Original Article

Effects of Microwave and Light Emitting Diode as Disinfection Methods on Color Stability of Polymethyl Methacrylate and Polyamide Denture Base Resins

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Abstract

Objective: To determine the effects of disinfection through microwave (MW) and LED disinfection on color stability of Polymethyl Methacrylate (PMMA) and Polyamide (PA) denture base resins.

Methodology: A total of 30 specimens of 25x25x5mm dimensions were fabricated in a split mold of stainless steel, which was categorized into 2 groups Polymethyl Methacrylate (PMMA) and Polyamide (PA). These were further differentiated into groups of no exposure (Group A) or microwave (group B) and LED (group C) exposure. Primary color parameters were determined according to CIELab color space for all specimens once immediately after fabrication, using a spectrophotometer within the visible light range of 400 to 700nm. For group B & C, the specimens were exposed to disinfection regimens thrice a week for 4 weeks. After 4 weeks, the specimens were again examined. Data was statistically analyzed using one-way ANOVA and post hoc Tukey's tests (SPSS ver 26), $p < 0.05$.

Results: ANOVA for the PMMA presented no significant results in comparison with PA. On Post Hoc analysis of PA, a significant difference (0.006) was found between groups B and C. Color stability of PMMA remained unaffected statistically after disinfection, but color of PA was adversely affected by MW.

Conclusion: The denture base resins' disinfection regimens did not significantly change color of PMMA. Total color change in PMMA according to NBS remained in the lower range of appreciable color change. For PA, MW disinfection is not feasible as it caused unacceptable color change of the PA base resin.

Keywords: Denture base resin, Color stability, Disinfection, Microwave, LED

Introduction

Regardless of the rising demand for implant treatments, polymethyl methacrylate remains the most preferred material for denture construction for many reasons but mainly because of its ease of fabrication & adequate material properties.[1] However, aesthetics of PMMA prostheses can be impaired by the presence of metal clasps. Also, the presence of residual monomer content[2] has been of concern for dentists. In such circumstances, polyamide can be a feasible alternative to PMMA[3] for the reason that PA do not require metallic retentive clasps and exhibit no monomer content. Polyamides are adopted for patients with allergy to methacrylate (MMA) monomer, hard tissues like alveolar bone undercuts, in very thin mucosa or indiscriminate bone resorption. These are also used for the fabrication of temporary dentures after implant surgeries.[4]

Oral & denture hygiene, if neglected can lead to denture related stomatitis due to microbial growth on the prostheses & can cause denture related stomatitis.[5] For prophylaxis against stomatitis in denture wearers, denture disinfection is achieved through chemical & mechanical procedures combined, but these alone or in combination can deteriorate the physical & mechanical properties of denture base resins.[6] To overcome the complications of denture disinfection with these protocols, microwave energy has been approved as an effortless, safe & efficient disinfection routine.[7] In a review recently, microwave disinfection is claimed to be an effective therapy against denture stomamtitis.[8] Disinfection with microwave has mostly been carried out in water.[9] This may further polymerize the resin.[10] This heating of base resin can be a reason for the change in polymer structure & this in turn may be responsible for the detrimental outcomes of microwave disinfection on base resins.[11]

Although, microwave energy has been a proven disinfection protocol, researchers are incongruent about the adverse effects of this disinfection regimen on the mechanical & physical properties of PMMA. In search for a better disinfection technique for dentures, blue light (LED) of wavelength 405nm has been proven to have bactericidal & fungicidal effects. It can proficiently obstruct production of candida biofilm in comparison with conventional disinfection methods. Hence, blue LED light may be a potential disinfection technique for dentures.[12]

For any dental prosthesis or restoration, color stability is one of the primary requisites. It is defined as the ability of a material to retain its color in a specified environment over time.[13] Any changes in the color of the denture bases is a sign of material aging or damage[14] & may cause patient dissatisfaction and ultimate denture replacement.[15] So for these reasons, its vital for a base resin to retain the color during use & that different disinfection protocols do not influence its color. Color is mainly affected by denture cleansers.[16] The analyses of color change and denture cleansers have been extensively done[17,18] but with varied results.[16,17,18,19,20] Color stability of base resins after disinfection with microwave has been documented with mixed results. Some researchers illustrated notable color changes in the denture bases, when subjected to irradiation with microwave, while others revealed constancy in color[21,22,23]

However, there is very limited information available for LED disinfection and its effects on color of PMMA and PA base resins. Therefore, the present study aimed to investigate the effects of MW and LED disinfection on color of PMMA and PA denture base resins.

Methodology

This was an In-vitro, experimental study, that was conducted at Peshawar Dental College and Material Research Laboratory, University of Peshawar over a course of six months. The study had a total of thirty specimens. The specimens were divided into 2 categories, depending on the material used; PMMA and PA. The 15 specimen of each group were then further divided into 3 groups: control (group A, no disinfection), MW disinfected (group B) & LED treated (group C)21, having 5 specimens each (n=5) (Table 1). The dimensions were 25×25×5mm.

After fabrication following the manufacturer's instructions, the specimens were analyzed immediately for initial color measurement via a spectrophotometer. Afterwards, specimens underwent their allotted disinfection protocol: the control group (A) was placed in distilled water at room temperature, with water being changed equating the water change for interventional groups. Individual samples of group B were disinfected in a microwave oven at 1000W for 3 minutes, placed in 200ml distil water, three times a week for 4 weeks22. Group C samples were irradiated in LED device for 30 minutes in distil water, thrice a week for 4 weeks. Water for the interventional groups were changed after 2 disinfection regimens and every 4th day for group A. Following the completion of 12 disinfection cycles, (at the end of the 4 weeks)23, the final color measurements were calculated from the data obtained by a UV VIS NIR spectrophotometer in University of Peshawar (Perkin Elmer Lambda 1050 Serial# L6020055)

Using CIELab, primary color parameters (Lightness-L*, red/green-a1* and yellow/blue-b1*) for all specimens were calculated. L*, a* and b* were derived from tristimulus values (X,Y,Z), which were computed from reflectance data acquired from spectrophotometer with 5nm intervals within the visible light range of 400-700nm, against a white background, according to the given set of calculations[24]:

1st step: The reflectance values of the specimen were multiplied with reflectance values of the illuminant of the spectrophotometer (illuminant used was D65,

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(R×D65), where R is the reflectance value of the sample, D65 is the reflectance of the illuminant)

2nd step: The computed quantity was then multiplied by the CIE color matching functions ($\bar{x}$, $\bar{y}$, $\bar{z}$) at every 5th wavelength interval between 400 and 700nm (R×D65×$\dot{x}$, R×D65×$\dot{y}$, R×D65×$\dot{z}$) and added for all the wavelength intervals (ΣR×D65×$\dot{x}$, ΣR×D65×$\dot{y}$, ΣR×D65×$\dot{z}$)

3rd step: In the third stage, the obtained values were normalized by multiplying the summations of the second stage with K

(X= K×ΣR×D65×$\bar{x}$), (Y= K×ΣR×D65×$\bar{y}$), (Z= K×ΣR×D65×$\bar{z}$), where K is the luminosity function of a perfect diffuser and is used as a normalizing constant and K=1/ΣD65×$\bar{y}$

4th step: The tristimulus values thus derived were further calibrated through CIE L*a*b* numbers of the samples through the given formulas:

L* = 116 f (Y/Yn) -16

a* = 500[f(X/Xn) – f(Y/Yn)]

b* = 200[f(Y/Yn) – f(Z/Zn)]

here, X,Y,Z are tristimulus values of samples, those with indexes n refers to tristimulus values of a perfect diffuser for the illuminant, D65 and f(X/Xn) = (X/Xn)1/3 for values greater than 0.008856 and f(X/Xn) = 7.787(X/Xn) + 16/116 for values equal to or less than 0.008856 and the same with Y and Z replacing X in turn

5th step: After calculating the initial L1, a1, b1, the specimens underwent their allotted disinfection protocols & then again examined via the spectrophotometer (the same used earlier for the initial color measurements) for the final color measurements; L2, a2, b2, by the same set of steps mentioned above

6th step: The secondary parameters (ΔL*, Δa*,Δb*) then were used to further subtract initial values from final values:

ΔL* = L*2 – L*1

Δa* = a*2 – a*1

Δb* = b*2 – b*1

7th step: Color changes were determined via the equation:

ΔE* = [(ΔL*)2+(Δa*)2+(Δb*)2]1/2

8th step: ΔE was correlated to clinical environment and therefore the values were converted to National Bureau of Standards, NBS units via

NBS units = ΔE* × 0.9225

L is the lightness axis from black (0) to white (100)

a is the red-green axis from -150 (red) to 100 (green)

b is the yellow-blue axis from -100 (yellow) to 150 (blue)26

Mean values of color changes with standard deviations were recorded. Data collected was statistically analyzed via ANOVA (one-way SPSS version 26) & post hoc Tukey's test, significant set at $p < 0.05$.

Results

The highest total color change (ΔE) in PMMA was noted for MW disinfected group (B1 as 3.48), while the lowest values were exhibited by the control group (A1, 2.47) Table 2. The change in color was found to be in the perceivable color change range for A1 & in the marked color change range for B1 & C1, according to NBS (Table3).

ANOVA for the PMMA groups presented no significant results, the total change in color was recorded more for MW (B1), followed by LED (C1) and the least change was displayed by the control group (A1). Post hoc also gave non-significant results for group comparisons Table 4.

For PA, group B2 (MW) ΔE was recorded as 10.85, displaying the maximum change, followed by A2, ΔE of 7.31 & then C2 with Δe of 3.4, the minimum change in color (Table 5). When these values are correlated with the NBS system for expressing color differences, it was observed that both groups, A2 & B2 were in the marked color change range, whereas, the LED disinfected group (C2) displayed changes in the appreciable color change range.

ANOVA gave a highly significant result of 0.008 for color change in PA groups after disinfection. When further analysed (Table 6), it was seen that there were non-significant differences for control & interventional groups, but significance was recorded for the two interventional groups (B2 & C2).

Discussion

The study assessed the effects of two disinfection techniques: MW and LED on color of two base resins; PMMA & PA. Color observation is an observable paradox,

Table 1. Description of the assigned specimens

Specimens	Group A Control	Group B Microwave Irradiated	Group C LED Treated
PMMA	A1	B1	C1
PA	A2	B2	C2

(n=5)

Table 2. Mean values of changes in color (ΔE) with standard deviations for PMMA through ANOVA (n=5)

Specimens		ΔL Mean	Δa Mean	Δb Mean	ΔE Mean	ΔE×0.92 (NBS)	F	p
Color PMMA	Control (A1)	-2.61	0.12	-0.02	2.68	2.47±1.60	0.26	0.774
	MW (B1)	-3.76	0.21	0.29	3.78	3.48±3.65		
	LED (C1)	-3.67	0.11	0.09	3.68	3.39±1.38		

Table 3. National Bureau of Standards (NBS) System for Expressing Color Differences

Critical Marks for Color Difference	NBS* Units
Trace	0.0-0.5
Slight Change	0.5-1.5
Perceivable Change	1.5-3.0
Appreciable Change	3.0-6.0
Marked Change	6.0-12.0
Change to Another Color	12.0 & more
*Nimeroff I. Colorimetry National Bureau of Standards Monograph 104;1968:47	

Table 4. Multiple Comparison for the Total Change in Color (ΔE) of PMMA using Post Hoc Tukey HSD

Multiple Comparison				
Tukey HSD				
Dependent Variable	(I) Groups	(J) Groups	Mean Difference	Sig
Color PMMA	Control (A1)	MW	-1.01	0.793
		LED	-0.91	0.826
	MW (B1)	Control	1.01	0.793
		LED	0.09	0.998
	LED (C1)	Control	0.91	0.826
		MW	-0.09	0.998
*. The mean difference is significant at the 0.05 level. *. Most significant 0.00				

which varies between different individuals & lighting conditions. Any changes in color can be judged through eye survey or via instrumental estimation. Optical color evaluation can be inaccurate because it is built on the observer's psychological reaction to electromagnetic radiation and many other factors, such as illumination, metamerism, & object position etc.[27] Recent color measuring devices have the ability to estimate or evaluate color reliably.[28] These tools measure color and present it in three coordinates, called tristimulus values (L*, a*, b*). These coordinates detect an object's color within CIELab color space. L* equate the brightness, a* locates the red-green chroma and b* shows yellow-blue chroma. Color differences between different subjects can be measured by collating the changes in corresponding coordinate numbers for each and every object or for the same specimen by deriving the coordinates before, after an intervention and then deducing the initial readings from the final measurements.[24] The steps for evaluation of color difference is given in 6th step of the color methodology section. Quantitative value of colors allows accurate magnitude of color differences.[28] As tristimulus values provide precise color determination and thus any changes in color, hence color quantification in the present study was done through reflectance data obtained from spectrophotometer.

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		LED	0.09	0.998
	LED (C1)	Control	0.91	0.826
		MW	-0.09	0.998
*. The mean difference is significant at the 0.05 level. *. Most significant 0.00				

Table 5. Mean values of changes in color (ΔE) with standard deviations for PA through ANOVA (n=5)

Specimens		ΔL Mean	Δa Mean	Δb Mean	ΔE Mean	ΔE×0.92 (NBS)	F	p
Color PA	Control (A2)	-7.89	0.27	-0.20	7.95	7.31±3.80	7.526	0.008
	MW (B2)	-11.71	-0.40	-1.28	11.79	10.85±2.79		
	LED (C2)	-1.96	0.04	-0.15	3.70	3.4±2.31		

Table 6. Multiple Comparison for the Total Change in Color (ΔE) of PA using Post Hoc Tukey HSD

Multiple Comparison				
Tukey HSD				
Dependent Variable	**(I) Groups**	**(J) Groups**	**Mean Difference (I-J)**	**Sig**
Color PMMA	Control (A2)	MW	-3.54	0.198
		LED	3.90	0.146
	MW (B2)	Control	3.54	0.198
		LED	7.44*	0.006
	LED (C2)	Control	-3.90	0.146
		MW	-7.44*	0.006
*. The mean difference is significant at the 0.05 level. *. Most significant 0.00				

For the color results, it can be summarized from Table 2 that there were changes in the specimens of PMMA, but statistically, non-significant ($p>0.05$) color differences were reported. Therefore, the study's null hypothesis of no change in color of PMMA before and after disinfection with MW and LED, is accepted.

Unlike PMMA, for PA (Table 5) significant color differences were recorded for all groups ($p<0.05$). The comparison of both interventional groups, MW and LED with control gave non-significant differences, but highly significant results were documented when MW group was compared with LED disinfected group of PA (Tables 6). Therefore, the null hypotheses regarding color changes in PA after exposure to MW and LED disinfection is partially rejected.

The changing trends for all groups of both PMMA and PA is attributed to the fact that control & interventional specimens were all placed in water during the whole experimental time including the disinfection times in MW and LED. It is documented that if polymer is placed or stored in water, there is diffusion of water molecules in the polymer matrix.[29] This is according to the results noted by Hong et al., and stated that immersion of polymers in water causes changes in color & the longer the immersion time, the more pronounced the color change.[27] Such observation was also endorsed by Jabeen et al., but presented no details regarding the values of color change after storage in water.[21] Similar reports were also documented by al-Qarni etal., for compression and injection molded PMMA as 1.6 and 1.9 respectively.[13] Although the values seem different from those of the present study results, but it can be attributed to the difference in brand of PMMA used, and also to the fact that the samples of al-Qarni et al study were immersed in water for 7 days only, whereas in this study, the samples were kept in distilled water for 4 weeks.

Durkan et al., documented ΔE of 5.89 for PMMA control group, after a period of 20 days in distilled water, and 1.06 for PA after the same time period.[30] The difference of this research work can be attributed to the different brands of PMMA and PA used in the studies. Durkan et al., used PMMA by the brand name of Rodex, which is Butadien-Styrengreft PMMA copolymer, whereas PMMA used was heat cured type in the present analysis. The use of a portable colorimeter in 2013 can be accounted as another reason for the difference in color values from this study, where color was evaluated with a spectrophotometer.

Likewise, Sagsoz, et al., filed ΔE for PA as 3.85 after 7 days' immersion in water and 6.21 after 30 days.[31] The outcomes are befitting with the present work, where PA control group exhibited 7.31 (Table 5) after 4 weeks of water immersion. ΔE for PMMA after 7 days of water immersion was noted down as 2.52, and 2.40 after 30 days of immersion. This result of Sagsoz, et al., thus endorses the results of the present investigation.

When considering the results of Matar & El-Sharkawy, control group of heat cure PMMA had ΔE of 3.3, which lies in the appreciable change range of NBS.[22] This can be regarded in agreement with the present study results, as the authors have not specified the immersion time for the control group in their work. Also, their MW irradiated specimens showed change in color, ΔE as 3.3 and 3.2 after 5 and 15 minutes of disinfection. This also concedes with the results of the MW disinfected group of this paper, as ΔE of group B1 (MW disinfected PMMA) is 3.48 (Table 2) after a total of 36 minutes of disinfection (for 3 weeks, the specimens were disinfected for 3 minutes, 3 times a week). The NBS standardized values for the total change in color for both of the mentioned studies belong to the appreciable change range. Statistically, the results were non-significant, thus endorsing the present investigation results.

Matar & El-Sharkawy also observed PA under the same conditions that were used for PMMA assessment.[22] The results for the control group of PA displayed ΔE as 3.1 and that of MW disinfected group as 3.1 and 3.2 after 5 and 15 minutes of disinfection respectively. The result is in congruence with present study as all the specimens of PA exhibited change in color. Statistically, the results were non-significant for the control & interventional groups of both studies. The differences in values of color for PA groups between the two studies is due to the fact that different brands of PA resin were used & in the present quest, the specimens underwent intervention for a longer duration than the previous study by Matar & El-Sharkawy.

Polychronakis et al., 2015 analyzed the combined ramifications of MW & chemical disinfectants on PMMA & PA base resins.[23] The specimens were irradiated in a 450W MW device with a commercial cleanser, dissolved in water. The samples were disinfected for a total of 10 cycles. This chemical disinfection had significant results. This differing result from the present study can be due to differences in number of specimens & exposure time to MW irradiation. These can be contributing factors, alongside the different brands of polymers used in the two studies, for the different results. Also Polychronakis et al., used a portable colorimeter for color measurement, contrasting to a more sophisticated spectrophotometer used in this observation.

Polychronakis et al., 2018 investigated the effect of repeated MW irradiation for disinfection on PMMA and PA.[29] The results were statistically significant for both materials after simulated daily disinfection with a MW device of 450W for seven and a half (7.5) months. Polychronakis et al contradicts the present study results, as they had significant differences between the control & irradiated samples. Apart from the different brands of PMMA and PA being used, Polychronakis et al., 2018 used colorimeter for color measurements unlike the present paper, where spectrophotometer is used. Most importantly, MW device used in the current investigation is of higher power (1KW) than the previous study device (450 W).

It is noted that color changes recorded in PA so far were more pronounced than that in PMMA. The reason for this considerable change for PA can be the presence of auxochromes in addition to chromophores and free radicals[32,33] that cause more change in PA than PMMA. Chromophores are responsible for the color of a molecule, and auxochromes are functional groups of atoms that are adherent with the chromophores. These auxochromes alter a chromophores' potential for light absorption or can modify the wavelength or intensity of absorption. These auxochromes along the free radicals & chromophores may elicit staining33,34. Literature search could not provide research studies related to LED disinfection and its effects on color of base resins

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to make analogy with the present investigation.

Literature on properties of denture base resins after LED disinfection could not be found to shed light on the results of the present investigation as no direct comparison of the results could be done. Although, MW and LED have proven to be effective for disinfection of denture bases, but the different disinfection strategies are reported to have deleterious effects on some properties of denture base resins. Further studies for establishing more standardized disinfection regimens & evaluating other properties of denture base resins are required to establish proper disinfection protocols, especially regarding LED disinfection. Also, the interventional period needs to be extended to examine the consequences of repeated disinfection protocols on denture base resins. In-vivo or clinical trials will also help in establishing proper disinfection protocols to be followed by the patients.

Conclusion

MW and LED disinfection regimens did not significantly change PMMA color. Total color change in PMMA according to NBS remained in the lower range of appreciable color change, therefore not one disinfection protocol can be preferred over the other. MW caused the highest undesirable color change in PA. LED disinfection had lower color change in PA, comparable to that caused by LED in PMMA. For PA, MW disinfection is not feasible as it caused unacceptable color change of the PA base resin.

References

1. Alqutaibi AY, Baik A, Almuzaini SA, Farghal AE, Alnazzawi AA, Borzangy S, et al. Polymeric Denture Base Materials: A Review Polymers (Basel) 2023;15(15):3258 DOI: 10.3390/polym15153258.
2. Rashid H, Sheikh Z, Vohra F Allergic effects of the residual monomer used in denture base acrylic resins Eur J Dent 2015;9(4):614-19 DOI: 10.4103/2F1305-7456.172621.
3. Lee CJ, Bok SB, Bae JY, Lee HH Comparative adaptation accuracy of acrylic denture bases evaluated by two different methods Dent Mater J 2010;29(4):411-17 DOI: 10.4012/dmj.2009-105.
4. Sampaio-Fernandes M, Galhardo J, Campos S, Oliveiro SJ, Reis-Campos JC, Stegun RC, et al. Color changes of two thermoplastic resins used for flexible partial dentures Comput Methods Biomech Biomed Eng Imaging Vis 2020;1-6 DOI: 10.1080/21681163.2020.1771617.
5. Kostic M, Pejcic A, Igic M, Gligorijevic N Adverse reactions to denture resin materials Eur Rev Med Pharmacol Sci 2017;21(23):5298-305 DOI: 10.26355/eurrev_201712_13909.
6. Kurt A, Erkose-Genc G, Uzun M, Sarı T, Isik-Ozkol G The effect of cleaning solutions on a denture base material: elimination of Candida albicans and alteration of physical properties J Prosthodont 2018;27(6):577-83 DOI: 10.1111/jopr.12539.
7. Brondani MA, Siqueira AR A critical review of protocols for conventional microwave oven use for denture disinfection Community Dent Health 2018;1-7 DOI: 10.1922/cdh_4372brondani07.
8. Sousa TM, Farias OR, Batista AU, Medeiros ES, Santiago BM, Cavalcanti YW Effectiveness of denture microwave disinfection for treatment of denture stomatitis: a systematic review and meta-analysis Int J Dent Hyg 2021;19(1):62-77 DOI: 10.1111/idh.12477.
9. Popescu MC, Bita BI, Tucureanu V, Vasilache D, Banu MA, Avram AM, et al. Superficial and inner examination of a microwave-irradiated dental acrylic resin and its metal-polymer interface Microsc Microanal 2018;24(1):49-59 DOI: 10.1017/S1431927618000089.
10. Jaiswal P, Pande N, Banerjee R, Radke U Effect of repeated microwave disinfection on the surface hardness of a heat-cured denture base resin: an in vitro study Contemp Clin Dent 2018;9(3):446 DOI: 10.4103/ccd.ccd_271_18.
11. Fortes CB, Collares FM, Leitune VC, Schiroky PR, Rodrigues SB, Samuel SM, et al. Effect of disinfection techniques on physical-mechanical properties of a microwave-activated acrylic resin Polímeros 2018;28(3):215-19 DOI: 10.1590/0104-1428.004616.
12. Tsutsumi-Arai C, Arai Y, Terada-Ito C, Takebe Y, Ide S, Umeki H, et al. Effectiveness of 405-nm blue LED light for degradation of Candida biofilms formed on PMMA denture base resin Lasers Med Sci 2019;34:1457-64 DOI: 10.1007/s10103-019-02751-2.
13. Al-Qarni FD, Goodacre CJ, Kattadiyil MT, Baba NZ, Paravina RD Stainability of acrylic resin materials used in CAD-CAM and conventional complete dentures J Prosthet Dent 2020;123(6):880-87 DOI: 10.1016/j.prosdent.2019.07.004.
14. Zuo W, Feng D, Song A, Gong H, Zhu S Effects of organic-inorganic hybrid coating on the color stability of denture base resins J Prosthet Dent 2016;115(1):103-08 DOI: 10.1016/j.prosdent.2015.07.008.
15. Arana-Correa BE, Sepúlveda-Navarro WF, Florez FL, Urban VM, Jorge JH, Campanha NH Colour stability of acrylic resin denture teeth after immersion in different beverages Eur J Prosthodont Restor Dent 2014;22(2):56-61.
16. Ozyilmaz OY, Akin C Effect of cleansers on denture base resins' structural properties J Appl Biomater Funct Mater 2019;17(1):2280800019827797 DOI: 10.1177/2280800019827797.
17. Bohra PK, Ganesh PR, Reddy MM, Ebenezar AR, Sivakumar G Color stability of heat- and cold-cure acrylic resins J Clin Diagn Res 2015;9(1):ZC12 DOI: 10.7860/JCDR/2015/11620.5400.
18. Gruber S, Kamnoedboon P, Özcan M, Srinivasan M CAD/CAM complete denture resins: An in vitro evaluation of color stability J Prosthodont 2021;30(5):430-39 DOI: 10.1111/jopr.13246.
19. Motawea I, Gamal El Deen H, Eltayeb H Effect of denture cleansers on flexural strength, color stability, and surface roughness of flexible and microwave-cured acrylic resin Al-Azhar Dent J Girls 2017;4(3):311-23 DOI: 10.21608/adjg.2017.5272.
20. 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):913-19 DOI: 10.1111/jopr.12649.

21. Hong G, Li Y, Ma J, Zheng Y The effects of different denture cleaning methods on surface roughness and hydrophobicity of denture base materials Dent Mater J 2018;37(5):842-49 DOI: 10.4012/dmj.2017-392.
22. Machado AL, Giampaolo ET, Pavarina AC, Jorge JH, Vergani CE The effect of repeated simulated microwave disinfection on the strength of denture base resins J Prosthet Dent 2006;95(2):114-19 DOI: 10.1016/j.prosdent.2005.11.003.
23. Ribeiro DG, Pavarina AC, Dovigo LN, Giampaolo ET, Vergani CE Effect of thermal cycling on the microhardness of resins used for denture bases and for direct relining Braz Dent J 2009;20(4):336-41 DOI: 10.1590/s0103-64402009000400010.
24. Daneshkazemi AR, Jafari H, Karami Z Effect of denture cleansers on color stability of acrylic resins with different denture teeth Front Dent 2020;17(4):1-6 DOI: 10.18502/fid.v17i4.4646.
25. Singh K, Thakur M, Bansal N, Saini M, Anuradha P Effects of denture cleansers on color stability, surface roughness, and hardness of denture base materials: A comparative in vitro study Indian J Dent Sci 2020;12(4):202-07 DOI: 10.4103/ijds.ijds_41_20.
26. Amin FA, El Kholy MS, Ghanem A Color stability of two denture base materials immersed in a denture cleanser J Dent Health Oral Disord Ther 2018;9(1):36-42 DOI: 10.15406/jdhodt.2018.09.00331.
27. Lee JH, Jo JY, Kim SC, Ahn JS Color stability of denture base resins containing an organic–inorganic hybrid coating Materials (Basel) 2017;10(10):1162 DOI: 10.3390/ma10101162.
28. Bural C, Aktaş E, Deniz G, Kılıç HS Effects of oral cavity conditions on hardness, color stability, and water sorption of polyamide denture base material J Adv Prosthodont 2015;7(5):375-83 DOI: 10.4047/jap.2015.7.5.375.
29. Polyzois GL, Tarantili PA, Frangou MJ, Andreopoulos AG Effect of glutaraldehyde disinfectant solutions on some properties of heat-cured acrylic resins Int J Prosthodont 2000;13(2):150-54.
30. Zuo W, Song A, Zhu S The effects of oral rinsing agents on the color stability of denture base acrylic resins Materials (Basel) 2017;10(8):1013 DOI: 10.3390/ma10081013.
31. Mahajan R, Kumar V, Nair KV, Babaji P Effect of microwave sterilization on flexural strength and hardness of heat-cured acrylic resins J Contemp Dent Pract 2016;17(9):733-38 DOI: 10.5005/jp-journals-10024-1917.
32. Neppelenbroek KH, Pavarina AC, Vergani CE, Giampaolo ET, Machado AL Hardness of heat-polymerized acrylic resins processed in metallic and plastic flasks Braz Dent J 2005;16(2):109-15 DOI: 10.1590/S0103-64402005000200004.
33. Saavedra G, Neppelenbroek KH, Vergani CE, Mesquita MF, Giampaolo ET Hardness and impact strength of heat-polymerized acrylic resins: Effect of water bath and microwave post-polymerization treatments J Prosthodont 2007;16(3):263-69 DOI: 10.1111/j.1532-849X.2007.00201.x.
34. Davi LR, Neppelenbroek KH, Vergani CE, Miani PK, Machado AL Effect of post-polymerization heat treatments on the mechanical properties of acrylic resins Braz Dent J 2009;20(3):205-10 DOI: 10.1590/S0103-644020.

Authors' Contribution Statement

HR contributed to the conception, design, acquisition, analysis, and drafting of the manuscript. MR contributed to the conception, design, acquisition, interpretation of data, and drafting of the manuscript. AH contributed to the acquisition, analysis, interpretation of data, drafting of the manuscript, and final approval of the version to be published. MI contributed to the acquisition, analysis, drafting of the manuscript, and critical review of the manuscript. ZR contributed to the acquisition, analysis, drafting of the manuscript, and critical review of the manuscript. AH contributed to the analysis, interpretation of data, drafting of the manuscript, and critical review of the manuscript. Mahrukh contributed to the design, analysis, interpretation of data, drafting of the manuscript, and critical review of the manuscript. All authors are accountable for their work and ensure the accuracy and integrity of the study.

Confilct of Interest

Authors declared no conflict on interest

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Data Sharing Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.