingly different information from Gad et al.'s (2021) study, which concluded that the impact of sodium hypochlorite on denture base color is more pronounced than that of effervescent solutions.[37] This stands in contradiction to our observed results. This discrepancy might be attributed to variations in the chemical composition of the employed effervescent solutions or the potentially higher concentration of sodium hypochlorite utilized in Gad's study.

Robinson's research revealed that denture-cleaning solvents can permeate the polymer network, expanding the intermolecular spaces. Consequently, this process results in the removal of internal pigments and allows for the infiltration of external pigments, ultimately leading to color changes.[37] In this study, a consistent trend was observed across all groups, where the ΔL^* values were positive, indicating the samples' clarification. This finding aligns with prior research indicating the potential of disinfectants to lighten acrylic resins, attributed to mechanisms such as water absorption, alterations in the

polymer matrix, and the chemical degradation and dissolution of their compounds.[32-35] However, contrary observations were reported by Ozyilmaz et al. (2021)[38] in a study where they noted a decrease in the L* parameter following immersion in effervescent solutions. This discrepancy could potentially stem from differences in the type of effervescent used and variations in the immersion protocols employed across the studies.
In conclusion, the color stability of thermosetting denture bases was notably superior to that of the bases produced by 3D printers.
Specifically, chlorhexidine 2% induced significantly more color change than other disinfectants. Notably, among all groups, the least color change was observed in heat-hardened samples immersed in sodium hypochlorite and hydrogen peroxide. Regarding surface roughness, the greatest change in thermosetting denture bases resulted from exposure to 0.5% sodium hypochlorite. In contrast, for 3D printer bases, the effect of various disinfectants did not exhibit significant differences in changing surface roughness.

List of acronyms

ΔE - color change
ΔL - brightness change
ΔR - surface roughness change
3D - tridimensional
ANOVA - analysis of variance
NBS - National Bureau of Standards
PMMA – polymethylmethacrylate
STL - Standard Tessellation Language

Contributions of Authors

FF, SN: manuscript preparation, editing, review; SA, FF: study concept, literature review. MB: experimental procedures; BA: statistical analysis. All authors read and approved the final edited typescript.

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Conflict of Interest

The authors declare they have no financial, personal, or other conflicts of interest.

Ethical Publication Statement

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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References

1. Kohli S, Bhatia S. Polyamides in dentistry. International Journal of Scientific Study . 2013;1(1):20-5.
2. Abbasi S, Nikanjam S, Shishehian A, Khazaei S, Fotovat F, Pana NH. A comparative evaluation of wear resistance of three types of artificial acrylic teeth after removing the glaze layer. Dent Res J (Isfahan). 2022 Jul 18; 19:59. PMID: 36159046; PMCID: PMC9490251.
3. Campbell SD, Cooper L, Craddock H, Hyde TP, Nattress B, Pavitt SH, Seymour DW. Removable partial dentures: The clinical need for innovation. J Prosthet Dent. 2017 Sep;118(3):273-280. doi: 10.1016/j.prosdent.2017.01.008. Epub 2017 Mar 23. PMID: 28343666.
4. Sharma A, Shashidhara H. A review: Flexible removable partial dentures. J Dent Med Sci. 2014;13(12):58-62.
5. Leles CR, Ferreira NP, Vieira AH, Campos AC, Silva ET. Factors influencing edentulous patients' preferences for prosthodontic treatment. J Oral Rehabil. 2011 May;38(5):333-9. doi: 10.1111/j.1365-2842.2010.02158.x. Epub 2010 Oct 12. PMID: 21039748.
6. Boucher CO. Complete denture prosthodontics--the state of the art. 1975. J Prosthet Dent. 2004 Oct;92(4):309-15. doi: 10.1016/j.prosdent.2004.05.017. PMID: 15507901.
7. Vafaee F, Mohammadi A, Khoshhal M, Allahbakhshi H. A Comparative study of heat and self-cured acrylic resins on color stability of 5 brands of denture teeth. Avicenna Journal of Dental Research. 2015;8(1):1-5. doi: 10.17795/ajdr-30328.
8. Alla RK, Sajjan S, Alluri VR, Ginjupalli K, Upadhya N. Influence of fiber reinforcement on the properties of denture base resins. 2013;4(1):1-7. doi:10.4236/jbnb.2013.41012

9. Moravej A, Salehi M, Salehi A, Khosravi A, Yaghmoori K, Rezvan F. Evaluation of the Flexural Strength Values of Acrylic Resin Denture Bases Reinforced with Silicon Dioxide Nanoparticles: A Systematic Review and Meta-analysis. International Journal of Scientific Research in Dental and Medical Sciences. 2023;5(1):21-6. doi: 10.30485/ijsrdms.2023.379362.1420
10. Tandon R, Gupta S, Agarwal SK. Denture base materials: From past to future. Indian J Dent Sci. 2010;2(2):33-9.
11. Fotovat F, Shishehian A, Alijani S, Alafchi B, Parchami P. Comparison of shear bond strength of orthodontic stainless-steel brackets on temporary crowns fabricated by three different methods: An in vitro study. Int Orthod. 2022 Jun;20(2):100641. doi: 10.1016/j.ortho.2022.100641. Epub 2022 May 24. PMID: 35624022.
12. Schweiger J, Edelhoff D, Güth JF. 3D Printing in Digital Prosthetic Dentistry: An Overview of Recent Developments in Additive Manufacturing. J Clin Med. 2021 May 7;10(9):2010. doi: 10.3390/jcm10092010. PMID: 34067212; PMCID: PMC8125828.
13. Chen SG, Yang J, Jia YG, Lu B, Ren L. TiO2 and PEEK Reinforced 3D Printing PMMA Composite Resin for Dental Denture Base Applications. Nanomaterials (Basel). 2019 Jul 22;9(7):1049. doi: 10.3390/nano9071049. PMID: 31336607; PMCID: PMC6669468.
14. Unalan Degirmenci B, Hayas Kakai RT, Guducuoglu H, Ozcan M. Evaluation of the effectiveness of current disinfection methods in complete denture patients. Quintessence Int. 2021 Dec 1;53(1):36-46. doi: 10.3290/j.qi.b1702307. PMID: 34235910.
15. Gajwani-Jain S, Magdum D, Karagir A, Pharane P. Denture cleansers: A review. IOSR Journal of Dental and Medical Sciences. 2015;1(14):94-6. doi: 10.9790/0853-14249496
16. Alam M, Jagger R, Vowles R, Moran J. Comparative stain removal properties of four commercially available denture cleaning products: an in vitro study. Int J Dent Hyg. 2011 Feb;9(1):37-42. doi: 10.1111/j.1601-5037.2009.00432.x. PMID: 21226849.
17. Montagner H, Montagner F, Braun KO, Peres PE, Gomes BP. In vitro antifungal action of different substances over microwaved-cured acrylic resins. J Appl Oral Sci. 2009 Sep-Oct;17(5):432-5. doi: 10.1590/s1678-77572009000500015. PMID: 19936521; PMCID: PMC4327669.
18. Wong WT, Chan WI, Liao PH, Lo KV. A hydrogen peroxide/ microwave advanced oxidation process for sewage sludge treatment. J Environ Sci Health A Tox Hazard Subst Environ Eng. 2006;41(11):2623-33. doi: 10.1080/10934520600928086. PMID: 17000550.
19. Machado AL, Breeding LC, Vergani CE, da Cruz Perez LE. Hardness and surface roughness of reline and denture base acrylic resins after repeated disinfection procedures. J Prosthet Dent. 2009 Aug;102(2):115-22. doi: 10.1016/S0022-3913(09)60120-7. PMID: 19643225.
20. Vojdani M, Giti R. Polyamide as a Denture Base Material: A Literature Review. J Dent (Shiraz). 2015 Mar;16(1 Suppl):1-9. PMID: 26106628; PMCID: PMC4476124.
21. Ragain JC. A review of color science in dentistry: Colorimetry and color space. J Dent Oral Disord Ther. 2016;4:1-5.
22. Firouz F, Izadi A, Fotovat F, Ghorbani Gholiabad S, Nikanjam S. The effect of different solutions on optical behavior of polished and glazed zirconia-reinforced lithium silicate ceramics. Journal of Kerman University of Medical Sciences. 2018;25(5):428-40.
23. de Freitas Fernandes FS, Pereira-Cenci T, da Silva WJ, Filho AP, Straioto FG, Del Bel Cury AA. Efficacy of denture cleansers on Candida spp. biofilm formed on polyamide and polymethyl methacrylate resins. J Prosthet Dent. 2011 Jan;105(1):51-8. doi: 10.1016/S0022-3913(10)60192-8. PMID: 21194588.
24. 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 Jan-Mar;17(1):61-67. doi: 10.4103/0972-4052.197940. PMID: 28216847; PMCID: PMC5308072.
25. Nikanjam S, Abbasi S, Khazaei S. Effect of different bleaching methods on optical behaviors of CAD/CAM ceramics. Avicenna Journal of Dental Research. 2021;13(4):113-8. Doi: 10.34172/ajdr.2021.22
26 Chung YJ, Park JM, Kim TH, Ahn JS, Cha HS, Lee JH. 3D Printing of Resin Material for Denture Artificial Teeth: Chipping and Indirect Tensile Fracture Resistance. Materials (Basel). 2018 Sep 21;11(10):1798. doi: 10.3390/ma11101798. PMID: 30248955; PMCID: PMC6213768.
27. Wilson T, Nair VV, Karunakaran H, Ravichandran R, Viswambharan P, Rajeev SL. Evaluation of Tensile Bond Strength of Zinc Containing and Zinc Free Denture Adhesives on Different Denture Base Resin Materials: An in Vitro Study. International Journal of Scientific Research in Dental and Medical Sciences. 2023;5(3):117-26. Doi: 10.30485/ijsrdms.2023.404515.1509
28. Carvalho CF, Vanderlei AD, Marocho SM, Pereira SM, Nogueira L, Paes-Júnior TJ. Effect of disinfectant solutions on a denture base acrylic resin. Acta Odontol Latinoam. 2012;25(3):255-60. PMID: 23798071.
29. Srinivasan M, Kamnoedboon P, McKenna G, Angst L, Schimmel M, Özcan M, Müller F. CAD-CAM

removable complete dentures: A systematic review and meta-analysis of trueness of fit, biocompatibility, mechanical properties, surface characteristics, color stability, time-cost analysis, clinical and patient-reported outcomes. J Dent. 2021 Oct;113:103777. doi: 10.1016/j.jdent.2021.103777. Epub 2021 Aug 13. PMID: 34400250.

30. Gruber S, Kamnoedboon P, Özcan M, Srinivasan M. CAD/CAM Complete Denture Resins: An In Vitro Evaluation of Color Stability. J Prosthodont. 2021 Jun;30(5):430-439. doi: 10.1111/jopr.13246. Epub 2020 Sep 9. PMID: 32864812.
31. 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 May;120:104089. doi: 10.1016/j.jdent.2022.104089. Epub 2022 Mar 8. PMID: 35271942.
32. Jain S, Sayed M, Ahmed WM, Halawi AHA, Najmi NMA, Aggarwal A, et al. An in-vitro study to evaluate the effect of denture cleansing agents on color stability of denture bases fabricated using CAD/CAM milling, 3D-printing and conventional techniques. Coatings. 2021;11(8):962.doi: 10.3390/coatings11080962
33. azzetti G, Burgess JO, Gardiner D, Ripps A. Color stability of fluoride-containing restorative materials. Oper Dent. 2000 Nov-Dec;25(6):520-5. PMID: 11203865.
34. Hersek N, Canay S, Uzun G, Yildiz F. Color stability of denture base acrylic resins in three food colorants. J Prosthet Dent. 1999 Apr;81(4):375-9. doi: 10.1016/s0022-3913(99)80001-8. PMID: 10095204.
35. Kessler A, Reichl FX, Folwaczny M, Högg C. Monomer release from surgical guide resins manufactured with different 3D printing devices. Dent Mater. 2020 Nov;36(11):1486-1492. doi: 10.1016/j.dental.2020.09.002. Epub 2020 Sep 21. PMID: 32972769.
36. Rocha MM, Carvalho AM, Coimbra FCT, Arruda CNF, Oliveira VC, Macedo AP, Silva-Lovato CH, Pagnano VO, Paranhos HFO. Complete denture hygiene solutions: antibiofilm activity and effects on physical and mechanical properties of acrylic resin. J Appl Oral Sci. 2021 Sep 3;29:e20200948. doi: 10.1590/1678-7757-2020-0948. PMID: 34495105; PMCID: PMC8425897.
37. Gad MM, Abualsaud R, Fouda SM, Rahoma A, Al-Thobity AM, Khan SQ, Akhtar S, Al-Abidi KS, Ali MS, Al-Harbi FA. Color Stability and Surface Properties of PMMA/ZrO2 Nanocomposite Denture Base Material after Using Denture Cleanser. Int J Biomater. 2021 Apr 7;2021:6668577. doi: 10.1155/2021/6668577. PMID: 33927766; PMCID: PMC8049834.
38. Ozyilmaz OY, Kara O, Akin C. Evaluation of various denture cleansers on color stability and surface topography of polyetherketoneketone, polyamide, and polymethylmethacrylate. Microsc Res Tech. 2021 Jan;84(1):3-11. doi: 10.1002/jemt.23558. Epub 2020 Aug 5. PMID: 32757255..

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