A comparative study to check fracture strength of provisional fixed partial dentures made of autopolymerizing polymethylmethacrylate resin reinforced with different materials: An *in vitro* study

Parikshit Gupt, Archana Nagpal[1], Rupandeep Kaur Samra[1], Ramit Verma[1], Jasjeet Kaur[1], Surbhi Abrol[1]

Private Practitioner, Prosthodontist, [1]Department of Prosthodontics, Himachal Dental College, Sundernagar, Himachal Pradesh, India

Abstract

Aim: The purpose of the study was to evaluate the fracture strength of provisional fixed partial dentures made of autopolymerizing polymethylmethacrylate (PMMA) resin using different types of reinforcement materials to determine the best among them.

Materials and Methods: Fifty samples were made (10 samples for each group) with autopolymerizing PMMA resin using reinforcement materials (stainless steel wire: looped and unlooped and glass fiber: loose and unidirectional) as 3-unit posterior bridge. The test specimens were divided into five groups depending on the reinforcing material as Group I, II, III, IV, and V; Group I: PMMA unreinforced (control group), Group II: PMMA reinforced with stainless steel wire (straight ends), Group III: PMMA reinforced with stainless steel wire (looped ends), Group IV: PMMA reinforced with unidirectional glass fibers, and Group V: PMMA reinforced with randomly distributed glass fibers. Universal testing machine was used to evaluate and compare the fracture strength of samples. Comparison of mean ultimate force and ultimate stress was done employing one-way analysis of variance and Tukey's *post hoc* tests.

Results: The highest and lowest mean ultimate force and mean ultimate stress were of Group IV and I, respectively. Tukey's *post hoc* honestly significant difference multiple comparison for mean ultimate force and stress shows the increase in strength to be statistically significant ($P < 0.05$) except for the samples reinforced with randomly distributed glass fibers ($P > 0.05$).

Conclusion: Unidirectional glass fibers showed the maximum strength, which was comparable to mean values of both stainless steel wire groups. Low cost and easy technique of using stainless steel wire make it the material of choice over the unidirectional glass fiber for reinforcement in nonesthetic areas where high strength is required.

Keywords: Autopolymerizing polymethylmethacrylate resin, fracture, glass fibers, stress stainless steel

Address for correspondence: Dr. Parikshit Gupt, Akshay Dental Care, 98/2 Ward No. 6, Bangran Road, Sundernagar - 173 025, Himachal Pradesh, India.
E-mail: parikshitgupt@gmail.com
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INTRODUCTION

The use of provisional prosthesis in fixed partial dentures (FPD) in cases with full mouth or partial oral rehabilitation has been an indispensible protocol for restoring function, esthetics, occlusion, and providing pulpal protection until a permanent prosthesis can be given which may take from a week to several months.[1] They should be able to withstand occlusal forces so as to fulfill the above-mentioned requirements during the transitional period.

There are various materials used for fabrication of provisional restorations such as polymethylmethacrylate (PMMA), light-activated urethane dimethacrylate, and bis-acryl composite.[2,3] Out of these, autopolymerizing PMMA resin is the commonly used material for fabricating provisional restoration because of its availability, ease of processing and repair, low cost, and light weight.[3]

Normally, provisional restorations are indicated for a short period. Occasionally, interim treatment has to function for extended intervals and provide long-term tooth protection and stability while adjunctive treatment is accomplished.

The strength of PMMA resin is only about one-twentieth that of metal-ceramic alloys, making fracture of the provisional restorations much more likely, especially for long-span provisional restoration cases, high-stress areas, cases with bruxism, or long-term use.[1,2] The frequent mechanical failures of provisional fixed prostheses usually cause inconvenience, loss of time, and embarrassment for both clinician and patient.

In provisional FPDs made of autopolymerizing PMMA resin, the fracture occurs mostly in the connector region, and thus, reinforcement of this region is very critical.[2] To overcome this problem, either the connector size should be increased or reinforcement can be done to improve its strength and to make it sustainable for longer duration.

Various materials such as stainless steel wires, glass fibers, polyethylene fibers, nylon fibers, and carbon fibers have been used to reinforce autopolymerizing PMMA resin to improve its strength.[3-5] Nylon fibers were found to improve strength of autopolymerizing PMMA resin, but water absorption affected its mechanical properties. Addition of zirconium oxide to the unfilled methylmethacrylate resin, resulted in a composite material exhibiting significant improvements in the modulus of elasticity, transverse strength, toughness, and hardness even though water sorption over time had a negative influence on mechanical properties. Carbon fibers were also known to improve its strength but gave poor esthetics and caused difficulty in polishing. Metal bands increased the stiffness of provisional FPDs, but the influence of the metal bands on the ultimate strength of provisional FPDs was minor. Stainless steel wires of varying thickness have also been used for this purpose but may cause problems in esthetic areas. Still, many stainless steel variants can be used as reinforcement materials in nonesthetic areas because of its low cost as ease of availability.[6] Stainless steel wires were also used with surface treatment like sandblasting to increase surface area of interaction with resin or by achieving chemical bond between PMMA resin and wire by treatment with chemical (silicoater).[7] Carrol and Von Fraunhofer included loops at the end of wire to provide macroscopic retention to improve strength.[8] Glass fiber reinforcement has also been found to enhance its strength without affecting esthetics.[9,10] Many methods for positioning and placement of reinforcing materials have also been described to achieve maximum benefit from the reinforcing material.[4,9,11,12]

Randomly diffused glass fibers in different concentrations were also known to strengthen PMMA resin, but enough data are not available to support their use for reinforcing the provisional restorations.[12]

Various studies have been carried out to evaluate the effect of reinforcement on strength of autopolymerizing PMMA resin. Very little data are available regarding the comparison of fracture strength of provisional fixed partial restoration reinforced with unlooped stainless steel wire, stainless steel wires looped at the ends, unidirectional glass fibers, and randomly diffused glass fibers. Thus, the present *in vitro* study was done to evaluate the fracture strength of provisional FPDs made of autopolymerizing PMMA resin using different types of reinforcement materials to determine the best among them.

MATERIALS AND METHODS

The study was proceeded into the following phases:

a. Fabrication of metal die for a 3-unit bridge
b. Fabrication of test specimens with autopolymerizing PMMA resin. The test specimens were divided into five groups depending on the reinforcing material as given in the following table

   Grouping of test specimens fabricated with autopolymerizing PMMA resin:

   1. Group I: PMMA unreinforced (control group)
   2. Group II: PMMA reinforced with stainless steel wire (straight ends)
   3. Group III: PMMA reinforced with stainless steel wire (looped ends)

4. Group IV: PMMA reinforced with unidirectional glass fibers
5. Group V: PMMA reinforced with randomly distributed glass fibers.

c. Testing of the different group samples for fracture strength under universal testing machine.

Fabrication of master die

A metal die representing two abutments with an edentulous space in between was fabricated [Figure 1]. The die had a rectangular base and two abutments representing mandibular second premolar and mandibular second molar. Before preparation of the abutment teeth, an index was made using polyvinylsiloxane (PVS) putty-wash impression (Putty and light body, Affinis, Coltene). For fabrication of the master die, the abutments were first prepared on typodont model (Frasaco) with a 1 mm wide shoulder finish line and a uniform taper of 6°. Then, first premolar, first molar, and third molar were removed from typodont. The vacant sockets were filled with wax (Modeling wax, Pyrax, Roorkee, India). A PVS putty-wash impression was then made and was poured with blue inlay wax (Pyrax, Roorkee, India) to fabricate wax pattern for master die. Wax pattern was then checked for any inaccuracy. Two rests were prepared on either side of edentulous space buccolingually [Figure 2]. This wax pattern was then sprued and invested using phosphate-bonded investment material and casted to form a metal die. Sandblasting and polishing of the metal die were done to form a finished master die. Purpose of making metal die was to ensure same abutment dimensions for each fabricated autopolymerizing PMMA resin prosthesis.

An all-metal FPD with a sanitary pontic was made on this precision master die. For this, inlay wax (Pyrax, Roorkee, India) was poured in the putty-wash index, made prior to preparation of abutments, and seated on the prepared abutment on the typodont. After complete solidification of wax pattern, it was retrieved and verified on master die [Figure 3]. Marginal fit was checked and necessary corrections were made. Furthermore, the sanitary pontic was made with clearance of 2 mm between the ridge and tissue surface of pontic. This wax pattern was then casted into metal and then finished and polished. Then, PVS putty impression material (Putty and light body, Affinis, Coltene) was placed on edentulous region, and finished 3-unit metal FPD was placed over it. Complete seating was ensured. After complete setting of PVS index, it was retrieved and excess was trimmed and finished. This putty index acted as a block out in fabrication of test samples for creating a sanitary pontic.

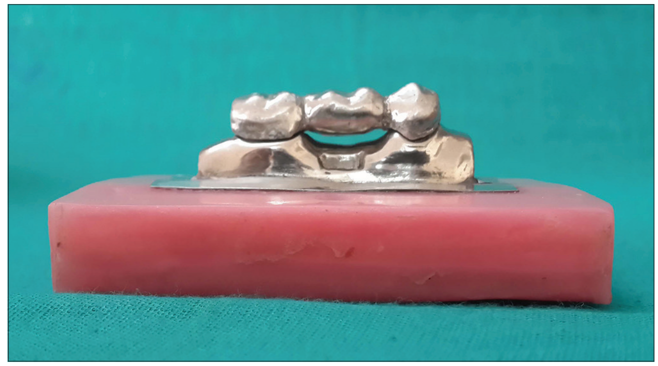


Figure 1: Master metal die with 3-unit metal bridge

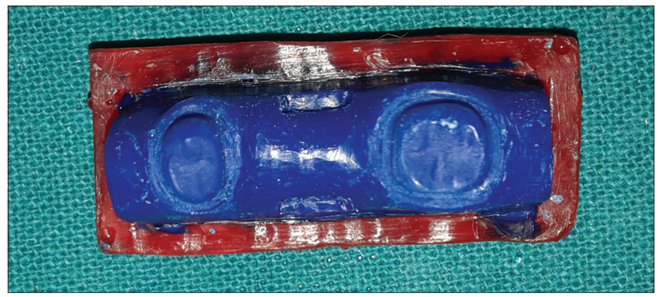


Figure 2: Wax pattern of master die with rests on buccal and lingual side

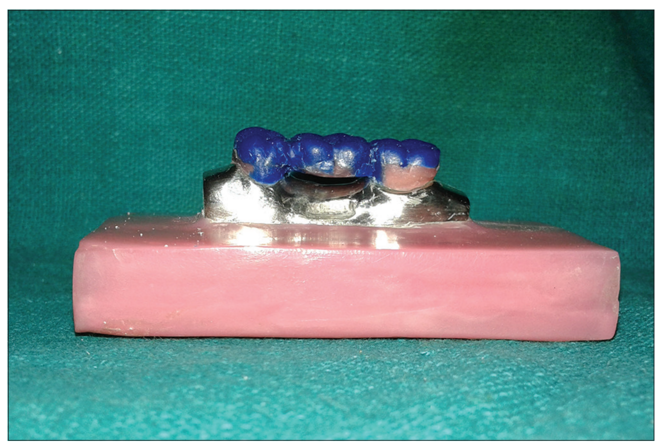


Figure 3: Wax pattern of 3-unit bridge on master die

For fabrication of a sample, a custom tray was made using autopolymerizing PMMA resin (DPI-RR Cold Cure, Bombay Burmah Trading Corporation Ltd.). First, the putty index for sanitary pontic along with the 3-unit metal bridge was seated on the master die, and a putty-wash impression was made. Impression was poured with Type IV gypsum. Two sheets of baseplate wax (Modeling wax, Pyrax, Roorkee, India) were adapted on this model, separating media was applied, and a custom tray was fabricated using autopolymerizing PMMA resin. After complete polymerization of autopolymerizing PMMA resin, the wax spacer was removed, and a putty-wash impression of the master die with putty index and 3-unit metal bridge was made. This impression was used for fabrication of the provisional FPD samples. After fabrication of five samples, the impression was discarded and a new impression was made for further fabrication of samples.

Fabrication of samples

For fabrication of samples for Group I (control group), separating medium (DPI Cold Mould Seal, Bombay Burmah Trading Corporation Ltd.) was applied on the metal die and then PVS index for sanitary pontic was seated. Then autopolymerizing PMMA resin (DPI-RR Cold Cure, Bombay Burmah Trading Corporation Ltd.) was mixed as prescribed by the manufacture. The mixed autopolymerizing PMMA resin in dough stage was carried in the PVS index using stainless steel cement spatula. The index was then seated on the metal die and resin was allowed to polymerize. The impression was removed after 15 min and checked for any inaccuracy. Ten samples were made for this group.

For Group II samples, 19-gauge stainless steel wire (Smith stainless steel wire, K. C. Smith and Co., UK) was used for reinforcement of provisional FPDs. Separating media was applied on the master die. The stainless steel wire was adapted to the occlusal table of prepared tooth and then bent axiogingivally to a level half the height of abutment. The second bend was given to extend the wire horizontally in the edentulous span. An obtuse bend was given at the mesial and distal connector levels to give a V-shape with it apex at mid inferior point of the connector between the pontic [Figure 4]. A little amount of autopolymerizing PMMA resin was mixed and used to stabilize and secure its position [Figure 5]. Rest of the procedure was same as done for the first group. Ten samples were made for this group.

For Group III samples, 19-gauge stainless steel wire (Smith stainless steel wire, K. C. Smith and Co., UK) was used in the same manner as for Group II samples except that it was looped at the free ends. Separating media was applied to the master die [Figure 6]. A little amount of autopolymerizing PMMA resin was mixed and used to stabilize and secure its position [Figure 7]. Rest of the procedure was same as done for the first group. Ten samples were made for this group.

Figure 4: Stainless steel wire configuration with straight ends

For Group IV samples, unidirectional glass fiber (everStick, Stick Tech Ltd, Finland) was used for reinforcement. A strip of unidirectional glass fiber was cut to the length of 2 cm. These fibers were then wet with monomer (DPI-RR Cold Cure, Bombay Burmah Trading Corporation Ltd.) for 10 s [Figure 8]. Separating media was applied on the master die. A little amount of autopolymerizing PMMA resin was mixed and used to stabilize and secure its position [Figure 9]. Rest of the procedure was same as done for the first group. Ten samples were made for this Group.

For Group V samples, loose short glass fibers (Duplep Global Mumbai, India) were used for reinforcement. First, polymer and monomer were dispensed in separate dappen dishes in ratio 3:1 by volume, which was the total amount of material to be used for the samples. This was weighed on electronic weighing balance. The combined weight was 7.54 g (polymer) +2.60 g (monomer) = 10.14 g. The amount of glass fiber to be added was calculated as 1% by weight of resin mix, which came out to be 0.10 g (1% of 10.14 g). For each sample, 0.01 g of glass fibers was used. Glass fibers were cut into short lengths of approximately 2 mm. Now, the glass fibers were dipped in silane coupling agent (Monobond S, Ivoclar Vivadent) for silanization for 10 min in a petri dish [Figure 10]. Then, they were air-dried and again dipped in monomer (DPI-RR Cold Cure, Bombay Burmah Trading Corporation Ltd.) for 10 s [Figure 11]; then, glass fiber was added to the autopolymerizing PMMA resin to form 1% of powder/liquid mix. Separating media was applied to the master die. Rest of the procedure was same as done for the first group. Ten samples were made for this group.

A total of minimum 50 samples were be made [Figure 12]. Each sample was stored in water in a closed jar for a week to simulate intraoral conditions. Each sample was then subjected to Universal Testing Machine (H50KS,

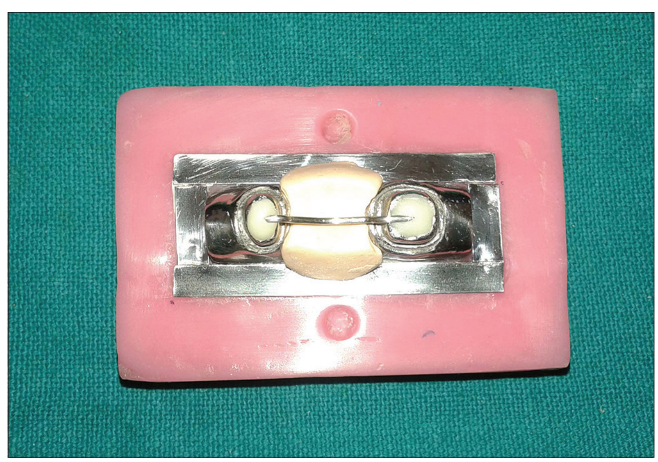


Figure 5: Stabilizing stainless steel wire with straight ends using autopolymerizing polymethylmethacrylate resin

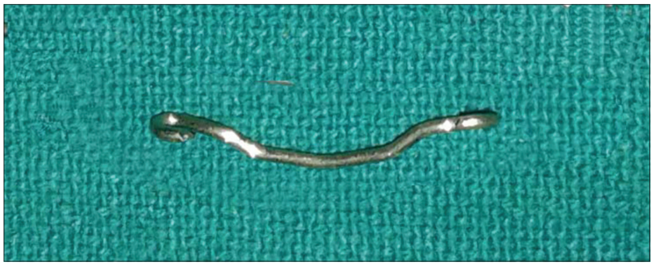


Figure 6: Stainless steel wire configuration with looped ends

Figure 8: Unidirectional glass fibers treated with monomer

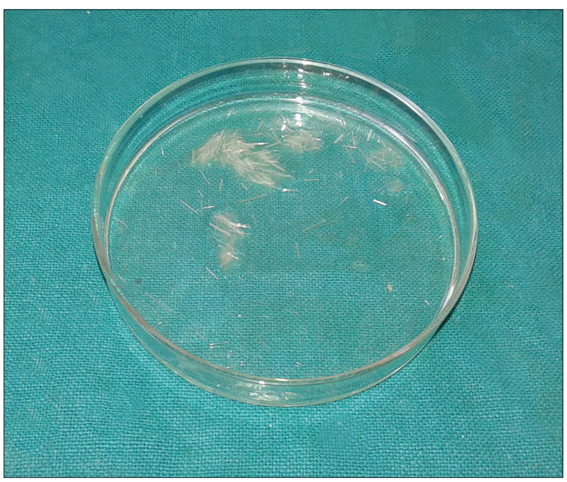


Figure 10: Loose glass fibers treated with silane coupling agent

Tinius Olsen) [Figure 13]. The test samples were loaded with a 5.93 mm diameter steel ball placed on the machine arm loaded in the region of the central fossa of the pontic with a crosshead speed of 5 mm/min till the fracture occurred. Data were recorded for initial fracture in each sample of all the five groups. The results were evaluated and data was analyzed statistically.

The statistical analysis was done using the Statistical Package for the Social Sciences (SPSS) version 16 (IBM Inc., Chicago, IL) Descriptive statistics were used to find

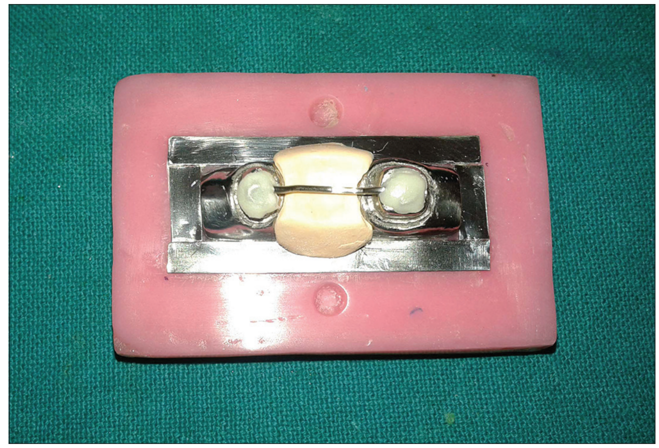


Figure 7: Stabilizing stainless steel wire with looped ends using autopolymerizing polymethylmethacrylate resin

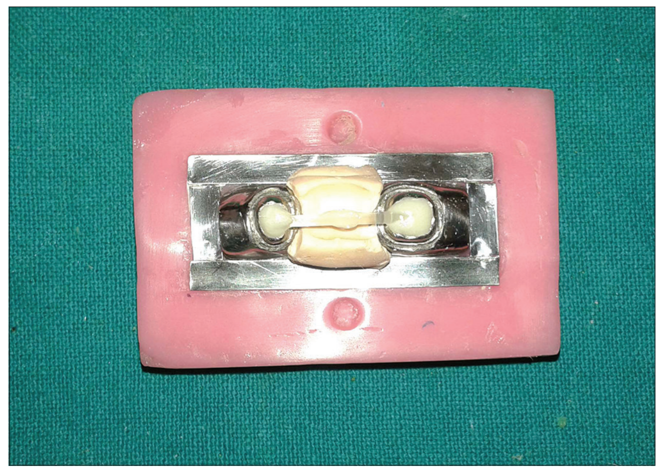


Figure 9: Stabilizing unidirectional glass fiber using autopolymerizing polymethylmethacrylate resin

Figure 11: Loose glass fibers treated with monomer

mean ultimate force and mean ultimate stress in various groups. Comparison of mean ultimate force and ultimate stress was done employing one-way analysis of variance. The level of significance was fixed at $P < 0.05$.

RESULTS

The mean ultimate force of various groups is shown in Table 1 and Graph 1. The mean ultimate force of unreinforced group was 1314 N, for those reinforced with stainless steel wire (straight ends) was 1785.6 N, reinforced with stainless steel wire (looped ends) was 1741.4 N, reinforced with unidirectional glass fibers was 1937.3 N, and reinforced with randomly distributed glass fibers was 1431.4 N.

The mean ultimate stress of various groups is shown in Table 2 and Graph 2. The mean ultimate stress of unreinforced group was 49.72 MPa, for those reinforced with stainless steel wire (straight ends) was 67.12 MPa, reinforced with stainless steel wire (looped ends) was 62.73 MPa, reinforced with unidirectional glass fibers was 70.09 MPa, and reinforced with randomly distributed glass fibers was 52.38 MPa.

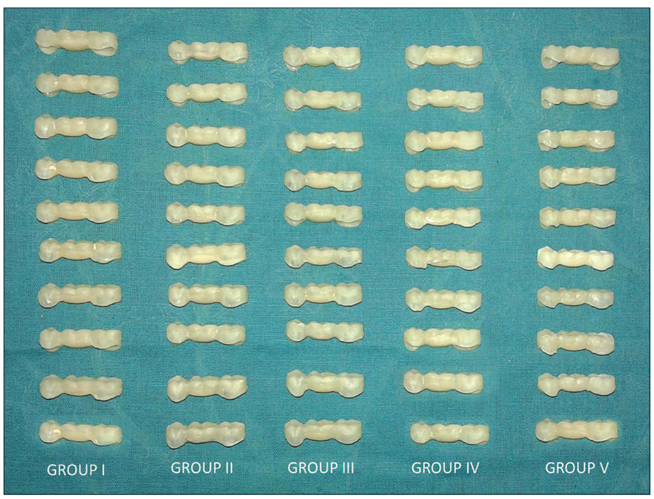
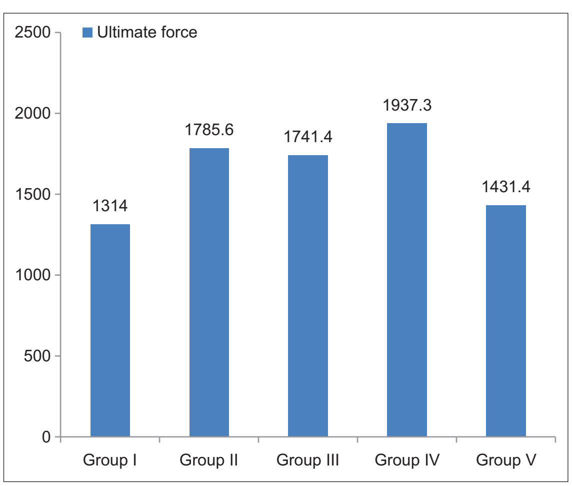


Figure 12: Samples of all groups of autopolymerizing polymethylmethacrylate resin



Graph 1: Graphical representation of mean ultimate force in various groups

In the present study, all the experimental groups other than unreinforced PMMA group samples have shown a definite increase in mean ultimate strength with reinforcements. The fracture resistance of provisional FPDs made of PMMA is definitely improved after reinforcement with glass fibers and stainless steel wire (both looped and straight ends). The samples of PMMA reinforced with unidirectional glass fibers showed the highest mean ultimate strength and those which were unreinforced showed lowest mean ultimate strength.

Similar results were seen with mean ultimate stress. Tukey's *post hoc* honestly significant difference (HSD) multiple comparison for mean ultimate force among all the groups shows that the increase in strength was statistically significant for all experimental groups in comparison with samples of unreinforced PMMA group ($P < 0.05$) except for the samples reinforced with randomly distributed glass fibers ($P > 0.05$). These results also show that samples reinforced with stainless

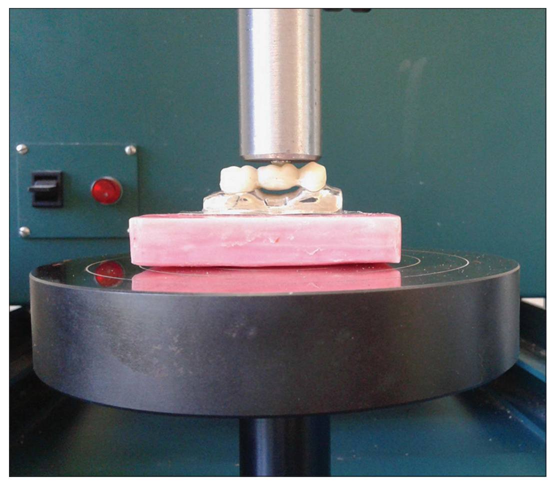
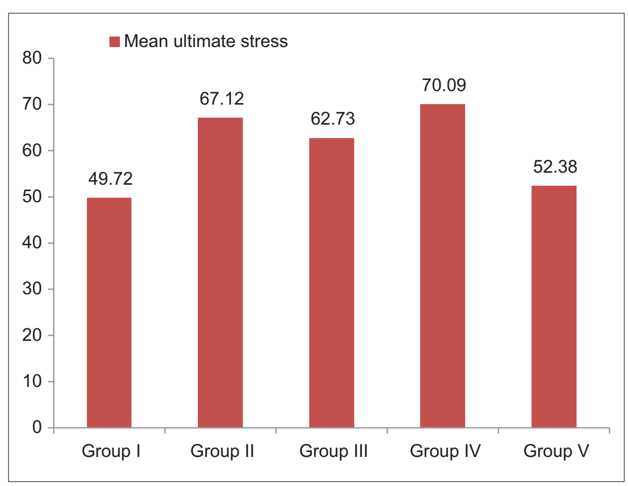


Figure 13: Test sample loaded under universal testing machine



Graph 2: Graphical representation of mean ultimate stress in various groups

steel wire (both with straight ends and looped ends) and unidirectional glass fibers require higher mean ultimate force than the samples reinforced with randomly distributed glass fibers [Table 3]. The Tukey's *post hoc* HSD multiple comparison for mean ultimate stress also gave similar results [Table 4].

DISCUSSION

In the present study, among the various reinforcements used to the increase fracture strength of autopolymerizing PMMA resin, samples reinforced with unidirectional glass fiber showed maximum increase in mean ultimate force and stress followed by samples reinforced stainless steel wire with straight ends, looped ends, and randomly distributed loose glass fibers.

Table 1: The mean ultimate force of various groups

Groups	*n*	Mean (*N*)	SD	Minimum (*N*)	Maximum (*N*)
Group I	10	1314	168.2	1122	1613
Group II	10	1785.6	374.4	1238	2230
Group III	10	1741.4	245.2	1445	2218
Group IV	10	1937.3	382.1	1557	2829
Group V	10	1431.4	107.5	1225	1605

SD: Standard deviation

Table 2: The mean ultimate stress of various groups

Groups	*n*	Mean (MPa)	SD	Minimum (MPa)	Maximum (MPa)
Group I	10	49.72	7.072	42.2	58.8
Group II	10	67.12	13.8	42.4	80.7
Group III	10	62.73	8.14	57.1	80.3
Group IV	10	70.09	13.73	56.4	102.0
Group V	10	52.38	2.55	47.7	56.1

SD: Standard deviation

Table 3: *Post hoc* Tukey's honest significant difference multiple comparison within groups for mean ultimate force

Group I comparison		Mean difference	*P*	Statistical significance
Group I	Group II	−471.6	0.004	S
Group I	Group III	−427.4	0.012	S
Group I	Group IV	−623.3	0.000	S
Group I	Group V	−117.4	0.878	NS
Group II	Group III	44.2	0.997	NS
Group II	Group IV	−151.7	0.750	NS
Group II	Group V	354.2	0.049	S
Group III	Group IV	−195.9	0.534	NS
Group III	Group V	310	0.110	NS
Group IV	Group V	505.9	0.002	S

S: Significant, NS: Not significant

Table 4: *Post hoc* Tukey's honest significant difference multiple comparison within groups for mean ultimate stress

Group I comparison		Mean difference	*P*	Statistical significance
Group I	Group II	−17.4	0.004	S
Group I	Group III	−13.01	0.050	S
Group I	Group IV	−20.37	0.001	S
Group I	Group V	−10.63	0.156	NS
Group II	Group III	4.39	0.871	NS
Group II	Group IV	−2.97	0.966	NS
Group II	Group V	14.74	0.016	S
Group III	Group IV	−7.36	0.499	NS
Group III	Group V	10.35	0.161	NS
Group IV	Group V	17.71	0.002	S

S: Significant, NS: Not significant

As stated earlier, for a reinforcement to successfully reinforce a material, it should have bonding with the matrix of resin. For the bonding of glass fiber, the use of silane coupling agent has been advocated. In case of unidirectional glass fibers, the manufactures provide it with preimpregnation with silane coupling agents. This preimpregnation helps the polymer of high viscosity to achieve better bonding by allowing easy wetting of the glass fiber with monomer of acrylic resin. Wetting with monomer facilitates the resin to contact surface of every fiber, ensuring better bonding resulting in higher fracture resistance. This premodification of the glass fiber supports the result that we have achieved and are in agreement with the studies done by Viswambaran *et al*.,[1] Gupta and Reddy[13] Naveen *et al*.,[14] and Kapri.[15]

Studies conducted by Stipho[12] and Karacaer *et al*.[16] on effect of concentration of loose glass fiber on reinforcement autopolymerizing PMMA resin showed that there was a definite increase in the transverse strength. Their study found that only in specific low concentration of glass fiber, there was enhancement in the strength of resin. They concluded that just 1% of glass fibers were able to increase the strength. Similar study was also done by Solnit[17] However, the increase in strength was not found to be significant to those without reinforcement which was coinciding with our results. Incorporation of loose glass fibers treated with silane coupling agent and autopolymerizing PMMA resin monomer did increase strength but not as much as other reinforcements.

Polymerization shrinkage of acrylic resin and poor wetting of fibers within the dough can lead to voids formation, which can hamper the strength of acrylic. This can be prevented by proper wetting of glass fiber with monomer. However, excess use of monomer would increase the polymerization shrinkage.[3]

The fracture of FPD, when load is applied from occlusal surface, initiates from region facing tension, i.e., the undersurface of pontic. Furthermore, it is stated that reinforcement comes into action only if they are not at neutral axis, which is a line approximately in the middle of the connectors where neither tension nor compression occurs.[17] Moreover, the placement of loose glass fibers cannot be controlled so clumping of fibers is another reason.[12] Hence, the reinforcement with loose glass fibers was not able to give as much strength as other groups, which is in accordance with the above explanation.

The direction of placement of fibers also plays a significant role in increasing the strength when a reinforcement is placed parallel to the long axis of specimen and perpendicularly to the impact force.[3] It was also found that the strength of PMMA resin showed significant increase when reinforced with stainless steel wire, but results were found to be comparable with those of unidirectional glass fiber samples which coincides with the studies done by Viswambaran *et al*.[1] and Vallittu and Lassila[5] This can be attributed to possibility of adhesion of glass fiber with the resin matrix. In a similar study done by Geerts *et al*.,[18] stainless steel wire showed better results than glass fiber but was insignificant ($P > 0.05$). The looped-end stainless steel wire was incorporated to achieve macromechanical bonding between the wire and matrix resin but did not show significant results when compared to straight end wire, although it showed a significant increase from unreinforced samples, probably because it could not bond with the resin but only gained retention in the matrix.

All the precautions were taken following a standard protocol for fabrication of the test specimens. The factors such as the climate temperature, presence of internal porosity, and the releases of stresses during finishing and polishing procedures could not be controlled. Polymerization shrinkage and voids in glass fiber reinforcements could have also altered the results though the standard prescribed procedures were followed.

The intraoral conditions could not be simulated while testing of samples such as repeated rhythmic loading of the prosthesis under masticatory loads, which leads to fatigue of the prosthesis and causes fracture, and also, the lateral forces were not taken into consideration, which if considered would have given more relevant results.

Moreover, only 3-unit bridge span was considered for the study. Therefore, further investigations are required under more closely simulated clinical conditions.

CONCLUSION

Respecting the limitations of our study, the following conclusions are drawn:

1. There was definite increase in the fracture strength of the experimental groups in comparison with samples made of autopolymerizing PMMA resin without any reinforcement
2. Unidirectional glass fibers showed the maximum strength, which was comparable to mean values of both stainless steel wire groups
3. Low cost and easy technique of using stainless steel wire make it the material of choice over the unidirectional glass fiber for reinforcement in nonesthetic areas where high strength is required.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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