Original Article

A Comparative Evaluation of Effect of Reinforced Autopolymerizing Resin on the Flexural Strength of Repaired Heat-polymerized Denture Base Resin before and after Thermocycling

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ABSTRACT

Aims and Objective: Denture fractures are a common problem in clinical practice. Despite the use of different reinforcement materials (metal wires, metal plates, and various types of fibers) for denture repairs, recurrent fractures are still common. The purpose of this study was to compare the maximum flexural loads of the heat-polymerized denture base resin when repaired with autopolymerizing resin reinforced with relatively smaller diameter metal wires and glass fibers, before and after thermocycling.

Materials and Methods: Heat polymerized rectangular specimens were fabricated and repaired with autopolymerized resin and different reinforcement materials. Stainless steel wires, coaxial wires, beta-titanium wires, and glass fibers were used as reinforcement materials. Metal wires were sandblasted before placing in the center of the specimen along with autopolymerizing resin. Control specimens were repaired without any reinforcements. Intact heat- and self-cure specimens were also prepared for comparison. Half of the specimens of each group were subjected to thermocycle stressing (5°C and 55°C, 30 s dwell time) for 2000 cycles. All the specimens, nonthermocycled as well as thermocycled, were then tested for flexural strength by using 3 point flexural test in Lloyd's Universal testing machine at 5 mm/min crosshead speed. The maximum flexural loads (N) for each specimen were recorded. The readings, thus obtained, were subjected to statistical analysis using two-way ANOVA and Tukey's multiple comparison test.

Results: The metal wire reinforcements increased the flexural strength of repaired specimens, whereas, glass fiber reinforcement produced slightly lower flexural strength when compared to those of control specimens, i.e., repair without any reinforcement. The highest flexural strength was demonstrated by specimens repaired with coaxial wire reinforcements (50.01 and 43.77 N before and after thermocycling, respectively). The increase in flexural strength with the use of stainless steel wire (45.12 and 41.56 N) and beta-titanium wire reinforcements (45.54 and 42.61N) was insignificant.

Conclusions: Coaxial wire reinforcement produced significantly higher flexural loads than control. Increase in strength with stainless steel wire and beta-titanium wire was insignificant, whereas glass fiber reinforcement reduced the strength.

KEYWORDS: *Autopolymerizing resin, flexural strength, reinforcement, repair denture*

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INTRODUCTION

Heat polymerizing polymethyl methacrylate (PMMA) has been the most commonly used denture base material for the fabrication of removable complete

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and partial dentures for >70 years. The use of PMMA is still continued due to its favorable working characteristics; processing ease, accurate fit, stability in the oral environment, superior esthetics, and use with inexpensive equipment. It has also been used for the fabrication of orthodontic and pedodontic appliances, and interim fixed partial dentures. Despite its popularity in satisfying esthetic demands, it is still far from ideal in fulfilling the mechanical requirements of a prosthesis.[1]

Fractures of the PMMA dentures are common in clinical practice. Most fractures of the dentures occur inside the mouth during the function, primarily because of resin fatigue. The denture base resin is subjected to various stresses during function; these include compressive, tensile, and shear stresses. Some of the factors responsible for denture fracture include stress intensification, increased ridge resorption leading to an unsupported denture base, deep incisal notching at the labial frenum, sharp changes at the contours of the denture base, deep scratches, and induced processing stresses. The causes of such fractures have been analyzed by Beyli and Von Fraunhofer.[2] They suggested that poor fit and lack of balanced occlusion were most frequent causes, but material breakdown and dropping of the denture were also recognized as possible causes.

Denture repairs involve joining two parts of the fractured denture with a denture repair material. Several techniques and materials have been used to repair fractured dentures. Regardless of the reason for fracture or the method of repair, the ultimate goal of denture repair is to restore or reinforce the denture's strength to avoid recurrent fractures. To produce satisfactory results, the repair procedure has to be rapid, easy to perform, inexpensive, not change the original color, and preserve the dimension of the dentures.[1] However, this goal cannot always be achieved. The different materials used to repair fractured acrylic resins include heat polymerized, autopolymerized, visible light polymerized, and microwave-polymerized acrylic resins.

Heat polymerized resins have been proven to have higher mechanical properties when compared to autopolymerized resins. However, laboratory packing and flasking procedures for heat polymerized resins are time-consuming and present risk of denture deformation by heat.[3]

Autopolymerized resin is the most commonly employed repair material. Unfortunately, its strength has been shown to range from 18% to 60% of intact heat polymerizing denture resin. Repairs with visible light-polymerized resin result in even lower final strength.

When a denture base is repaired with autopolymerizing resin, recurrent fractures frequently occur at the repair interface or in adjacent areas which may be attributed to inadequate flexural strength and change in physical and mechanical properties of repair material due to the wide variation of temperature in the oral environment.[4] To overcome this problem and to improve the mechanical properties of the repaired acrylic resin denture bases, various attempts have been made by modifying joint designs, using pretreatment for repair surface and by various reinforcements in the repairing material.

Several types of reinforcements in the form of fibers, including carbon, aramid, polyethene and glass fibers have been investigated with varying results. Furthermore, the use of metal wires and plates in the reinforcements of denture base resin reduced the likelihood of denture fractures caused by extensive biting or impact forces problems. The strength of such repairs can be increased by roughening of the surface of metal reinforcement, to improve adhesion between resin and metal. However, these resulted in poor esthetics, restricting their use to locations at which esthetics is least important. Moreover, the larger diameter wires cannot be easily incorporated in the average 2 mm thickness of denture bases.[5] The smaller diameter wires can be used for reinforcement, but their effectiveness in improving the strength of the repairs has not been yet established.

Therefore, the present study compared the flexural strength of the heat-polymerized denture base resin when repaired with autopolymerizing resin reinforced with four different reinforcing material, i.e., stainless steel wires, coaxial wires, beta-titanium wires and glass fibers, before and after thermocycling.

Materials and Methods

A total of 210 specimens were fabricated, of which 180 specimens were of heat-polymerized denture base resin (Trevalon) and divided into six groups of thirty specimens [Figure 1] each (Groups A, B, C, D, E, and F), and thirty specimens of autopolymerizing resin (DPI RR Cold Cure) were prepared (Group G).[6,7] The study protocol was reviewed and approved by the Ethical Committee of Government Dental College, Amritsar (Letter no. BFUHS/2k10/p-TH/8264 dated 06-07-2010).

The specimens for this study were prepared at the Department of Prosthodontics, Government Dental College, Amritsar and testing was done at Central Institute of Plastics Engineering and Technology, Amritsar, from November 2009 to June 2011. A detachable brass die [Figure 2] was made for the purpose of fabricating intact test specimens (70 mm × 10 mm × 3 mm). The die also had the provision to fabricate two blocks (33.5 mm × 10 mm × 3 mm) of each test specimen of heat-polymerized denture base resin with a central groove (16.5 mm × 3 mm × 2.1 mm) and a 3 mm brass spacer [to create space for autopolymerizing resin Figure 3].

The specimens of Group A, B, and C were repaired with autopolymerizing resin after reinforcement with stainless steel, coaxial, and beta-titanium wires, respectively. The wires were cut into pieces of 10 mm length and made rough by sandblasting with 50 µm aluminum oxide particles in Precision Blasting Unit (DENTASTRAHL Combi, KRUPP). The wires were then treated with an adhesive primer (3M ESPE) and placed in the center of the groove created for the repair material. After this, autopolymerizing resin (DPI RR Cold Cure) was filled into 3 mm space and the groove, followed by curing at room temperature.

The specimens of Group D were repaired with autopolymerizing resin reinforced with glass fibers (1% by weight). The glass fibers were cut in 10 mm length and were immersed in the monomer of autopolymerizing resin for 10 min, before placing them into the central groove. Autopolymerizing resin was then filled into 3 mm space and the groove, followed by curing at room temperature.

Specimens of Group E were repaired with autopolymerizing resin without any reinforcement. This group acted as a control group.

Specimens of Group F (heat polymerizing resin) and Group G (autopolymerizing resin) were prepared as a single piece without any space or groove and were used for comparative study.

Half of the specimens of each group were subjected to thermocycle stressing by immersing in two water baths [Figure 4] at 5°C and 55°C for 2000 cycles with a 30 s dwell time in each water bath. All the specimens, nonthermocycled as well as thermocycled, were then tested for flexural strength using three-point flexural test in Lloyd's Universal Testing Machine [Figure 5] at 5 mm/min crosshead speed. The maximum flexural loads (N) for each specimen were recorded. The readings, thus obtained, were subjected to statistical analysis using two-way ANOVA and Tukey's multiple comparison test.

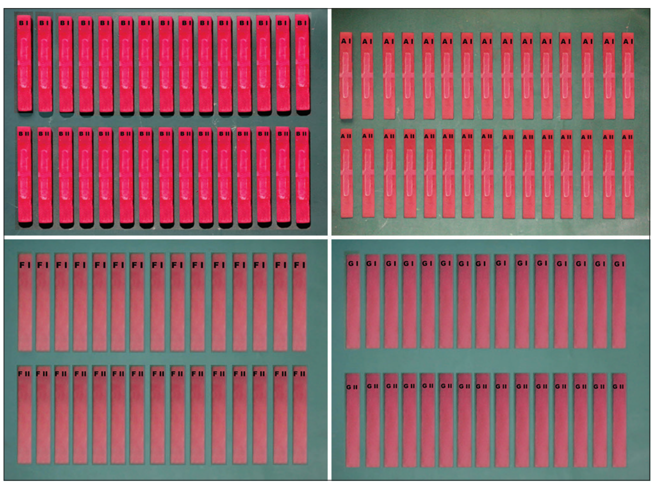


Figure 1: Specimens

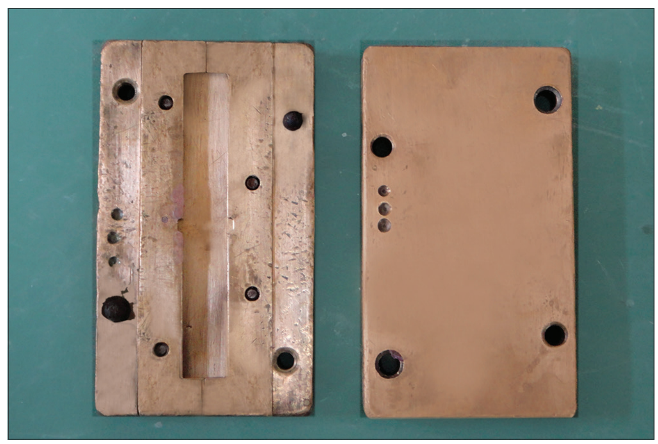


Figure 2: A detachable brass die

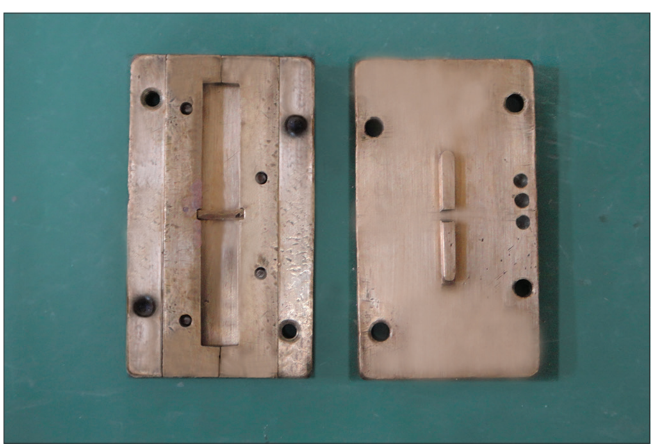


Figure 3: Detachable brass die with a central groove

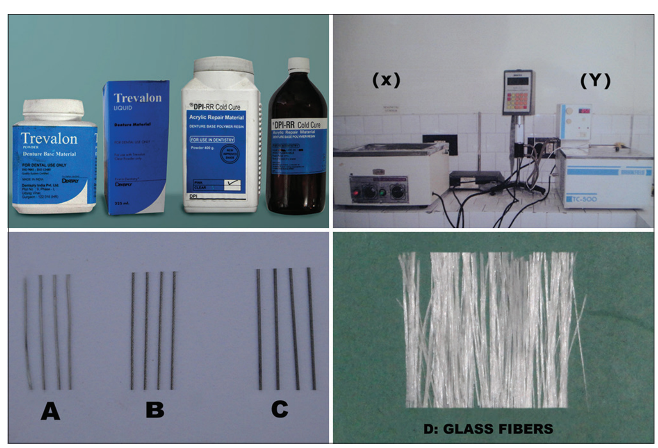


Figure 4: Materials used in this study

Results

Analysis of flexural strength values for all the study groups by two-way ANOVA indicated a very highly significant difference between the means of all main groups (F = 14056.27, P < 2.2E-16) and between the means of subgroups (F = 94.41, P < 2.2E-16) [Table 1].

Results of the two-way ANOVA [Table 2] have led us to the conclusion that difference in the means of groups was highly significant. Since the number of main groups was more than two; therefore, to determine as to which of the means of groups were significantly different, the observed differences between each of the possible pairs among the groups were through Tukey's multiple comparison test [Table 3].

Discussion

The purpose of the present study was to compare and evaluate the flexural strength of heat polymerized denture base resin (Trevalon) when repaired with autopolymerizing resin (DPI RR Cold Cure) reinforced with four different materials (stainless steel wire, coaxial wire, beta-titanium wire, and glass fibers) before and after thermocycling.

Flexural strength of all study groups was statistically analyzed using two-way ANOVA test and then with Tukey's multiple comparison test to make all valid comparisons.

According to the present study, the highest mean flexural strength was demonstrated by intact heat-polymerized denture base resin Trevalon [195.80 and 194.34 N before and after thermocycling, respectively Table 1]. It was followed by autopolymerizing resin DPI RR Cold Cure [162.90 and 154.76 N Table 1] before and after thermocycling. Within the repaired groups, the highest mean flexural strength was obtained with Group B, i.e., repair after reinforcement with coaxial wires and least was obtained with Group D, i.e., specimens reinforced with glass fibers [Graph 1].

The mean values of flexural strength of repaired specimen groups, before and after thermocycling [Graph 2], in the descending order were as follows: coaxial wire reinforcement - Group B [50.01and 43.77 N Table 1], beta-titanium wire reinforcement - Group C [45.54 and 42.68 N Table 3], stainless steel wire reinforcement - Group A [45.12 and 41.56 N Table 1], control group – Group E, i.e., no reinforcement [43.52 and 39.56 N Table 1], and glass fiber reinforcement - Group D [42.05 N and 39.61 N Table 1].

From Tukey's multiple comparison test [Table 3] within the repaired groups, it was observed that there was no significant difference between the mean flexural strength of Group A and Group C, Group A and Group E, and between Group D and Group E. The flexural strength of Group B and C were significantly different from the control Group, while flexural strength of Group A and D were not significantly different from the control Group.

The present study is in agreement with the study conducted by Minami *et al*.[4] which suggested that heat-polymerized

Table 1: Mean values for flexural strength of the study groups before and after thermocycling

Main groups	Subgroup I	Subgroup II	Decrease in strength after thermocycling (%)
Group A	45.12	41.56	7.89
Group B	50.01	43.77	12.47
Group C	45.54	42.68	6.28
Group D	42.05	39.61	5.80
Group E	43.52	39.56	9.10
Group F	195.80	194.34	0.75
Group G	162.90	154.76	4.99

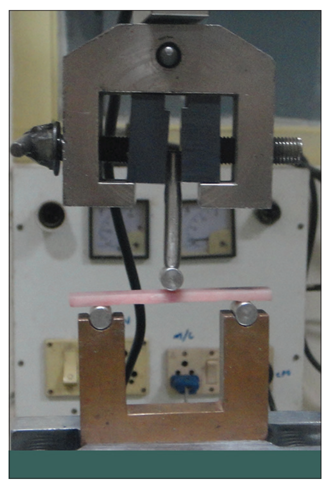


Figure 5: Three point flexural test in Lloyd's Universal Testing Machine

Table 2: Two-way analysis of variance table for flexural strength

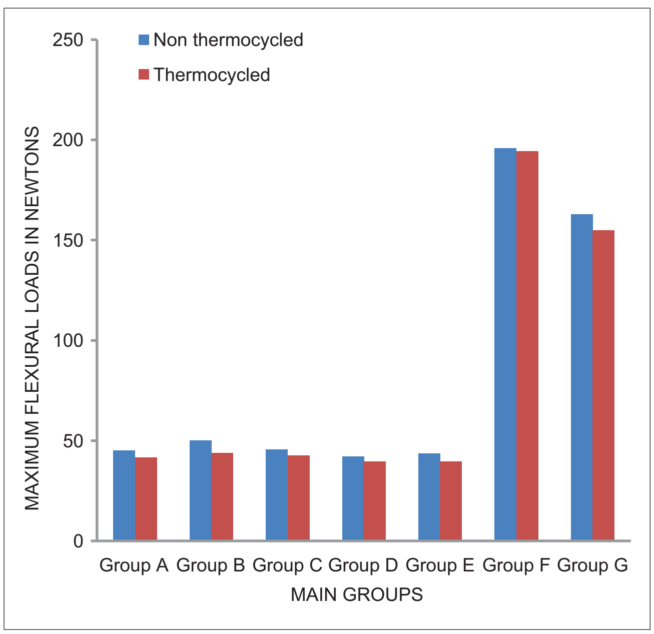
Source of variation	Degrees of freedom	Sum of squares	Mean square	F (variance ratio)	P value for F
Main groups	6	785,447	130,908	14,056.27***	<2.2E-16
Subgroups	1	879	879	94.41***	<2.2E-16
Main × subgroups interaction	6	244	41	4.36***	0.00037
Residuals	196	1825	9		
Total	209	788,395			

*Siginificant (P<0.05), **Highly significant (P<0.01), ***Very highly significant (P<0.001), NS=Nonsignificant (P≥0.05)[8,9]

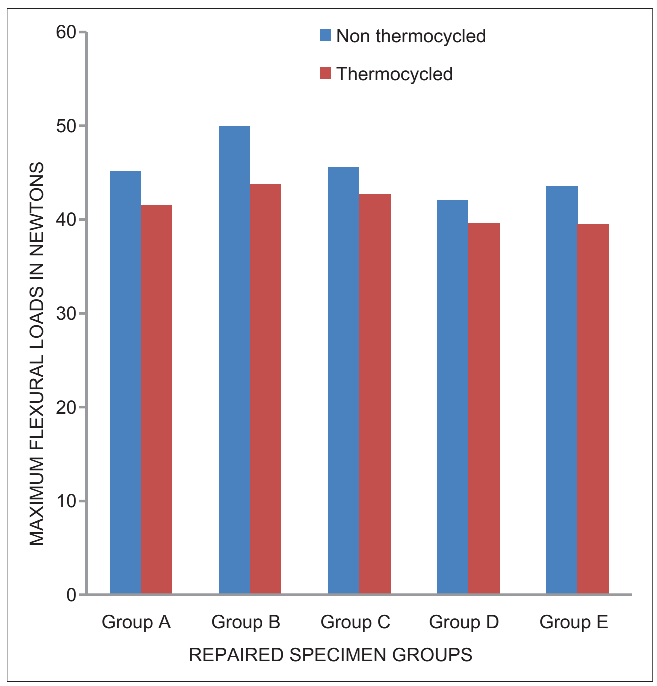
Table 3: Tukey's multiple comparison of means at 95% family-wise confidence level

Comparison among main groups	Difference	Lower	Upper	*P*	Significance level
B-A	3.546	1.198	5.893	0.0002323	***
C-A	0.773	−1.574	3.120	0.9575894	NS
D-A	−2.509	−4.856	−0.161	0.0276200	*
E-A	−1.796	−4.143	0.551	0.2593546	NS
F-A	151.730	149.382	154.077	0.0000001	***
G-A	115.496	113.148	117.843	0.0000001	***
C-B	−2.773	−5.120	−0.425	0.0095439	**
D-B	−6.055	−8.402	−3.707	0.0000001	***
E-B	−5.342	−7.689	−2.994	0.0000001	***
F-B	148.184	145.836	150.531	0.0000001	***
G-B	111.950	109.602	114.297	0.0000001	***
D-C	−3.282	−5.629	−0.934	0.0009050	***
E-C	−2.569	−4.916	−0.221	0.0219374	*
F-C	150.957	148.609	153.304	0.0000001	***
G-C	114.723	112.375	117.070	0.0000001	***
E-D	0.713	−1.634	3.061	0.9713907	NS
F-D	154.239	151.891	156.587	0.0000001	***
G-D	118.005	115.657	120.353	0.0000001	***
F-E	153.526	151.178	155.873	0.0000001	***
G-E	117.292	114.944	119.639	0.0000001	***
G-F	−36.234	−36.581	−33.886	0.0000001	***

*Siginificant (*P*<0.05), **Highly significant (*P*<0.01), ***Very highly significant (*P*<0.001), NS=Nonsignificant (*P*≥0.05)[8,9]



Graph 1: The comparisons of mean flexural strength of the study groups. Group A: Reinforcement with stainless steel wires. Group B: Reinforcement with coaxial wires. Group C: Reinforcement with beta titanium wires. Group D: Reinforcement with glass fibers. Group E: Repaired with autopolymerizing resin without reinforcement (Control Group). Group F: Intact specimens of heat polymerized denture base resin (Trevalon). Group G: Intact specimens of autopolymerizing resin (DPI RR Cold Cure)



Graph 2: The comparisons of mean flexural strength of the repaired specimens before and after thermocycling. Group A: Reinforcement with stainless steel wires. Group B: Reinforcement with coaxial wires. Group C: Reinforcement with beta titanium wires. Group D: Reinforcement with glass fibers. Group E: Repaired with autopolymerizing resin without reinforcement (Control Group)

denture base resin was comparatively stronger than the autopolymerizing resin and repaired specimens had significantly lower flexural strength values as compared to the intact heat-polymerized denture base resin specimens.

The present study also confirmed the results of study conducted by McCrorie and Anderson,[10] who demonstrated that the transverse strength of repairs made with self-cure resin was up to 57% that of the original heat cure material.

Vallittu and Lassila[11] used semicircular wire (1.0 mm × 2.0 mm), braided wire plate (0.8 mm × 2.4 mm) and clasp wire (1.0 mm) for reinforcement of PMMA resin (Novodon Rapid Denture Base). Some wires of each type were made rough by sandblasting with aluminum oxide or by grinding with a heated stone. They concluded that all metal wire strengtheners increased the fracture resistance which is confirmed by the observations of the present study.

The thickness and position of the strengthener within the resin can affect its reinforcing properties. In the present study, relatively thin gauge (0.016 inch) wires were placed perpendicular to the line of fracture, which did not produce considerable improvement in flexural strength except with the coaxial wires. This result is in partial agreement with the study conducted by Ruffino[12] who discussed the effect of steel strengtheners on the fracture resistance of acrylic resin complete denture base and stressed the importance of the position of the metal strengthener and its effect on strength. For maximum strengthening, the metal should be placed perpendicular to the anticipated line of stress and fracture and not coincident with that line. The resistance to deflection of a thick steel strengthener, compensate for the discontinuity the strengthener produced and produced improved strength.

Jennings *et al*. (1960)[13] fabricated the acrylic test blanks reinforced with stainless steel lingual bar, braided wire plate, 0.4 mm stainless steel round wire and stainless steel mesh. They confirmed that stainless steel lingual bar and 0.4 mm stainless steel round wire increased the transverse strength considerably.

In the present study, 0.016 inch (0.4 mm) stainless steel wire reinforcement increased the strength 45.12 and 41.56 N [Table 1] both before and after thermocycling, however, this increase in strength was not significant when compared with the control (43.53 and 39.56 N, i.e., no reinforcement). This observation is in accordance with the study carried out by Carroll and Von Fraunhofer,[5] in which 0.016, 0.025, 0.036, and 0.051 inch orthodontic wires and flat and braided two strand brass wire reinforcement in acrylic resin sheets produced transverse strength values of 640.2 ± 75.5, 674.9 ± 25.2, 807.3 ± 43.7, 1113.8 ± 38.8, and 700.3 ± 69.3 kg/cm^2, respectively. The increase in transverse strength with 0.016 inch wire reinforcement was not significantly different from the control (598.5 ± 30.0 kg/cm^2).

Polyzois *et al*.,[1] Vojdani and Khaledi,[14] and Geerts *et al.* (2008)[15] had similar results, and they found that 1 mm diameter stainless steel wire reinforcement increased the strength of the PMMA resin when compared with the unreinforced resin specimens.

In the present study, glass fibers in 1% concentration were also used to reinforce the autopolymerizing resin repair material. The flexural strength of repaired specimens after glass fiber reinforcement [42.05 and 39.61 N Table 1] both before and after thermocycling was slightly lower than the control [43.52 and 39.56 N Table 1], i.e., repairs carried out without any reinforcement and this difference in flexural strength was not significant.

There have been controversial results regarding the effective concentration of fibers and their effect on the flexural strength of reinforced resins. In general, low concentrations of fibers have been used.

The result of the present study are in agreement with the observations of Uzun *et al*.,[16] who reported that transverse strength of specimens reinforced with glass fibers (406.50 ± 49.14 MPa) did not differ significantly from the control group, i.e., unreinforced PMMA (400.51 ± 96.52 MPa).

Keyf and Uzun[17] incorporated different concentrations (0.5%, 1%, and 1.5%) of glass fibers in autopolymerizing resin (Dentalon Plus). It was observed that 0.5% glass fiber incorporation had the higher transverse strength (54.45 MPa) than control (52.82 MPa) while strength was decreased (48.13 MPa and 49.67 MPa) when higher concentration (1% and 1.5%, respectively) were used. This result is confirmed by the results of the present study. Similar results also have been earlier demonstrated by Minami *et al.* (2005)[4] in their study. They found that repaired specimens involving glass fiber reinforcement produced flexural strength lower than the control, i.e., repairs without any reinforcement.

However, many attempts to strengthen the acrylic resin with metal wires and glass fibers failed because stress concentrations occur around embedded materials and the net effect of embedding fibers or metals actually weakens the polymer. This is often due to poor adhesion between the acrylic resin matrix and the fiber/metal inserts.

Some important effective factors for variation of flexural strength in repaired specimens are the joint surface contours,[18] processing methods and type of repairing acrylic resin,[4,19,20] distance between the repaired sites,[19] type of wires,[10,12,15] and the amount of residual stress.[17]

There are numerous studies and methods concerning the strengthening of PMMA or enhancing the adhesion between the metal and acrylic resin. These methods includes metal surface sandblasting,[21] chemical surface treatment,[21] application of adhesive resins,[21-23] or strengthening material such as glass fibers[24] and metal wires.[4,10,12,15,22]

Gad *et al*.[25] did a study to evaluate the effect of incorporation of glass fiber, zirconia, and nano-zirconia on the transverse strength of repaired denture base. There was no significant difference between the groups repaired with repair resin without reinforcement, 2 wt% zirconia, and glass fiber reinforced resin and concluded that reinforcing of repair material with nano-zirconia may significantly improve the transverse strength of some fractured denture base polymers.

The present study design has limitations for simulating the clinical situation, as the specimen tested was different from actual denture configuration. This study also failed to simulate repetitive mechanical stressing during mastication, which is inevitable with repaired dentures. Further investigations under more closely simulated clinical conditions are necessary.

Conclusions

The present study compared the flexural strength of the heat-polymerized denture base resin (Trevalon) when repaired with autopolymerizing resin (DPI RR Cold Cure) reinforced with four different reinforcing material, i.e., stainless steel, coaxial, and beta-titanium wires, and glass fibers, before and after thermocycling.

In the present study, it was observed that:

1. Intact specimens of heat-polymerized denture base resin Trevalon had the higher flexural strength (195.80 and 194.34 N) than the intact specimens of autopolymerizing resin-DPI RR Cold Cure (162.90 and 154.76 N) before and after thermocycling
2. The metal wire reinforcements (i.e., stainless steel wires, coaxial wires, and beta-titanium wires) increased the flexural strength of repaired specimens, whereas, glass fiber reinforcement produced slightly lower flexural strength as compared to those of control specimens, i.e., repair without any reinforcement
3. The highest flexural strength was demonstrated by specimens repaired with coaxial wire reinforcements (50.01 and 43.77 N before and after thermocycling, respectively). The increase in flexural strength with the use of stainless steel wire (45.12 and 41.56 N) and beta-titanium wire reinforcements (45.54 and 42.61N) was insignificant
4. The results of the present study indicate that thermocycling negatively affected the flexural strength of intact and repaired specimens of heat-polymerized denture base resin.

Within the limitations of the present study and on the basis of results obtained, it may be concluded that to improve the strength of repair of the fractured heat-polymerized denture base, out of the four reinforcement material used, reinforcement with coaxial wires is the best option.

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Conflicts of interest

There are no conflicts of interest.

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