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Comparison of Flexural Strength of Conventional and Fiber Reinforced Denture Base Resin when Cured with Two Different Processing Techniques: An In Vitro Study

Praval Pratap Singh[1*] Naveen S Yadav[2] Akash Sharma[3] Amit Gupta[4]

[1]Reader, Department of Prosthodontics, Peoples College of Dental Sciences, Bhopal, MP, India.
[2]Professor and Head, Department of Prosthodontics, Peoples College of Dental Sciences, Bhopal, MP, India.
[3]Senior Lecturer, Department of Periodontics, Maharana Pratap College of Dentistry & Research Centre, Gwalior, MP, India.
[4]Senior Lecturer, Department of Periodontics, Maharana Pratap College of Dentistry & Research Centre, Gwalior, MP, India.

ABSTRACT

Background: Polymethyl methacrylate has been one of the widely used denture base materials with many favourable qualities but the material needs improved fracture resistance. The purpose of this study is to measure the effect of fiber strengtheners on the flexural properties of denture base resin material. This study also aims to analyse the effect of different polymerization techniques (conventional water bath technique and the microwave processing technique) on the flexural strength of fiber reinforced denture base resin so as to develop a denture base resin with optimum flexural strength that is clinically acceptable.

Material and methods. Thirty specimens of similar dimensions were prepared for each of the control group and 4 experimental groups: conventional acrylic resin and the same resin reinforced with glass and nylon fibers and cured by water bath and microwave technique. Flexural strength was evaluated with a 3-point bending test. The results were analyzed with a 1-way analysis of variance.

Results. All reinforced specimens showed better flexural strength than the conventional acrylic resin. Specimens reinforced with glass fibers and cured by the conventional water bath technique showed the highest flexural strength.

Conclusion. Within the limitations of this study, it could be concluded that the flexural strength of heat-polymerized PMMA denture resin was improved after fibre reinforcement especially glass fibres. The specimens cured by water bath technique showed more flexural strength than microwave curing technique also the difference was not significant.

Keywords: Denture Base Resin, Flexible reinforced Denture Base Resin, Flexural Strength, Processing Technique.

INTRODUCTION

One of the most widely used materials in prosthetic dentistry is polymethyl methacrylate (PMMA). Since its introduction to dentistry, it has been successfully used for denture bases because of its ease of processing, low cost, light weight, and colour-matching ability. However, acrylic resin denture base materials have poor strength, including low impact strength and low fatigue resistance.[1, 2, 3] A study by Johnston and colleagues showed that 68% of acrylic resin dentures break within a few years after fabrication.[4] Flexural fatigue occurs after separate flexing of a material, whereas impact fractures occur when force is applied extraorally.

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*Correspondence **Dr. Praval Pratap Singh.**
Department of Prosthodontics, Peoples College of Dental Sciences, Bhopal, MP, India.
Email: drpraval.pratap@gmail.com

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To overcome these shortcomings, experiments with alternate polymers were conducted, but the polymers failed to produce dentures of greater accuracy or better performance. Various modifications of polymethyl methacrylate also have been tested to improve the existing material; these modifications include chemical modification to produce graft copolymer high-impact resins and mechanical reinforcement through the inclusion of glass fibers[5, 6], sapphire whiskers[7, 8], aramid fibers[7, 9], carbon fibers[10, 11], stainless steel mesh[12], nylon[13], or (more recently) ultra-high-modulus polyethylene fibers[14].

The conventional technique of processing denture base polymers is by monomer/polymer dough moulding and polymerization in a water bath. Other processing techniques using microwave energy or light curing are also used. The conventional hot water bath technique has been considered the best means of processing heat-cured denture resins; however, it does have disadvantages. The method is inefficient because of the relatively long time needed to properly cure the material, and it is not a particularly clean procedure. Microwave processing of denture bases is cleaner, more time efficient, bigger homogeneity of the mixture, excellent adaptation and has less residual monomer content.[15, 16]

This in vitro study is performed to compare the flexural strength of commonly used polymethyl methacrylate resin and that of polymethyl methacrylate resin reinforced with glass and nylon fibers processed by two techniques, the conventional water bath technique and by using microwave energy.

MATERIAL AND METHODS

This *in vitro* study aims to compare the flexural strength of conventionally prepared heat polymerized acrylic denture base resin and fiber reinforced denture base resin cured by two different techniques i.e. using conventional water bath technique and the microwave processing. Acrylic resin specimens measuring 65mm x 10mm x 3mm were fabricated according to ADA Specification No.12[17, 18].

A total number of 150 specimens were fabricated which are divided into 5 groups of 30 specimens each, consisting of a control (conventional PMMA) and 4 groups of modified PMMA, as follows:

Group A: Control group conventional heat cured polymethyl methacrylate
Group B: Experimental group reinforced with glass fibers and cured by conventional water bath technique
Group C: Experimental group reinforced with glass fibers and cured by microwave technique
Group D: Experimental group reinforced with nylon fibers and cured by conventional water bath technique
Group E: Experimental group reinforced with nylon fibers and cured by microwave technique.

Wax specimens were fabricated using a standardized 3 piece mold(Fig 3).

PROCESSING OF ACRYLIC RESIN SPECIMENS

The wax patterns were invested with dental stone in regular brass flasks using conventional technique. Five patterns were invested in each flask. For the microwave cured specimens flasking was done similarly in special fiber reinforced plastic flasks with 5 specimens in one flask.

Mixing and packing of control group specimens

Once the flasks had cooled, denture base resin (Trevalon HI, Dentsply India Private Limited. Batch No: TH70102) available as polymer (powder form) and monomer (liquid form) was mixed in a porcelain jar according to manufacturer's instructions. The resin was left in the mixing jar until it reaches the dough stage, and then the mix was kneaded thoroughly to a homogenous dough. The dough was packed into the molds with a thin cellophane sheet placed over it. The flask lid was closed properly and placed under 1500 psi pressure in a bench press to compress the material into the mold. Trial closure was carried out, till no flash was present. After the final closure, the flasks were bench cured for 1/2 hour at room temperature.

Mixing and Packing of experimental group specimens

The remaining 4 experimental groups consisted of polymethyl methacrylate resin specimens of the same dimensions reinforced with glass fibers, or nylon fibers (Fig 1, 2). These fibers had a thickness of 10 to 15 mm and were cut to 5 mm length. The cut fibers were soaked in monomer for 10 minutes for better bonding with the acrylic resin; after the fibers were removed from the monomer, excess liquid was allowed to dry. The resin and fibers (2% by weight) were mixed thoroughly to disperse the fibers. On reaching dough stage, the mixture was kneaded and packed into the prepared mold.

Fig 1: Glass fibers.

Fig 2: Nulon fibers.

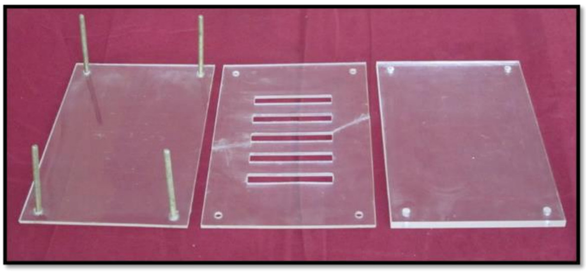


Fig 3: The three piece standardized mould.

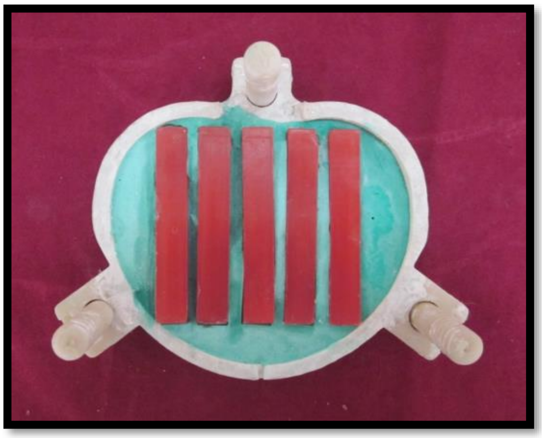


Fig 4: Investing of the wax pattern in special fibre reinforced flasks for microwave use.

Fig 5: Finished specimen.

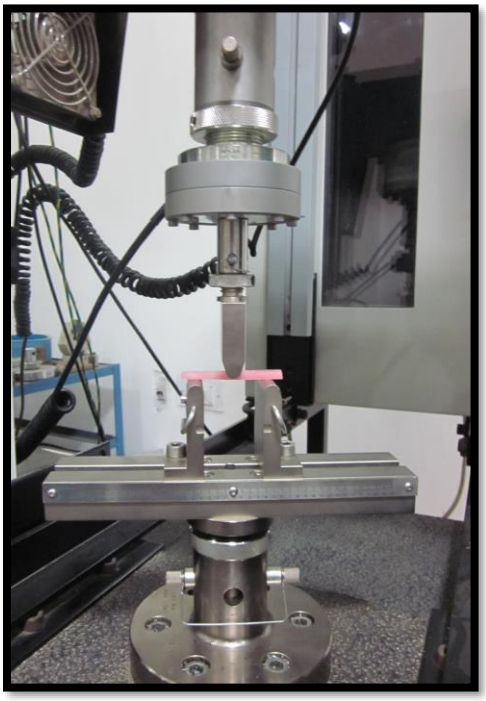


Fig 6: specimen placed on an instron universal testing machine.

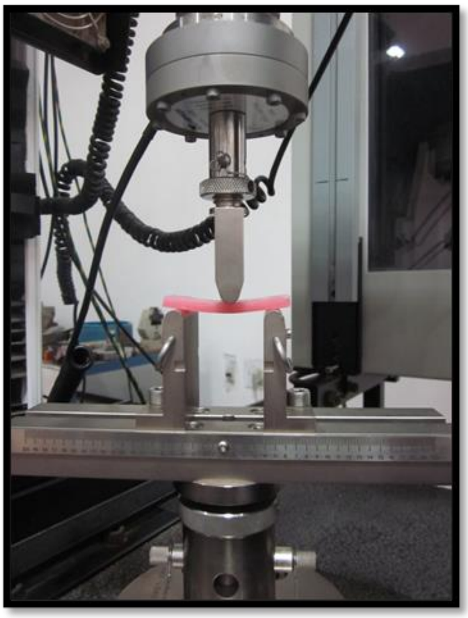


Fig 7: Three point bending test for analysis of flexural strength.

Processing of specimens using conventional heat cure method

All the specimens were polymerized using a standard processing cycle. The standard processing cycle chosen was the ADA specified short curing cycle. The clamped flasks were immersed in an acrylizer containing water at room temperature. The processing was carried out at 74^0C for 90 minutes and at 100^0 C for 30 minutes[15, 19]. After the completion of curing cycle, the acrylizer was switched off and flasks were bench cooled over night at room temperature before deflasking.

Processing of specimens using microwave method

All the specimens were polymerized by curing in the microwave oven for 3 min at 500 W. The flasks were bench cooled overnight at room temperature(Fig 4).

Retrieval of the test specimens:

After complete cooling, the test specimens were carefully retrieved, finished, numbered and stored in distilled water at 37^0C ± 1^0C in an incubator for 48hrs (Fig 5). Specimens whichever were unsatisfactory are discarded and remade.

FLEXURAL STRENGTH TESTING:

The flexural strength of the specimens was determined using a 3-point bend testing device in an Instrom Universal Testing Machine (Fig 6).[20] The device consists of a loading wedge and a pair of adjustable supporting wedges placed 48 mm apart.

The specimen was centered on the device in such a way that the loading wedge, set to travel at a crosshead speed of 2 mm/min, engages the center of the upper surface of the specimen.[20] The specimens were loaded until fracture occurs (Fig 7). The peak load (fracture load) was recorded in chart recorder.

The Peak load is converted to flexural strength by the formula:

$S = 3PL/2bd^2$

Where S= Flexural strength (N/mm^2)

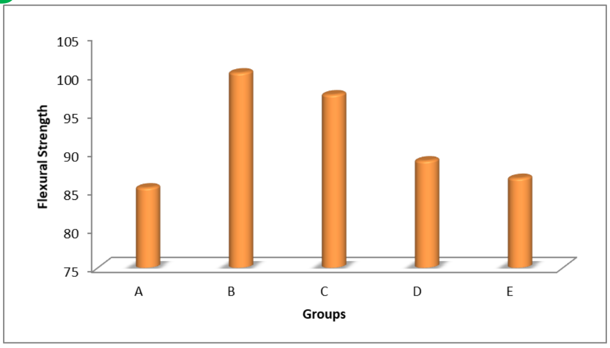
P = load at fracture
L = distance between jig supports
b = specimen width
d = specimen thickness

The results were tabulated, subjected to statistical analysis and compared.

Table 1: Comparison Of Mean Value Of Flexural Strength of Various Groups.

GROUP	NUMBER OF SPECIMENS	MEAN± STANDARD DEVIATION
A	30	85.37±2.953
B	30	100.27±2.149
C	30	97.43±2.144
D	30	88.87±1.833
E	30	86.60±1.276
TOTAL	150	91.71±6.386
F VALUE	295.087	
Df	4	
p value	0.00 (HIGHLY SIGNIFICANT)	

Graph 1: Comparison of mean value of flexural strength of various groups.



RESULTS

The mean values and standard deviations of the flexural strengths of various groups are listed in Table 1, Graph 1. The flexural strength of the experimental groups was significantly higher than the control group. The highest strength was of Experimental group B, i.e. glass fibre reinforced specimens cured by water bath technique. An analysis of the difference in flexural strengths was performed with a 1-way ANOVA, and the result was found to be significant ($P<.001$). Only the control and nylon-reinforced denture resins did not differ significantly.

DISCUSSION

Since its introduction to the field of dentistry in 1937, polymethyl methacrylate (PMMA) has become one of the materials routinely used for the fabrication of dentures. This is because of its good handling characteristics, ease of processing, accurate adaptation to the tissues, stability in the oral environment, aesthetic value, biocompatibility and cost effectiveness. Despite these excellent properties, there are certain drawbacks in this material and one of them is low fracture resistance.

Fractures of denture bases commonly occur intraorally and this has been attributed to resin fatigue caused by compressive, tensile and shear stresses acting on the denture during function. 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[21, 22].

The ultimate flexural strength (also called transverse strength or modulus of rupture) of a material reflects its potential to resist catastrophic failure under a flexural load. High flexural strength is crucial to denture wearing success, as alveolar resorption is a gradual, irregular process that leaves tissue-borne prostheses unevenly supported. As a foundation, the acrylic resin materials should exhibit a high proportional limit to resist plastic deformation and also exhibit fatigue resistance to endure repeated masticatory loads. An acrylic resin capable of sustaining higher flexure in combination with high resistance to cyclic loading may be less prone to clinical failure[4, 20].

Reinforcement of dental resin with short or long fibres has been described in the literature for nearly half a century now. Several different types of fibres have been used, with varying results but fibre reinforcement has never been adapted to routine clinical practice. Effective fibre reinforcement is dependent on many variables, including the type of the fibres, the percentage of fibres in the matrix, the modulus and distribution of the fibres, fibre length, orientation, forms, and interfacial bond.

Denture base polymers can be strengthened by the addition of reinforcements, such as metal wires and plates. However, metal reinforcing materials are problematic because their bonds with the resin matrix are weak. In addition, metal is unacceptable clinically because of its low aesthetic properties[11, 12]. Another method that has been used to reinforce the polymethyl methacrylate is adding various types of fibre reinforcements. The addition of different types of fibre, such as carbon, aramid, polyethylene, and glass fibre products, has been evaluated to overcome the physical and mechanical limitations of denture base resins.

Carbon fibres have been added to the resin matrix and have proved to be successful in increasing the strength of the denture base[23]. Despite producing successful reinforcement, the black colour the fibres impart to the resin can be unacceptable to some denture wearers. This together with the problems associated with different handling characteristics and the possibility of toxicity, has restricted their use.

Mullarky[24] in 1985 and Berrong, Weed and Young[7] in 1990 studied the reinforcement of acrylic resin with aramid fibres. They were successful in enhancing the fatigue resistance of the aramid fibre reinforced acrylic resin denture base material. But the incorporation of aramid fibres produced similar problems with respect to colour. The yellow appearance of the fibres was difficult to mask within the denture, necessitating thick layers of acrylic resin that added significantly to the bulk of the denture.

The concept of self-reinforcement (with a material that is chemically identical to the matrix holding the fibre in place) has been studied by Jagger, Harrison and Jandt[2]. Unfortunately the effect of the addition of untreated and surface treated chopped polymethyl methacrylate fibres did not produce a significant improvement in either the transverse strength or impact strength of acrylic resin. They found that the fibre arrangement in terms of fibre displacement and inter fibre spacing, may be important factors in the success of the reinforcement.

Nylon fibres are polyamide fibres and are based primarily on aliphatic chains. The chief advantage of nylon lies in its resistance to shock and repeated stressing. However, water absorption affects the mechanical properties of nylon. In this study, nylon-reinforced specimens were also fabricated and used for comparison of flexural strength with the glass fibres.

In 1996, Vallittu[25] suggested that the fatigue resistance of acrylic resin in removable partial dentures reinforced with glass fibres was superior to that in removable partial dentures reinforced with conventional metal wire. Aydin *et al.*[26] demonstrated that specimens reinforced with Stick glass fibres had the highest flexural strength, followed by glass fibres. The control specimens without fibre had the lowest values. The process of reinforcing denture base resins with glass fibre may be a useful way to strengthen denture bases beyond their normal limits.

Polymerization of heat-cured polymethyl methacrylate is usually carried out in a temperature-controlled water bath for a long period of time. Since the introduction of acrylic resins there has been a continual search for modified procedures to process resins faster. One of the alternatives to the conventional technique is microwave processing. The use of microwave energy was first reported in 1968 by Nishii[27] as an alternative polymethyl methacrylate processing method and has become increasingly popular as to conventional water-bath processing. The use of microwave energy to polymerize polymethyl methacrylate decreases the time to three minutes only, producing acrylic resin bases with the same quality as those polymerized by water bath technique. The microwave polymerization technique has advantages such us less equipment is required, the method is fast and clean, the final product has the same quality of physical properties, and it presents better accuracy of fit, resulting in improvement adaptation of denture base.

The mean value for flexural strength for Group A (Conventional heat cured specimens) was 85.33MPa, Group B (glass fibre reinforced specimens cured by water bath technique) was 100.27MPa, Group C (glass fibre reinforced specimens cured by microwave technique) was 97.43MPa Group D (nylon fibre reinforced specimens cured by water bath technique) was 88.87MPa and Group E (nylon fibre reinforced specimens cured by water bath technique) was 86.60MPa. Statistical analysis of the flexural strength of the five groups showed a significant difference. The glass fibre reinforced specimens showed the maximum strength, followed by nylon fibre reinforced specimens and lastly the control group specimens. Compared with conventional polymer materials, fibre reinforced polymers are successful in their application primarily because of their high specific modulus and specific strength. Because the modulus of elasticity of glass fibres is very high, most of the stresses are received by them without deformation. Thus, in this study, glass-reinforced specimens exhibited better flexural strength than the other specimen groups. The results in the present study are in agreement with previous studies conducted by John *et al.*[20], Vallitu *et al.*[25]

On comparing the mean flexural strength of conventional heat cured specimens with glass fibre reinforced specimens cured by water bath technique the flexural modulus showed significant difference (p value = 0.00). Also the p value (p value = 0.00) of comparison of control group and glass fibre reinforced specimens cured by microwave technique showed a significant difference.

Material fatigue is the predominant failure mechanism of dental appliances. The fatigue failure is caused by repeated occlusal loads that cause tensile stresses in some regions of the restoration; after a period of wearing time, the appliance fractures. Fatigue fractures can occur even though the static strength of the material is high enough to carry the occlusal stresses. There is evidence from previous in vitro tests that glass fibre reinforcement increased fatigue resistance of dental appliance up to 100 times compared with fatigue resistance of an unreinforced restoration. This indicates that the process of reinforcing denture base resins with glass fibre may be a useful way to strengthen denture bases beyond their normal limits.

Comparison of mean flexural strength of control group specimens and nylon fibre reinforced specimens showed a significant difference. An analysis of the mean values showed that the addition of nylon fibres did not result in a drastic improvement in the flexural strength.

On comparison of the processing techniques the inference can be derived that the water bath technique cured specimens have superior flexural properties irrespective of the type of fibre added. The microwave processed fibre reinforced specimens showed a significant improvement in flexural properties although significantly less than the conventional method but can be practically incorporated into use.

On the basis of the results obtained it can be concluded that the reinforcement of denture base resin fibre reinforcements improved the flexural strength of the resin and this method should be employed in the fabrication of fracture resistant dentures.

CONCLUSION

This *in vitro* study is performed to compare the flexural strength of conventionally cured denture base and fiber reinforced denture base cured by conventional technique and by microwave processing.

The following conclusions were obtained:

1. The addition of fiber reinforcements significantly increased the flexural strength of denture base resin.

2. The addition of glass fibers showed the maximum increase in flexural strength. Thus the process of reinforcing denture base resins with glass fiber may be a useful way to strengthen denture bases beyond their normal limits.

3. The nylon fiber reinforced specimens also showed improvement in flexural properties as compared to the conventional heat cured specimens.

4. The fiber of choice for reinforcement of dentures is glass fibers due to its suitable aesthetic value, handling characteristics and mechanical properties.

5. Flexural strength of fiber reinforced denture base resin cured by conventional technique was significantly higher than the control group conventional heat cured specimens. This shows that the addition of fiber reinforcements definitely improves the flexural properties of denture base resin and so should be used clinically for reinforcing dentures.

6. Microwave cured reinforced denture base specimens also showed an increased flexural strength as compared to the control group.

7. The effect of different polymerization techniques on flexural strength of fiber reinforced denture base resin was significant. The flexural strength of microwave cured specimens was comparatively less as compared to water bath cured specimens. However the difference suggest that microwave polymerization can also be used for processing fiber reinforced dentures as it is a more neater, cleaner and less cumbersome process.

8. It can be concluded that fiber reinforced acrylic resin is capable of sustaining higher flexure in combination with high resistance to cyclic loading may be less prone to clinical failure and hence should be routinely used in clinical practice to reinforce dentures especially in the thinner sections.

CONFLICTS OF INTEREST

The authors declare they have no potential conflict of interests regarding this article.

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