A study to evaluate the transverse strength of repaired acrylic denture resins with conventional heat-cured, autopolymerizing and microwave-cured resins: An *in vitro* study

Manisha Agarwal, Ajay Nayak, R. B. Hallikerimath
Department of Prosthodontia, KLES Institute of Dental Sciences, Belgaum, India

For correspondence
Dr. Manisha Agarwal, Department of Prosthodontia, KLES Institute of Dental Sciences, Belgaum, India.
E-mail: manishaagarwal_2000@yahoo.com

STATEMENT OF PROBLEM: Acrylic resin dentures are susceptible to fracture after clinical use; it is an unresolved problem in prosthodontics. The repair procedure should be simple, strong and should not affect dimensional accuracy. **PURPOSE:** This study evaluated the transverse strength of a conventional heat-polymerized (DPI-Heat Cure, Group I) acrylic resin and a microwave-polymerized (Acron MC, Group III) acrylic resin that were repaired with the same resins and with an autopolymerized acrylic resin (DPI-Repair Resin, Group II). **MATERIALS AND METHODS:** Sixty rectangular specimens of Groups I and III and 15 of Group II were manufactured and stored in distilled water at room temperature for 7 days. Forty-five specimens of Groups I and III were selected randomly. Fifteen specimens of each material remained intact (control), 15 from each group were sectioned in the middle to create a 10-mm gap and repaired with the materials of Groups I, II and III. After 7 days of storage at room temperature, transverse strength of the repaired and intact specimens was measured using a 3-point bending test. The nature of failure was noted as adhesive, cohesive or mixed. Student's unpaired *t*-test was performed. **RESULTS:** The intact microwave-cured resin (Group III) showed the highest transverse strength value (90.25 MPa), which was significantly stronger ($P < 0.05$) than other materials tested. No statistically significant difference was noted amongst the repaired groups. Repaired specimens exhibited three types of failure: adhesive (15.56%), cohesive (15.56%) and mixed being the maximum (68.89%). **CONCLUSION:** Microwave-polymerized resin showed the highest intact transverse strength, and autopolymerized resin exhibited repair strength similar to those found for the conventional heat- and microwave-polymerized acrylic resins.

Key words: Acrylic resin, failure, transverse strength

INTRODUCTION

Loss of teeth is a matter of great concern to a majority of people, and their replacement by artificial substitutes, such as dentures, is vital to the continuance of normal life. One of the problems encountered in the provision of such prosthesis is whether the limitations of strength and design meet the functional demands of the oral cavity.[1]

Generally, the most common causes of fracture are faults in denture fabrication, i.e. poor fit, lack of balanced occlusion, limitations in denture base material, improperly contoured occlusal plane, high frenal attachment, thickness of denture base, etc.[2] The ratio of upper and lower denture fracture has been found to be 2:1.[3]

Denture repairs involve joining two parts of a fractured denture with a denture repair material.[1] Satisfactory repairs must have adequate strength, be easily and rapidly completed, match the original colour of the material, retain its dimensional accuracy[4] and restore the original strength of the denture so as to avoid further fracture;[5] but this is not always possible.

So, the purpose of this study was to evaluate the transverse strength of intact and repaired specimens of conventional heat-cured and microwave-cured resins repaired with the same or autopolymerized resin; and to determine the nature of failure of repaired specimens as adhesive, cohesive or mixed.

Objectives of the study

- To study the transverse strength of intact specimens of conventional heat-cured, autopolymerized and microwave-cured resins.
- To study the transverse strength of repaired specimens of conventional heat-cured and microwave-cured resins repaired with the same or autopolymerized acrylic resin.

- To determine the nature of failure of repair as adhesive, cohesive or mixed.
- To determine the ideal material of repair for clinical use.

MATERIALS AND METHODS

The study was carried out in the Department of Prosthodontics, KLES Institute of Dental Sciences, Belgaum.

Selection of experimental design

Metal specimens of dimension 65 × 100 × 3.3 mm were prepared by a tool manufacturer.

Preparation of experimental samples

1-a. Preparation of molds for fabrication of intact acrylic patterns

Type-III dental stone (Everest) was used to invest metal dies [Figure 1]. Before investing, the metal dies were coated with a thin layer of petroleum jelly (Bioline) for easy removal of the die once the dental stone had set.

For easy removal of the metal dies and to avoid fracture on the molds, space was created on one side of the metal dies in the first pour of dental stone. It allowed for easy retrieval of the metal dies once the 2nd pour had set completely.

1-b. Packing

(i) *Heat cure (DPI heat cure acrylic):* The mix of polymethylmethacrylate was prepared in a mixing jar according to the manufacturer's instructions. Each flask was packed with acrylic resin once it reached the dough stage. Excess material (flash) was removed during trial closure.

(ii) *Microwave cure (Acron MC):* The mix was prepared in a mixing jar according to the manufacturer's instructions. Each flask was packed with resin once it reached the dough stage. Flash was removed during the trial closure.

(iii) *Autopolymerized resin (DPI-Repair Resin cold cure):* The mix was prepared again according to the manufacturer's instructions. When resin reached the free flowing stage, it was packed into the gypsum molds created, and pressure was applied using the clamps.

1-c. Processing

(i) *Heat cure:* Flasks were immersed in cold water in an acrylizer (Confident) gradually to be boiled for not less than 30 min and then left in boiling water for 30 min. These flasks were allowed to bench-cool before deflasking.

(ii) *Microwave cure:* After bench-curing, the flasks were transferred to the microwave oven (National) for processing according to the manufacturer's instructions (500 W for 3 min) [Figure 2]. The flasks were allowed to bench-cool before deflasking.

1-d. Retrieval of intact acrylic pattern, trimming and polishing

Following the bench-cooling procedure, the flasks were opened and acrylic patterns were carefully retrieved. Excess flash was trimmed using a laboratory micromotor (AC motor) and polished. Each sample was marked by its material group and sample number.

1-e. Storage

The samples were stored in distilled water (Swastik) for 7 days at room temperature before the repair procedure.

Group I - Sixty samples of conventional heat-cured material

Group II - Fifteen samples of cold cure

Group III - Sixty samples of microwave cure

2. Preparation of fractured samples

(i) After storage in distilled water for 7 days at room temperature, the samples were fractured at midline using a silicon carbide bur. A gap of 10 mm was created between the fractured specimens by removing the acrylic resin.

(ii) *Preparation of the fractured surfaces:* The fractured surfaces were cleaned with distilled water and dried with a blast of air. The surfaces were then chemically etched with acetone (Acetone; Jyoti Laboratory Chemicals) for 30 s before repairing.

(iii) Molds were prepared in the same manner as for intact acrylic pattern.

(iv) The fractured specimens were returned to the prepared molds in such a way that 10 mm gap [Figure 3] existed between the two sections of the specimens. Respective material according to the group (heat cure, cold cure and microwave cure) was added to the gap created in a free flowing stage, thus filling the space between the sections. The joint space was slightly overfilled to allow for polymerization shrinkage and finishing. The respective materials were processed as previously described according to the manufacturer's directions.

(v) The retrieved specimens were polished to a final dimension of 65 × 10 × 3.3 mm using a drilling machine and polished. These specimens were again stored in distilled water for 7 days at room temperature.

Group I - Fifteen samples of conventional heat-cured resin as control

Group IA - Fifteen samples repaired with conventional heat-cured resin

Group IB - Fifteen samples repaired with cold-cured resin

Figure 1: Investing of metal dies

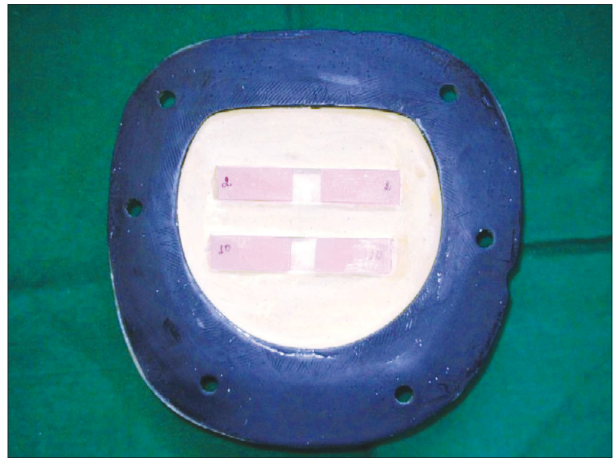

Figure 3: Fractured specimens with 10 mm gap

Figure 2: Microwave oven with fibre flasks

Figure 4: Tri-axial loading frame for testing transverse strength

Group IC - Fifteen samples repaired with microwave-cured resin

Group III - Fifteen samples of microwave-cured resin (Acron MC) as control

Group IIIA - Fifteen samples repaired with conventional heat-cured resin

Group IIIB - Fifteen samples repaired with cold-cured resin

Group IIIC - Fifteen samples repaired with microwave-cured resin

3. Measurement of transverse strength

Transverse strength of the repaired and intact specimens was measured using a 3-point bending test in a tri-axial loading frame with a 100-kg load cell at a cross-head speed of 4.4 mm/min [Figure 4].

Transverse strength of each specimen was determined using the formula:

$$S = \frac{3WL}{2bd2}$$

where W is the fracture load, L is the distance between the supports (50.0 mm), b is the specimen width and d is the specimen thickness.

4. Nature of fracture

The nature of fracture was noted as adhesive, cohesive or mixed by the visual inspection of fractured specimens.

It was noted as adhesive fracture if the fracture occurred only at the interface of the repair material and the main material.

It was noted as cohesive fracture if it occurred entirely in the repair material.

It was noted as mixed fracture if the fracture line traversed both at the interface and at the repair material.

The obtained data was subjected to statistical analysis using the Student's unpaired t-test.

RESULTS

Table 1 represents information on the transverse strength of intact specimens of Groups I, II and III, which showed that maximum strength was found with microwave-cured resin. The order was Group

III (mean 105.73), Group I (mean 90.25) and finally Group II (mean 85.08).

Table 2 shows that there was no statistical difference between Group II and Group I (*P*-value 0.0623). There was highly significant statistical difference between Group III and Group II (*P*-value 0.0003) and between Group I and Group III (*P*-value 0.0029).

Table 3 presents information on the transverse strength values of repaired specimens of Group I as Group IA, Group IB and Group IC. The table showed that maximum mean strength was obtained for Group IA, followed by Group IC and least was Group IB. However, Table 4 shows that there were no statistical significant differences between Group IA, Group IB and Group IC (*P*-value >0.2).

Table 5 presents information on mean transverse strength values of repaired specimens of Group III as Group IIIA, Group IIIB and Group IIIC. It showed that maximum mean transverse strength was observed with Group IIIA, followed by Group IIIB and Group IIIC. However, Table 6 shows that there was no statistical significant difference between the three groups, i.e. Group IIIA, Group IIIB and Group IIIC (*P*-value 0.4).

Table 7 represents the type of failure, in that mixed failure was maximum (68.89%), followed by adhesive (15.56%) and cohesive (15.56%).

Table 1: Transverse strength (MPa) for intact specimens

Base material	Mean	SD
Group I	90.25	6.32
Group II	85.08	8.13
Group III	105.73	17.30

Table 2: Results of Student's unpaired *t* test

Groups	*P*-value	Inference
I and II	0.0623	Not significant
II an III	0.003	Highly significant
I and III	0.0029	Significant

Table 3: Transverse strength (MPa) for repaired specimens of Group I

Base material	Mean	SD
IA	75.29	1340
IB	69.42	14.38
IC	74.46	17.04

Table 4: Student's unpaired *t* test

Group	*P*-value	Inference
IA and IB	0.2568	Not significant
IB and IC	0.9247	Not significant
IA and IC	0.3615	Not significant

Table 5: Transverse strength (MPa) for repaired specimens of Group III

Groups	Mean	SD
IIIA	73.51	9.13
IIIB	71.73	4.38
IIIC	71.02	7.19

DISCUSSION

Acrylic resin poly(methylmethacrylate) is most commonly employed in the construction of dentures. Despite its popularity, the material, although adequate in satisfying aesthetic demands, is far from ideal in fulfilling the mechanical requirements of such appliances. This is reflected in the unresolved problem of denture fracture and the accompanying costs of denture repair. Presently, the Dental Practice Board, UK spends approximately 7 million pounds annually to repair about 0.8 million dentures.

Results of a survey showed that 33% of the repairs carried out were due to debonded or detached teeth. Around 29% were repairs to midline fractures, more commonly seen in upper complete denture at a ratio of 2:1.[1]

Microwave polymerization of acrylic resin was first reported by Nishii.[6] Microwaves can be used to generate heat inside the resin. They are electromagnetic waves produced by a generator called magnetron. Domestic microwave ovens use a frequency of 2450 MHz, which gives a wavelength of about 12 cm. Methylmethacrylate molecules are able to orient themselves in the electromagnetic field of microwaves; at a frequency of 2450 MHz, their direction changes nearly five billion times a second. Consequently, numerous intermolecular collisions occur to cause rapid heating. Because microwaves do not pass through metals, conventional metallic flasks cannot be used when heating acrylic resin directly; thus, it is necessary to use specially designed fibre-reinforced plastic flasks. Microwave polymerization is cost-effective, time-saving, neater and more dimensionally stable.[7]

Denture fracture occurs both outside and inside the mouth. Outside the mouth, failure occurs through

Table 6: Student's unpaired *t* test

Group	*P*-value	Inference
IIIA and IIIB	0.5017	Not significant
IIIB and IIIC	0.4134	Not significant
IIIA and IIIC	0.7458	Not significant

Table 7: Types of failure

Type	Group IA	Group IB	Group IC	Group IIIA	Group IIIB	Group IIIC
Mixed	10 (66.67)	9 (60)	8 (53.33)	11 (73.33)	13 (86.67)	11 (73.33)
Adhesive	1 (6.67)	3 (20)	4 (26.67)	2 (13.33)	1 (6.67)	3 (26)
Cohesive	4 (26.67)	3 (20)	3 (20)	2 (13.33)	1 (6.67)	1 (6.67)

Mixed - 68.89%, adhesive - 15.56%, cohesive - 15.56%.

impact as a result of dropping of the dentures. The causes of denture fracture inside the mouth include:

i. Excessive bite force
ii. Improper occlusal plane
iii. High frenal attachment
iv. Lack of balanced occlusion
v. Poor fit
vi. Limitations in denture base material

In function, however, midline fracture is the result of flexural fatigue failure caused by cyclic deformation of the base, and is more likely to occur because flexure of the denture base occurs along the midline.[5]

The recurrent rate of fracture has been reported to be as high as 19.5-21.3% in all denture fracture cases. This reveals that repairing techniques for fractures dentures need to be further explored.[8]

Researchers have reported the influence of various factors, including repair surface, designing, repair surface treatment, etc.[9,10] The purpose of this study was to evaluate the transverse strength of intact specimens of conventional heat-cured, autopolymerized and microwave-cured resins; and the repair strength of conventional heat-cured and microwave-cured resins repaired with the same or autopolymerized resin.

A total of 60 samples were made from conventional heat-cured and microwave-cured resins, and 15 from chemically cured resin, with the help of metal dies that were made as per the ADA specification no. 12 for measurement of transverse strength. Out of the 60 samples, 15 samples served as the control group; Group I for conventional heat-cured resin, Group II for autopolymerized resin and Group III for microwave-cured resin. After storage in distilled water for 7 days to simulate the oral conditions, transverse strength of the intact specimens was tested under a tri-axial loading frame (3-point bending test).

In the present study, it was found that microwave resin had the highest intact transverse strength with a mean value of 105 MPa, followed by conventional heat-cured and chemically cured resin. This finding is in agreement with a study conducted on the mechanical properties of new denture base resin, which showed that microwave resin had the highest strength of 92 MPa,[11] but conversely, few studies have showed that microwave resin and heat-polymerized resin had almost similar transverse strength.[12]

The increased transverse strength of microwave-cured resin (Acron MC) was probably due to the presence of less rubber in its composition as compared to conventional heat-cured resin (DPI-Heat Cure), which makes the latter behave more elastically and thus demonstrate low final strength values.[13]

Few studies have shown that microwave-cured resins have decreased porosity,[14,15] because the heat required to break the benzoyl peroxide molecule into free radicals is created inside the resin (as microwave radiations have greater penetrating capability); hence heat is dispersed more efficiently and polymerization is rapid and decreases residual monomer content as compared to conventional heat-cured resin, which could also account for the increased transverse strength of Acron MC.

After storage in distilled water for 7 days, the specimens of Group I and III were fractured in the midline to create a gap of 10 mm to form a butt joint, and then the joint surfaces were chemically etched in acetone for 30 s as preparation of the repair surface of the sites to be joined is of paramount importance to assure a long life. Acetone dipping for 30 s has proved to provide the greatest transverse repair strength. Acetone could dissolve the polymer, thus promoting mechanical interlocking associated with monomer penetration and polymerization along the repair material.[5]

The repaired specimens were also tested for transverse strength under the same tri-axial loading frame. Results showed that there was no statistical difference between any of the repair materials used, but microwave resin produced the highest transverse strength. This is in accordance with a study that evaluated the repair strength of denture base resins using various methods like standard heat-activated resin, microwave-activated resin and autopolymerizing resin, which also had similar results as the present study.[16]

This *in vitro* study also showed that transverse strength of specimens repaired with heat-polymerized acrylic resin was up to 83% of the original strength of the material, and with autopolymerized resin under pressure it was up to 65% of the original strength. These values are similar to a study conducted to evaluate the transverse strength of repairs in PMMA.[17] This is also in agreement with a study conducted to evaluate some physical properties of self-curing resins for repairing dentures.[18]

The type of failure noted in this study was mixed almost 69%, similar to that found by a study demonstrating that acetone treatment of the joint sites increased the bond strength.[5]

The purely adhesive and cohesive failure was only 15%, regardless of the denture base material used, thus showing that the strength of the repair material was not a compromise. Adhesion is a result of intimate molecular attraction if a liquefied adhesive material first wets the surface (e.g. acetone) to penetrate the pits and fissures, thus preventing purely adhesive failure.

Finally, it must be noted that *in vitro* studies are limited in predicting the success of a material or technique in clinical use. The use of a simple rectangular shaped specimen rather than a complex denture design, as well as the absence of longer periods of water storage or thermal cycling, is a limitation of the present study.

Clinical implications

The present study showed that microwave resins have better transverse strength, and so it can be used to cure dentures as it is more time-saving, and the dentures retrieved are cleaner and have decreased porosities, but are costlier and require special equipment.

It showed that there are no significant differences on the strength of repaired specimens as influenced by the repair material. Hence autopolymerizing resin can be effectively used to repair dentures if it is cured under pressure because it is dimensionally more stable.

As the type of failure noticed in the study was of a mixed type, it implies that the adhesion between the materials is more important than the strength of the repair material. Hence, prior to repairing the dentures, proper surface treatment of the fractured parts should be carried out with acetone in order to achieve a stronger bond.

CONCLUSIONS

Within the limitations of the present study, the following conclusions can be drawn:

(i) The intact microwave-cured resin (Acron MC) showed statistically superior transverse strength as compared to conventional heat-cured (DPI-Heat Cure) and autopolymerized resin (DPI-Repair Resin).

(ii) There was no statistical difference between the transverse strength of intact conventional heat-cured resin and autopolymerized resin when cured under pressure.

(iii) The autopolymerized resin exhibited repair strength comparable to those found for conventional heat-cured resin and microwave-polymerized resin.

(iv) Repair methods exhibited a low incidence of purely adhesive and cohesive failure and a high incidence of mixed failure.

REFERENCES

1. Darbar UR, Hugget R, Harrison A. Denture fracture a survey. Br Dent J 1994;7:342-7.
2. Alcibiades JZ, Gregory LP, Stavrous AY. Repairs in complete denture: Results of a survey. Quint Dent Technol 1997;149-55.
3. Beyli MS, Dent MD, Fraimhofer JA. An analysis of cause of fracture of acrylic resin dentures. J Prosthet Dent 1981;46:238-40.
4. Guegory LP andreas GA, Panagiotis EL. Acrylic resin denture repair with adhesive resin and metal wires: Effect on strength parameters. J Prosthet Dent 1996;75:381-7.
5. Chiayi S, Frank AC, Bradley B. Strength of denture repairs as influenced by surface treatment. J Prosthet Dent 1984;52:844-8.
6. Clerk JP. Microwave polymerization of acrylic resins used in dental prosthesis. J Prosthet Dent 1987;57: 650-9.
7. Michael DT, Mark WR. Microwave processing for denture reline, repairs and rebases. J Prosthet Dent 1992;69: 340-3.
8. Hargeaves AS. The prevalence of fractured dentures: A survey. Br Dent J 1969;126:1091-103.
9. Rafael G, Josef G. The transverse strength of acrylic resin strips and of repaired acrylic samples. J Oral Rehabil 1984;11:237-47.
10. John EW, Peter CM, Rober AL, Carol LB. Effect of repair surface design, repair material and processing method on the transverse strength of repaired acrylic denture specimens. J Prosthet Dent 1992;67:815-20.
11. John LS, Bernard L, Phill VR. Comparison of the adaptation of acrylic resin cured by microwave energy and conventional water bath. Quintessence Int 1991;22: 181-6.
12. Rached RN, Cury DB. Heat cured acrylic resin repaired with microwave cured one: bond strength and surface texture. J Oral Rehabil 2001;28:370-5.
13. Rached RN, Powers JM, Altair A, Del Bel Cury. Repair strength of autopoymerizing, microwave and conventional heat polymerized acrylic resin. J Prosthet Dent 2004;92: 79-82.
14. Ng ET, Tan LH, Chew BS, Thean HP. Shear bond strength of microwaveable acrylic resin for denture repair. J Oral Rehabil 2004;31:798-802.
15. Rached RN, Powers JM, Cury AA. Efficacy of conventional and experimental technique for denture repairs. J Oral Rehabil 2004;31:1130-8.
16. Polyzois GL, Handley RW, Stafford GD. Repair strength of denture base resins using various methods. Eur J Prosthodont Restor Dent 1995;3:183-6.
17. Auein L, Grant AA. The transverse strength of repairs in polymethyl methacrylate. Aust Dent J 1971;16:232-4.
18. John WS, Claire LB, George CP. Self curing resins for repairing dentures: Some physical properties. J Am Dent Asssoc 1955;57:307-15.

Source of Support: Nil, **Conflict of Interest:** None declared.