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Research article

Accuracy of repaired maxillary dentures from two different repairing techniques: In vitro study

Sara Zaky Mohamed [a,b], Mohamed Mohamady Ghobashy [c], Noha Taymour [d], Safinaz Abdelwahab [e,f], Viritpon Srimaneepong [g], Dinesh Rokaya [h,i,*]

[a] Department of Prosthodontics, Faculty of Dentistry, Zarqa University, Zarqa, 13110, Jordan
[b] Department of Prosthodontics, Faculty of Dentistry, Suez Canal University, Ismailia, Egypt
[c] Radiation Research of Polymer Chemistry Department, National Center for Radiation Research and Technology (NCRRT), Egyptian Atomic Energy Authority, P.O. Box 8029, Cairo, Egypt
[d] Department of Substitutive Dental Sciences, College of Dentistry, Imam Abdulrahman Bin Faisal University, P.O. Box 1982, Dammam 31441, Saudi Arabia
[e] Department of Dental Biomaterials, Faculty of Dentistry, Umm El Qura University, Makkah, Saudi Arabia
[f] Department of Dental Biomaterials, Faculty of Dentistry, Suez Canal University, Ismailia, Egypt
[g] Department of Prosthodontics, Faculty of Dentistry, Chulalongkorn University, Bangkok, 10330, Thailand
[h] Clinical Sciences Department, College of Dentistry, Ajman University, Ajman, United Arab Emirates
[i] Center of Medical and Bio-Allied Health Sciences Research, Ajman University, Ajman, United Arab Emirates

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ABSTRACT

Background: Denture fracture is a common problem with acrylic dentures. The fractured denture can be repaired using various techniques such as self-cure acrylic resin acrylic resin and fiber-reinforced acrylic resin.
Purpose: The purpose of this study was to compare the accuracy of dentures repaired with self-cure acrylic resin and fiber-reinforced acrylic resin processed using two different techniques (long-cure and microwave processing).
Materials and methods: A total of 20 maxillary complete dentures were processed with two techniques; heat (long cycle) processing (10 dentures) and microwave processing (10 dentures). The maxillary cast and denture surface were scanned with Medit intraoral (Medit i700, Medit, South Korea) and STL files were created. Then, the dentures were sectioned at the midline and repaired using self-cure acrylic resin and fiber-reinforced acrylic resin and scanned with Medit intraoral. Finally, adaptation deviations were analyzed from computer software (Geomagic Control X, 3D Systems Inc., USA). The adaptation deviations in each group (long cure and microwave) were compared using an Independent T-test. Two-way ANOVA was done to see whether curing techniques and repairing methods affect the accuracy of repair. A P-value of 0.05 was considered significant.
Results: The adaptation deviation was slightly higher in the fiber-reinforced acrylic resin group (0.565 ± 0.093) than in the self-cure acrylic resin group (0.536 ± 0.066). However, there was no statistical difference in the adaptation deviations of repaired dentures with self-cure acrylic resin and fiber-reinforced acrylic resin in the long-curing (P-value 0.245) and the microwave (P-value 0.638). Similarly, the adaptation deviation was slightly higher in the long-curing group (0.577 ±

* Corresponding author.
E-mail addresses: szaky@zu.edu.jo (S.Z. Mohamed), Mohamed.ghobashy@eaea.org.eg (M.M. Ghobashy), ntyoussef@iau.edu.sa (N. Taymour), safinaz30@gmail.com (S. Abdelwahab), viritpon.s@chula.ac.th (V. Srimaneepong), d.rokaya@ajman.ac.ae (D. Rokaya).

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0.075) than in the microwave group (0.524 ± 0.079). However, there was a statistically significant difference in the adaptation deviation of repaired dentures between long-curing and microwave techniques with self-cure acrylic resin (P-value 0.016) but no difference in fiber-reinforced acrylic resin (P-value 0.127). The result of Two-way ANOVA shows that there is no statistically significant interaction between curing techniques (long curing and microwave) and repairing methods (self-cure acrylic resin and fiber-reinforced acrylic resin) for adaptation deviations (P-value 0.646). However, the curing techniques show statistically significant differences (P-value 0.039).

Conclusion: Acrylic dentures can be repaired with self-cure resin or fiber-reinforced self-cure resin using various processing methods. The accuracy of the denture after repair is unaffected by the repairing method (self-cure acrylic resin and fiber-reinforced acrylic resin) but the accuracy of the denture after repair is affected by the curing techniques (long-curing and microwave). In self-cure resin, the microwave processing showed higher adaptation deviation and less accuracy, whereas the long-curing processing showed lower adaptation deviation and high accuracy.

1. Introduction

Polymethyl methacrylate acrylic resin (PMMA) has various applications in prosthetic dentistry, i.e. for the fabrication of various dentures, artificial teeth, obturators, temporary or provisional crowns, and for the repair of dental prostheses [1,2]. The polymerization reaction of acrylic resin is initiated and activated by generating a free radical either chemically or with energy (heat, light, or microwaves). Heat activation of acrylic resin is the conventional method for processing acrylic resin using long or short cycles. In microwave processing, the resin is subjected to a brief curing cycle of 3 min at 500–600 W/cycle of radio waves. The monomer content is reduced proportionately with the polymerization degree [3,4].

The disadvantage of acrylic resin is it has less flexural and impact strength which can result in the fracture of the denture [1,5]. In addition, PMMA can swell and dissolve in various organic solvents due to its easily hydrolyzable ester groups [6,7]. It has been shown that denture fracture occurs in 64 % of cases and 68 % of dentures fracture within 3 years after they were provided [8]. Denture fractures because of flexural fatigue or impact. Flexural fatigue results due to repeated bending of a material, whereas catastrophic failure or impact failure is one of the mechanical material's mechanical limitations. Constant stress cycles combined with inadequate denture support result in stress concentration and fatigue failure [9,10]. Midline fracture is commonly seen in the maxillary dentures and the fracture runs through the labial frenulum owing to tensile stress from the masticatory forces.

Fractured dentures can be repaired without making new dentures [11]. When repairing, dimensional accuracy and strength are important requirements. The repaired denture should have enough strength and reproduce surface details [12]. The retention of the denture is also dependent on denture base adaptation after repair [13,14]. Denture repair can be done from various materials including heat-, auto/self-, visible-light-, and microwave-polymerized acrylic resin using various techniques [15–18]. Repairing fractured dentures with self-cure acrylic resins is a common method as it is less expensive and less time-consuming. The combination of self-cure acrylic resin with a variety of reinforcing elements, including glass fiber and metal wire, and commonly used in denture repair. Denture repaired with self-cure acrylic resin has certain drawbacks such as they have weak fracture strength, residual monomer content, low dimensional accuracies, and a high chance of re-fractures at the repaired site [19]. Glass fiber can be incorporated as reinforcing mesh in denture repair [20]. The fiber-reinforced acrylic resin has a substantial reinforcing impact, has less cytotoxicity, and can bend without fracture. The superimposition of the denture to evaluate the base adaptation of the denture base can be used to assess the accuracy of the denture [21–23]. The lower the adaptation, the higher the accuracy [23,24].

Since various materials and techniques can affect the accuracy of the repaired denture, our research question was 'Is there a difference in the accuracy of dentures repaired with self-cure acrylic resin and fiber-reinforced acrylic resin in two different techniques (long-cure processing and microwave processing)?' Hence, the objective of this study was to compare the accuracy of dentures repaired with self-cure acrylic resin and fiber-reinforced acrylic resin processed using two different techniques (long-cure processing and microwave processing).

Table 1
Materials used in this study.

Materials	Composition	Company
Acrostone	Conventional heat cure acrylic resin	Acrostone, Acrostone industrial zone, Salam city, Egypt
Self-cure acrylic resin	Specially designed for microwave processing	Acrostone, Acrostone industrial zone, Salam city Egypt
Acrylic teeth	Acrylic resin	Acrostone, Acrostone industrial zone, Salam city Egypt
Fiber mesh (3 mm)	Ultra-high-moleculer weight PE	Sanadent, Romania

2. Materials and methods

2.1. Complete denture fabrication and scanning

In this study, acrylic maxillary complete dentures with acrylic teeth were used. A total sample of 20 dentures was used by taking references from previous similar studies to obtain a statistical power of 95 % [25,26]. Table 1 shows the different materials used in this research. At first, dental stone casts were fabricated from the standardized edentulous maxillary jaw molds with type III stone (GH dental stone, Egypt) and trimmed. In group A, 10 complete dentures were fabricated using a conventional technique from the heat cure polymerization of acrylic resins with artificial acrylic teeth (Acrostone, Egypt). The heat cure resins were cured using a long cycle in a hot water bath at 72 °C for 6.5 h. In group B, 10 complete dentures were processed using a microwave (800W, Panasonic) for 3 min. All dentures were finished and polished using a pumice power.

The maxillary casts (Fig. 1) and denture surface were scanned with Medit intraoral (Medit i700, Medit, South Korea) and STL files were created.

2.2. Sectioning and repair of the complete denture

At first, a midline was drawn on the maxillary dentures. The dentures were sectioned in the midline into two halves using a metal disc and a gap of 2 mm was made.

For repairing the sectioned dentures, the edges were rounded and beveling was created along the fracture line with dimension (1 mm × 0.5 mm). Then, each half of the denture was positioned on the corresponding molds, and the two halves of the denture were aligned together using a sticky wax [18].

Before repairing, the wax was removed properly without affecting the connection. Then, half (10 dentures) were repaired with self-cure acrylic resin and another half (10 dentures) were repaired with fiber-reinforced acrylic resin. For the dentures repaired using self-cure acrylic resin, self-cure acrylic resin was used using conventional technique following the manufacturer's instructions for resin preparation and application at the site of the fracture. For the dentures repaired with fiber-reinforced acrylic resin, at first, slots (1.5 × 2 mm) were created. Then, fiber mesh (0.5 mm × 5 mm) was soaked in monomer for 20 min) and they engaged into the slots and subsequently, the acrylic resin was applied. Finally, the repaired areas of the dentures were polished using a handpiece and fine sandpaper.

The denture surface after the repair was scanned with Medit intraoral (Medit i700, Medit, South Korea) and STL files were created.

2.3. Superimposition

The STL file for each repaired denture of each technique for each repairing method was superimposed on the STL file of the associated cast using the software (Geomagic Control X, 3D Systems Inc., USA) as shown in Figs. 2 and 3. The adaptation deviations of the repaired dentures were calculated as done by the previous study [24]. The denture intelgo surface for each repaired denture was mapped separately at the mentioned points. Measurements and surface matching were used to evaluate adaptation deviations between the repaired dentures in comparison to the casts along the midline fracture. Measurements were taken at 23 places for each denture, 7 points at the incisive papilla area, and 16 along the denture midline (Figs. 2 and 3). The points were selected randomly at the repaired sites to evaluate the accuracy. Color surface maps were created to demonstrate the extent to which the denture base fits the cast (Fig. 3). The red refers to more than 1 mm adaptation deviation, yellow refers to 0.4–0.6 mm adaptation deviation, green refers to 0 mm adaptation deviation, and blue refers to −1 mm adaptation deviation Fig. 2A, B, 3A, and 3B. Subsequently, the accuracy of the

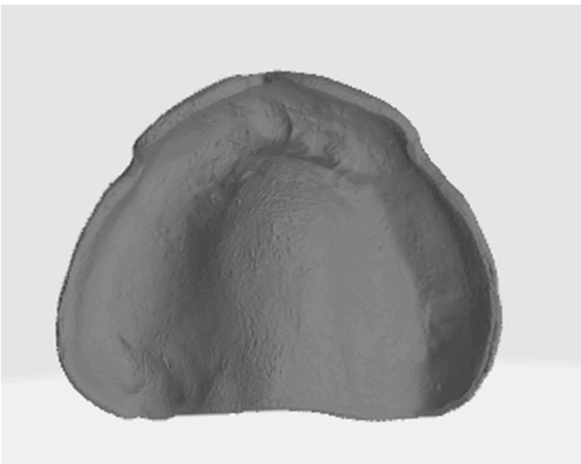

Fig. 1. Scanned image of the maxillary dental cast using Medit i700.

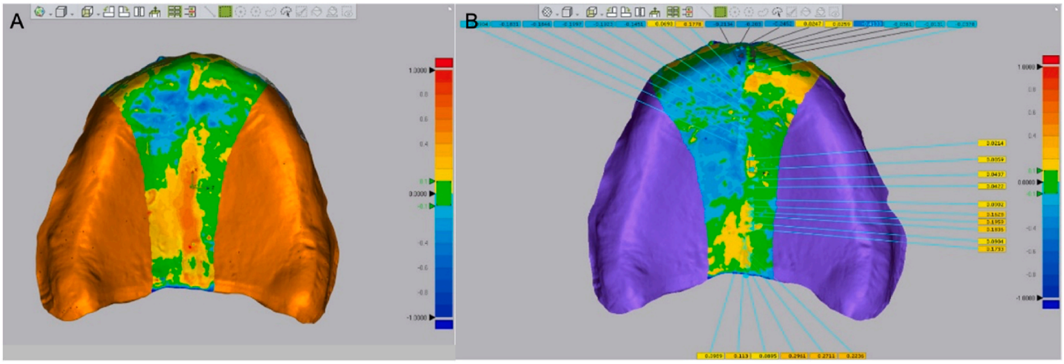

Fig. 2. Mapping of the fracture line area of the maxillary denture. Red refers to more than 1 mm adaptation deviation, yellow refers to 0.4–0.6 mm adaptation deviation, green refers to 0 mm adaptation deviation, and blue refers to −1 mm adaptation deviation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

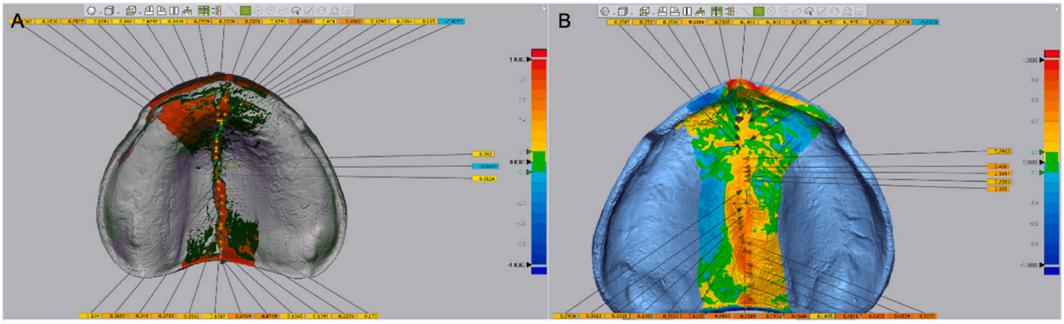

Fig. 3. Measurement of differences in incisive area and midline. Mapping of the fracture line area of the maxillary denture. Red refers to more than 1 mm adaptation deviation, yellow refers to 0.4–0.6 mm adaptation deviation, green refers to 0 mm adaptation deviation, and blue refers to −1 mm adaptation deviation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

repaired dentures with self-cure acrylic resin and fiber-reinforced acrylic resin processed using two different techniques (long-cure and microwave processing) was calculated.

2.4. Statistical analysis

The adaptation deviations of the repaired dentures were analyzed using SPSS software (Version 22 IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated where calculated. The lower the adaptation, the higher the accuracy. The Adaptation deviations of the repaired dentures using self-cure acrylic resin and fiber-reinforced acrylic resin in each group (long cure and microwave) were compared using an Independent T-test. Two-way ANOVA was done to see whether curing techniques and repairing methods affect the accuracy of repair. A P-value of 0.05 was considered significant.

3. Results

3.1. Curing methods

The descriptive statistics of the adaptation deviations of the repaired dentures with self-cure acrylic resin and fiber-reinforced acrylic resin are shown in Table 2. It showed that the adaptation deviation was slightly higher in the fiber-reinforced acrylic resin

Table 2
Descriptive statistics of the adaptation deviations (mm) of repaired dentures with self-cure acrylic resin and fiber-reinforced acrylic resin.

Repairing method	Mean	SD	Standard error	95 % Confidence interval for mean		Minimum	Maximum
				Lower bound	Upper bound		
Self-cure acrylic resin (n = 10)	0.536	0.066	0.015	0.505	0.567	0.413	0.641
Fiber-reinforced acrylic resin (n = 10)	0.565	0.093	0.021	0.521	0.609	0.400	0.699

SD = Standard deviation.

group (0.565 ± 0.093) than in the self-cure acrylic resin group (0.536 ± 0.066). However, there was no statistical difference in the adaptation deviations of repaired dentures with self-cure acrylic resin and fiber-reinforced acrylic resin in the long-curing (P-value 0.245) and the microwave (P-value 0.638) (Table 3).

3.2. *Curing techniques*

Similarly, the descriptive statistics of the adaptation deviations of repaired dentures in the long-curing and microwave techniques are shown in Table 4. It showed that the adaptation deviation was slightly higher in the long-curing group (0.577 ± 0.075) than in the microwave group (0.524 ± 0.079). However, there was a statistically significant difference in the adaptation deviation of repaired dentures between long-curing and microwave techniques with self-cure acrylic resin (P-value 0.016) but no difference in the fiber-reinforced acrylic resin (P-value 0.127) (Table 5). The microwave processing showed higher deviation and less accuracy, whereas the long-curing processing showed lower deviation and high accuracy.

In Table 6, the result of Two-way ANOVA shows that there is no statistically significant interaction between curing techniques (long curing and microwave) and repairing methods (self-cure acrylic resin and fiber-reinforced acrylic resin) for adaptation deviations (P-value 0.646). However, the curing techniques show statistically significant differences (P-value 0.039).

4. Discussion

The dimensional accuracy and stability of acrylic resin dentures may be affected by the processing method, the thickness of the bases, the shape, and size of the dentures, the materials used for repairs, and other factors [13]. Because insufficient heat is present during polymerization to create stress, denture accuracy is not impacted when applying self-cure acrylic resin. Long-cycle (heat-cured repairs), on the other hand, necessitate denture flasking and may deform the denture by releasing tension during processing [27,28].

In this study, we compared the adaptation deviation and accuracy of repaired dentures with self-cure acrylic resin and fiber-reinforced acrylic resin processed using two different techniques. There was no statistical difference in the adaptation deviations of repaired dentures with self-cure acrylic resin and fiber-reinforced acrylic resin in the long-curing processing (P-value 0.245) and the microwave processing (P-value 0.638). Hence, the accuracy of the denture after repair is unaffected by the repairing method (self-cure acrylic resin and fiber-reinforced acrylic resin).

In addition, there was a statistically significant difference in the adaptation deviation of repaired dentures between long-curing and microwave techniques with self-cure acrylic resin (P-value 0.016) but no statistically significant difference in fiber-reinforced acrylic resin (P-value 0.127). Hence, the accuracy of the denture after repair is affected by the curing techniques (long-curing and microwave). In self-cure resin, the microwave processing showed higher adaptation deviation and less accuracy, whereas the long-curing processing showed lower adaptation deviation and high accuracy. The result of Two-way ANOVA shows that there is no statistically significant interaction between curing techniques (long curing and microwave) and repairing methods (self-cure acrylic resin and fiber-reinforced acrylic resin) for adaptation deviations (P-value 0.646).

Various research studies have been conducted to explore the influence of various repair materials and techniques on flexural strength, but few studies have investigated the accuracy of fitting surfaces following denture repair. Acrylic resin is the most often used material for repairing partial and complete dentures, less this material has certain restrictions [29]. This research was done to compare the accuracy before and after the repair of dentures with self-cure acrylic resin and fiber-reinforced acrylic resin processed using different techniques (long-cure and microwave processing) and we found that there was no significant difference in the repair of dentures with self-cure acrylic resin and fiber-reinforced acrylic resin in both groups. In addition, while repairing the fiber-reinforced acrylic resin group, slots were made to create space for glass fiber to ensure proper contact and embedding of the fiber. Fibers have a reinforcing function and add strength to the fractured denture and prevent further fracture [30,31]. Additionally, the surface treatment of the fiber such as salinizing can improve the proper chemical bond between the glass fiber and the acrylic [32,33]. In our study, salinizing was not done but the glass-fibers were roughened mechanically with sandpaper.

This is consistent with research that used repairing dentures with a self-cure acrylic resin supplied with superior denture accuracy. The low heat generated by the self-cure acrylic resin most likely prevented residual tension from being released into the denture base material, thereby decreasing denture distortion. Superior adaptation was obtained using the self-cure acrylic resin repair method, which was more successful in adapting to the other methods and was not different from them [34,35]. Research on repairing methods demonstrated a statistically significant difference between the materials used to join the dentures for repair [36]. These results agree with this study showing significant differences before and after repair using both techniques.

Improving denture repair strength has been investigated using reinforced materials such as metal wires, fibers, fillers, and micro-fillers and it has resulted in repairing dentures with reasonable mechanical properties, although these materials have improved the

Table 3
Comparison of adaptation deviations (mm) of repaired dentures with self-cure acrylic resin and fiber-reinforced acrylic resin in various curing techniques.

Curing Technique	Self-cure acrylic resin (Mean ± SD)	Fiber-reinforced acrylic resin (Mean ± SD)	P-value
Long-curing (n = 10)	0.557 ± 0.069	0.597 ± 0.080	0.245
Microwave (n = 10)	0.515 ± 0.058	0.533 ± 0.098	0.638

SD = Standard deviation. Statistically significant at P-value <0.05.

Table 4
Descriptive statistics of the adaptation deviations (mm) of repaired dentures in the long-curing and microwave techniques.

Curing technique	Mean	SD	Standard error	95 % Confidence interval for mean		Minimum	Maximum
				Lower bound	Upper bound		
Long-curing (n = 10)	0.577	0.075	0.017	0.542	0.613	0.413	0.698
Microwave (n = 10)	0.524	0.079	0.018	0.487	0.561	0.400	0.688

SD = Standard deviation.

Table 5
Comparison of adaptation deviations (mm) of repaired dentures in long-curing and microwave techniques of various repairing methods.

Repairing method	Long-curing (Mean ± SD)	Microwave (Mean ± SD)	P-value
Self-cure acrylic resin (n = 10)	0.557 ± 0.069	0.515 ± 0.058	0.016[a]
Fiber-reinforced acrylic resin (n = 10)	0.597 ± 0.080	0.533 ± 0.098	0.127

SD = Standard deviation.
[a] Statistically significant at P-value <0.05.

Table 6
Results of Two-way ANOVA for adaptation deviations of repaired dentures in various curing techniques and repairing methods.

Source	Type III sum of squares	df	Mean square	F	P-value
Corrected model	0.038[a]	3	0.013	2.058	0.123
Intercept	12.136	1	12.136	1.990E3	<0.0001
Curing technique	0.028	1	0.028	4.597	0.039*
Repairing method	0.008	1	0.008	1.362	0.251
Curing technique* Repairing method	0.001	1	0.001	0.215	0.646
Error	0.220	36	0.006		
Total	12.393	40			
Corrected total	0.257	39			

[a] R Squared = 0.146 (Adjusted R Squared = 0.075). Statistically significant at P-value <0.05.

strength of denture repairs, researchers doubted having the same accuracy before and after repair [37]. Additionally, utilizing a small size gap for preparation had less effect dimensionally on dentures in this study, which corresponds with the study that stated that the gap between the two cracked segments should be 3 mm or less to minimize the bulk of repair material used. The lower the bulk of the repair material, the less polymerization shrinkage there will be [12].

It is suggested that the processing technique, thickness of the bases, and form and size of the dentures can all affect the dimensional correctness and stability of acrylic resin dentures [38]. The edge profile of the healing surface affects the repaired joint's fracture strength. For additional strength, several edge profiles are added including butt joints, rabbet, inverse rabbet, lap, joints with mechanical retention, and 45° bevel rounded [39]. The 45° bevel design modifies the interfacial stress pattern toward shear stress instead of the more damaging tensile stress, increasing the interfacial bond area. In addition, comparable findings have been reported in cases where the denture base resin contracts and expands in various locations. It has also been demonstrated that stress concentration can be reduced by using fiber-reinforced self-cure resin with a 45° bevel joint design for the damaged surfaces and surface preparation [40].

The resistance to fracture propagation of self-cure increased significantly when reinforced with glass fiber, although this effect was not impacted by the denture base's adaption [41]. In addition, Nagai et al. [30] reported that the glass fibers improved significantly the modulus of elasticity of the repaired acrylic resin. Also, it revealed that glass fibers have stopped the lengthening of the resin matrix during the flexural strength test in scanning electron microscopy which resulted in improvement in the flexural strength of the specimens.

In this research, we compared the adaptation deviation and accuracy of repaired dentures with self-cure acrylic resin and fiber-reinforced acrylic resin processed using two different techniques (long-cure and microwave processing) using 3D computer software. This is the strength of our study. The complete dentures were fabricated from the same acrylic to avoid bias. Finally, the limitation of this research is that in this study, we considered one type of fracture edge profile. In addition, the properties of duplicating mold material can affect the accuracy. The results were not compared among the two processing methods. Further studies can be done to study various types of fractures and various types of acrylic resin and techniques.

5. Conclusions

Within the limitation of this research, we found the adaptation deviation and accuracy of the repaired dentures are unaffected by the repairing method using self-cure acrylic resin and fiber-reinforced acrylic resin but the accuracy of the denture after repair is affected by the curing techniques (long-curing and microwave). In self-cure resin, the microwave processing showed higher adaptation deviation and less accuracy, whereas the long-curing processing showed lower adaptation deviation and high accuracy.

CRediT authorship contribution statement

Sara Zaky Mohamed: Writing – review & editing, Writing – original draft, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mohamed Mohamady Ghobashy:** Writing – original draft, Visualization, Validation, Resources, Methodology, Formal analysis, Data curation. **Noha Taymour:** Writing – review & editing, Writing – original draft, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation. **Safinaz Abdelwahab:** Writing – review & editing, Writing – original draft, Visualization, Resources, Methodology, Investigation, Conceptualization. **Viritpon Srimaneepong:** Writing – review & editing, Visualization, Validation, Supervision, Formal analysis, Data curation. **Dinesh Rokaya:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Formal analysis, Data curation, Conceptualization.

Ethics statement

Not applicable.

Data availability Statement

The data presented in this study are available on request from the corresponding author.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dinesh Rokaya is an Editorial Board Member of Heliyon. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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