Wettability of Heat Cured Acrylic Resin Interlaciated With Recycled Poly Methyl Methacrylate: An *In Vitro* Study

Nada Z. Mohammed, Amrah Y. Al-Jmmal, Mohammed M. Sadoon

Department of Prosthodontics Dentistry, University of Mosul, Mosul, Iraq

Abstract

Aim: This study was conducted to improve the wettability of heat cured acrylic resin by the incorporation of recycled poly methyl methacrylate (PMMA) as well as the assessment of how different aging times affected it. **Materials and Methods:** A total of 40 heat cured resin specimens were prepared and randomly divided into: The study and the control groups. Recycled PMMA was added to the study group at 1%, 3%, and 5% concentrations by volume. The wettability of control and study group specimens was assessed after being aged for different aging times by the assessment of wetting angle utilizing a sessile drop method and Image J analysis software. The collected data were analyzed statistically using IBM® Statistical Package for Social Sciences software (Armonk, NY, USA) version 23. Shapiro–Wilk, one-way analysis of variance, and Tukey's *post hoc* tests were employed for the statistical analysis at $P \leq 0.05$. **Results:** The addition of recycled PMMA significantly improves the wettability of acrylic resin ($P \leq 0.05$). The aging process had a significant impact on the wettability of control and study groups. The wettability of control and study groups increased with aging and this increase was directly associated with the aging time till 1 year of aging, their wettability started to decline although it remained less than that after 1 month of aging. **Conclusion:** It has been concluded that the incorporation of recycled PMMA significantly improves the wettability heat cured acrylic resin. The wettability of the aged control and study group was significantly affected by aging times.

Keywords: *Recycled poly methyl methacrylate, interpenetrating polymer network, wettability*

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Introduction

Teeth loss is one of the most popular problems that affect the oral cavity.[1] Partial or complete prostheses are the most common treatment options utilized to substitute the missing teeth.[2]

With the progress of polymer science, polymers that have interpenetrating polymer network (IPN) structures that are widely used in pharmaceutical and biomedical fields attract substantial attention to be utilized effectively in many dental applications.[3,4] The properties of such polymers were influenced by the physical and chemical properties of blended two or more polymers.[5] Heat-cured denture acrylic resin is a thermoplastic polymer with a wide range of applications, satisfactory working characteristics, accepted mechanical and chemical properties with inexpensive technical equipment.[6] It

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Address for correspondence: Dr. Amrah Y. Al-Jmmal, Department of Prosthodontics Dentistry, University of Mosul, Mosul 41002, Iraq.
E-mail: amra2012@uomosul.edu.iq

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has been regarded as one of the popular polymeric materials that have been utilized for the fabrication of denture bases of implant-supported prostheses, removable dentures, and maxillofacial prostheses.[7] Adequate degree of denture base materials wettability is regarded as a crucial characteristic of denture base that affects the bio-film formation and adhesion.[8] In addition to that it plays an important role in the success of prosthesis since it improves its adhesion to the underlying basal seat tissue.[9] The wettability could be defined as a liquid's capacity to maintain contact with a solid surface, it indicates the surface properties of that solid.[10] The wettability and correlation to, the surface free energy of the resin is a significant physico-chemical property that arises from the difference between the molecular energy at the resin surface and that in the bulk of resin and it affects the intermolecular interactions at the liquid/solid interface.[11]

Unfortunately, in certain cases, the characteristics of acrylic base prosthesis are not ideal in every aspect. With aging, the resorption of residual alveolar bone appears to be an endless process that harms the denture's retention and performance (e.g., chewing ability, speech, and esthetics).[12] That induces a progressive adverse change in the denture foundation area and thereby psychological stress that may negatively affect the quality of life in elderly denture wearers.[13] Therefore, it is essential to improve the association between the resorbed residual ridge and the ill-fitted denture by improving the wettability of the denture base and decreasing the effect of aging on it. Hence, there is a need to improve the wettability of the denture base in an attempt to satisfy its clinical use.[14] Physical and/or chemical modification of the polymeric matrix has been suggested by many researchers to overcome this shortcoming.[15-18] However, reviews of the impact of these modifications in correlation to the different aging times on the acrylic resin wettability are not yet available. Therefore, this study was conducted to evaluate the wettability of denture base resin after being interlaciated with recycled poly methyl methacrylate (recycled PMMA) as well as the assessment of how different aging times affected it.

The null hypothesis experienced in this research was that the wettability of heat cured acrylic resin is unaffected by the addition of recycled PMMA or the aging times.

Materials and Methods

The materials, which have been used in this research were:

- Heat cured acrylic resin (Spofadental, Jičín, Czech Republic).
- Recycled PMMA (Chain, Hong Kong).

Specimen's fabrication

Specimen's dimensions

Forty rectangular specimens with 20 mm × 15 mm × 1.5 ± 0.02 mm in length, width, and height respectively were made from heat cured denture base acrylic resin by conventional flasking, packing, finishing, and polishing procedures.[19] A short curing cycle in the thermostatically controlled water bath (heating to 100°C for 90 min then boiling for 45 min) was used according to the manufacturer's instruction.

Specimen's grouping

The prepared specimens are separated into:

Control group: 10 specimens.

Study group: 30 specimens incorporated at (1%, 3%, and 5%) with recycled PMMA by volume, 10 specimens for each concentration.

The specimens of control and study groups were subdivided into:

Not aged specimens: Five specimens from each group were immersed only in distilled water.

Aged specimens: Five specimens from each group were thermally aged for 10 cycles in a day at a temperature of 55° and 5° with a dwell time of half a minute. The thermal aging was done for different aging times of 1 month, 3 months, 6 months, 1 year, and 2 years periods (300 cycles, 900 cycles, 1800 cycles, 3650 cycles, and 3650 cycles, respectively).[20,21]

The wettability test procedure

The wettability of control and study group specimens was assessed by a sessile drop method utilizing ImageJ analysis software (National Institutes of Health, USA) by recording the wetting angle (contact angle) formed between the drop's tangent line and the specimen's surface. A micropipette was used to drop 15 mL of deionized water on the specimen's surface. The micropipette's tip was positioned 2 cm above the specimen's surface. The digital camera that was used to capture the image of the drop was fixed at about 20 cm away from the tip of the pipette. The mean of three readings for each specimen was considered.[22,23]

Statistical analysis of the collected data

With the IBM® Statistical Package for Social Sciences software (IBM Corp., Armonk, NY, USA), version 23 the obtained data was analyzed statistically. The normality test was used to check the obtained data utilizing the Shapiro–Wilk test. The nonsignificant results indicated homogeneity and normal distribution of the obtained data. Hence parametric analytic tests were used. Analysis of variance (ANOVA) analysis was used to verify if the wettability of the study group significantly differed from that of a control group or not. Tukey's *post hoc* test was employed to identify the level of significant difference. A *P* value of ≤0.05 was regarded as significant statistically.

Results

The wettability of the control group and study groups is listed in Table 1. The incorporation of recycled PMMA at (1%, 3%, and 5%) improves the wettability of the study group since there was a reduction in their measured wetting angle compared with the control group. The improved wettability of the study group was in direct relation with the amount of added recycled PMMA [Figure 1]. ANOVA analysis clearly indicated that the enhanced wettability of study group specimens was statistically significant in contrast to that of the control group either they were not aged or aged for all aging times. Except statistically none significantly increased in the wettability of study group specimens after 1 year of aging (3650 cycles) at *P* = 0.25 [Table 2].

Table 1: Mean ± SD and Tukey's test for the wetting angle of not-aged and aged control and study groups

Groups	Aging times				
	1 month Mean ± SD	3 months Mean ± SD	6 months Mean ± SD	1 year Mean ± SD	2 years Mean ± SD
Not aged Control	58.04 (6.4)^{A,a}	51.78 (2.6)^{A,bc}	46.08 (2.3)^{A,c}	46.89 (4.5)^{A,bc}	52.35 (2.5)^{A,ab}
1% recycled PMMA	51.14 (1.9)^{B,a}	51.13 (1.6)^{AB,a}	40.54 (2.0)^{B,b}	41.63 (1.1)^{B,b}	48.71 (2.3)^{AB,a}
3% recycled PMMA	54.57 (5.2)^{AB,a}	49.33 (2.1)^{AB,ab}	38.51 (0.6)^{B,c}	40.26 (1.3)^{B,c}	47.58 (3.1)^{B,b}
5% recycled PMMA	55.68 (5.2)^{AB,a}	47.02 (2.6)^{B,b}	37.02 (2.0)^{B,c}	40.06 (0.9)^{B,c}	46.91 (2.0)^{B,b}
Aged Control	55.18 (4.1)^{A,a}	46.88 (1.6)^{A,b}	46.81 (3.6)^{A,b}	47.79 (4.6)^{A,b}	48.64 (3.3)^{A,b}
1% recycled PMMA	50.67 (4.4)^{A,a}	46.91 (3.7)^{A,ab}	44.73 (1.3)^{AB,b}	45.19 (2.2)^{A,b}	45.06 (1.1)^{AB,b}
3% recycled PMMA	51.12 (6.3)^{A,a}	44.47 (0.9)^{A,b}	40.93 (2.8)^{B,b}	43.68 (4.0)^{A,b}	44.2 (2.6)^{B,b}
5% recycled PMMA	51.01 (2.3)^{A,a}	40.28 (1.6)^{B,b}	41.46 (2.4)^{AB,b}	43.05 (2.0)^{A,b}	43.58 (2.0)^{B,b}

SD = standard deviation.

Data denoted with capital letters (A–C) clarified a significant difference between the control and study groups (either they aged or not aged) at the same aging time according to Tukey's *post hoc* test ($P < 0.05$).

Data denoted with small letters (a–c) clarified a significant difference in the wettability of control and study groups (either they aged or not aged) at different aging times according to Tukey's *post hoc* test ($P < 0.05$)

Table 2: ANOVA analysis for the wettability of the study group incorporated with recycled PMMA as compared to that of the control group

Test	df	Not aged specimens		Aged specimens		
		F	p	F	p	
Between groups	3	3.03	0.06*	3.35	0.04*	After one month aging
Withingroups	16					
Total	19					
Between groups	3	4.3	0.02*	9.6	< 0.0001*	After three months aging
Within groups	16					
Total	19					
Between groups	3	22.8	< 0.0001*	5.3	0.01*	After six months aging
Within groups	16					
Total	19					
Between groups	3	8.3	0.01*	0. 5	0.25	After one year aging
Within groups	16					
Total	19					
Between groups	3	4.5	0.01*	4.2	0.02*	After two years aging
Within groups	16					
Total	19					

*Statistically significant at $P \leq 0.05$

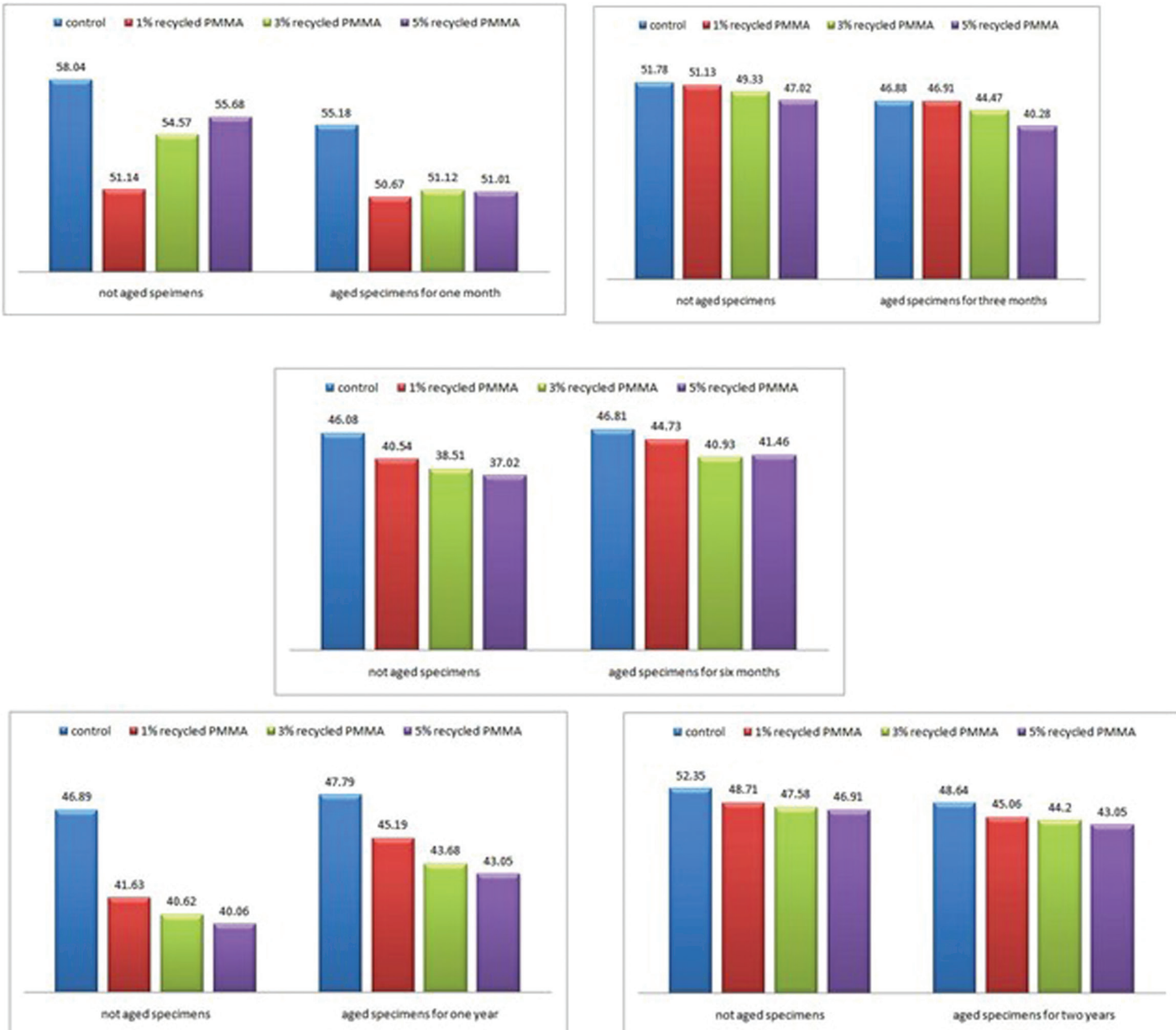

Figure 1: The effect of recycled PMMA on the wettability study group in contrast to the control group

Tukey's test showed that incorporation of recycled PMMA at 3% and 5% significantly improves the wettability of study group specimens either they are not aged or aged for 3 months, 6 months, 1 year, and 2 years. The wettability of not aged study group with 1% recycled PMMA significantly improved after 1 month of aging [Table 1].

According to the data obtained in this research, immersion in distilled water (without aging) improves the wettability of study and control groups. On the other hand, aging had a greater impact in increasing the wettability for most specimens of study and control groups compared with that of not aged. The wettability of study and control group specimens started to be decreased either they aged for 1 and 2 years (3650 and 7300 cycles, respectively), or not. Although it remains less than that after 1 month of aging. The greatest wettability (37.02) was achieved with the incorporation of recycled PMMA at 5% concentration after 6 months of aging [Figure 2].

ANOVA analysis explicated that the wettability of examined groups was significantly affected by the different aging times that were used in this research [Table 3]. Tukey's test displayed a significant increase in the wettability of examined study group specimens and control group specimens that were directly related to the aging time for almost aging times [Table 1].

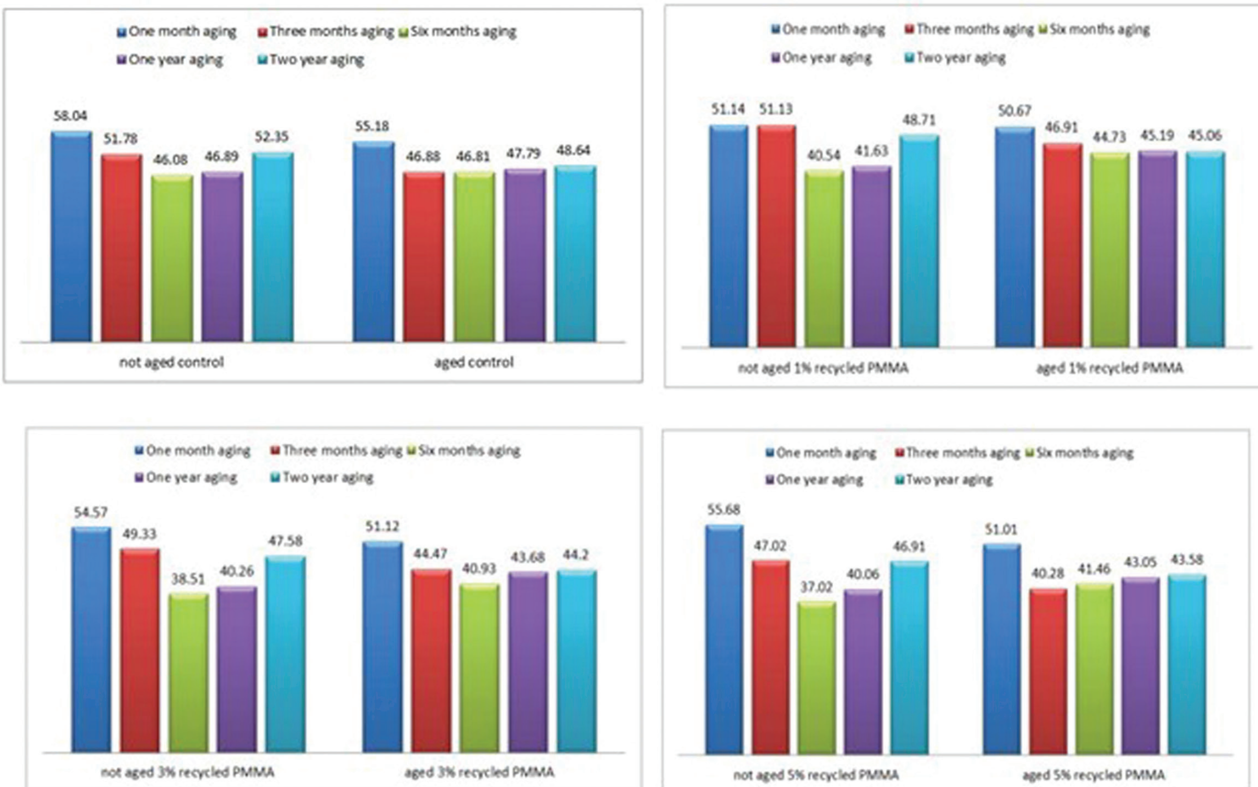

Figure 2: The effect of different aging times on the wettability of control and study groups

Table 3: ANOVA analysis for the wettability control and study groups after different aging times

	Test	df	Not aged specimens		Aged specimens	
			F	p	F	p
Control	Between groups	4	7.2	0.001*	6.7	0.01*
	Within groups	20				
	Total	24				
1% recycled PMMA	Between groups	4	35.6	< 0.0001*	7.5	0.01*
	Within groups	20				
	Total	24				
3% recycled PMMA	Between groups	4	21.1	< 0.0001*	5.5	0.004*
	Within groups	20				
	Total	24				
5% recycled PMMA	Between groups	4	29.6	0.0*	15.8	< 0.0001*
	Within groups	20				
	Total	24				

*Statistically significant at $P \leq 0.05$

Discussion

Good wettability is one of several factors that affect the retention of dentures.[21] IPNs resulted when polymeric networks of one or more of the blended polymers formed and interlaciated with other juxtaposition polymeric networks.[24] This strategy can be used to impart polymers with special properties in an attempt to satisfy their clinical application.[25,26]

The result of this research disclosed that the wettability of the study group incorporated with recycled PMMA at a concentration of (1%, 3%, and 5%) was improved since the measured values of wetting angles of these groups were less than that of the control group [Table 1]. This result could be explained according to the reason that the incorporated recycled PMMA affects the surface energy of the study group resulting from improved polymerization and reduced amount of residual monomer.[27,28] During the polymerization of denture base resin, its growing chains physically entangled with that of the incorporated recycled PMMA chains. Hence forming three-dimensional interlaciated polymeric networks like mat, which had significant consequences by impeding the leaking out of residual monomer consequently improving their degree of conversion.[29] This reason was in agreement with Akbari *et al.*[30] who related the improvement in the wettability after the addition of polyethylene glycol polymer to the change of the material surface charge. This result agreed with the conclusion reported by Chladek *et al.*,[31] who related the method of incorporating the filler and the resultant structural configuration of the polymer matrix to the morphological homogeneity of polymerized composites that in turn play an important role in determining their physico-chemical properties. This guide to the interpretation that altering surface features of acrylic resin materials changes the resin's surface energy and enhances their wettability.[32]

Statistical analysis showed that the wetting angle mean values of the study group incorporated with recycled PMMA either aged or not significantly decreased (for almost aging times), which indicates the improvement in their wettability in contrast to that of the control group. Therefore, the first section of the null hypothesis has been rejected [Table 2]. This result is in harmony with that reported by Cervino *et al.*,[33] modifying the chemical composition of the denture base materials might have a significant impact on its physical, mechanical, and as well as its biological characteristics.

About the effect of the amount of added recycled PMMA, the gained data of this research [Figure 1] demonstrated a reduction in the measured wetting angles of both aged and not aged study group specimens as the amount of added recycled PMMA increases, which indicates increasing their wettability when compared to the wettability of control group. Interpenetrating polymer network yields composite polymer with enhanced properties that are affected by its chemical composition and the degree of crosslinking, especially if the blended polymers are chemically compatible.[34]

The greatest wettability was achieved with the incorporation of recycled PMMA at 5% concentration. This result could be explained by the interaction of morphological and chemical alterations that occur, especially on the top layer of acrylic resin.[35] The decrease in the wetting angle measurements could be attributed to increased surface flaws like surface roughness and geometric flaws[36] Or it could be attributed to the heterogeneity of the chemical composition.[37]

ANOVA analysis showed a statistically significant effect (at $P \leq 0.5$) of the different aging times that were used in this research on the control and study groups' wettability [Table 3]. This result was agreed with another that revealed consistent results regarding the substantial effects of immersion time, especially in conjunction with thermal stress. Therefore, the second section of the null hypothesis has been rejected. This result could be explained according to the reason that wetting angle hysteresis could have resulted from the re-orientation of the polymer surface groups, which was provoked by the presence of liquid on it.[38] The wetting angle is a unique characteristic for each substance for the reason that it is related to the surface properties of both solid and liquid.[39] Or it could be explained according to Fathy *et al.*,[40] who reported that aging in water may cause swelling of the material indicating the entrance of water molecules into the polymeric matrix that might result in breaking the intermolecular bonding of the polymeric network leading to increase its roughness.[41] The wettability of the dental materials is influenced by their surface chemistry and roughness.[42] These explanations were in agreement with Rasan and Farhan[43] who reported that there is a direct relation between the surface roughness and the wettability.

The wettability of control and study group specimens was increased with aging for 1, 3, and 6 months (300 cycles, 900 cycles, and 1800 cycles, respectively). Their wettability started to decrease either they aged for 1 and 2 years (3650 and 7300 cycles, respectively) or not although it remained less than that after 1 month of aging [Figure 2]. Such an outcome might be clarified by the reason that water sorption increases the roughness of the specimen's surface.[44] This result was agreed with that obtained by Oyar *et al.*[45] Who concluded significant improvement in the wettability of roughened computer-aided design-computer-aided manufacturing PMMA specimens, especially after thermo-cycling. The stress induced by the heat of the aging process might increase the entrance of water into the polymeric matrix leading to the wide separation among the polymer chains.[46] Or it could be attributed increase in the number of polar groups resulting from the complimentary polymerization cycle.[47]

Using various commercially available denture base materials was a methodological limitation. Another limitation of this *in vitro* research was the difficulty in the simulation of the oral environment to the laboratory environment. Since the test specimens' surfaces were flat while the surfaces of dentures display irregularities, which are affected by the fluctuations of the mouth temperature, pH variations in a varied manner compared with that of flat tested specimens. Therefore, furthermore, *in vivo*, research studies using dentures in an attempt to clarify the impact of their interaction on the wettability of modified denture base materials were recommended.

Conclusion

The study group exhibited higher wettability compared with the study group, which was directly proportioned to the amount of added recycled PMMA. Therefore, it was recommended to construct the denture base from acrylic resin that was modified with recycled PMMA, particularly for the clinical cases where the retention was compromised. There was a positive correlation between the wettability of the study group and aging. Since their wettability increase as the aging time increases. It is possible to recommend similar searches to be done *in vivo* for proper and accurate simulation of the oral environment.

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Conflicts of interest

There are no conflicts of interest.

Authors contributions

Not applicable.

Ethical policy and Institutional Review board statement

As *In-Vitro* Study.

Patient declaration of consent

Not applicable.

Data availability statement

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