

Original Article

Flexural strength of polymethyl methacrylate reinforced with high-performance polymer and metal mesh

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ABSTRACT

Background: The flexural strength (FS) of a denture base material is of great concern, and many approaches have been used to strengthen the denture acrylic resins. The present study aimed to evaluate the effect of high-performance polymer (BioHPP) and metal mesh reinforcement on the FS of a heat-cured poly methyl methacrylate (PMMA) acrylic resin.

Materials and Methods: This experimental study was done on 30 rectangular specimens (64 mm × 13 mm × 3 mm) of a heat-cured PMMA resin. The specimens were divided into three groups ($n = 10$) to be reinforced with either metal mesh or BioHPP mesh; one group was left nonreinforced, serving as the control group. The FS of specimens was assessed through a 3-point bending test by using a universal testing machine at a crosshead speed of 2 mm/min. Kruskal–Wallis H and Dunn's *post hoc* tests were used to compare the FS among the groups ($\alpha = 0.05$).

Results: The FS in the metal-reinforced group was statistically significantly higher than the two other groups ($P < 0.001$). However, the FS of the BioHPP-reinforced samples was not statistically significantly higher than the nonreinforced ones ($P = 0.614$).

Conclusion: Reinforcing the PMMA with metal mesh significantly enhances its FS while BioHPP has no significant effect on the PMMA FS.

Key Words: Flexural strength, polyetheretherketone, polymethyl methacrylate, reinforcement

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INTRODUCTION

Since its introduction, polymethyl methacrylate (PMMA) resin has been extensively used in denture fabrication due to its favorable features such as ease of handling and repair, satisfactory esthetic characteristics, low cost, low water sorption and solubility, and adequate strength.^[1] However, it has some drawbacks such as dimensional instability, poor mechanical properties, and residual monomer content. In addition, this material is an insulator, and

thus, does not transmit temperature changes, which is important for gustatory sensation.^[2-4] The weak mechanical properties of PMMA can cause fracture in denture base material. The fracture of this material is usually due to its low impact, transverse, and fatigue strength.^[4,5]

Prosthodontists have previously pursued numerous methods for reinforcement of PMMA denture base material.^[1,3,6,7] Several researchers have employed

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a stainless steel mesh to enhance the mechanical properties of acrylic denture base material.^[8,9] However, none of these metal reinforces have gained wide acceptance among the dentists due to the recurrence of denture base fractures. Moreover, stainless steel mesh improves the transverse strength of PMMA resin only slightly. Besides, the fractured denture base which is reinforced with metal wires would be more difficult to repair because of the wires bulging from the fractured site.^[7]

High-performance polymer (BioHPP) is a thermoplastic polymer based on polyetherketone (PEEK), which has been created and optimized for dental use. PEEK is a synthetic polymeric material that was used in medical orthopedics for years.^[10] The high-mechanical strength of BioHPP is due to the special ceramic filler with a grain size of 0.3–0.5 μm .^[11] Ease of preparation and use, biocompatibility, measurable resistance of approximately 600 MPa, white color and acceptable esthetics, lack of abrasive effects on the remaining tooth structure, high polishability, and least environmental contamination are among the favorable properties of this thermoplastic polymer.^[12-14]

BioHPP is among the materials that have been recently implemented in dentistry, especially for dental implants as a framework material in implant-based bridges.^[15] This novel material is superior to metal mainly because of its white and esthetically satisfying appearance. Besides, this substance does not pose a risk of galvanic shock. Moreover, BioHPP can be applied in delicate thicknesses; it is easily polished, and does not abrade the natural teeth. This material is also as elastic as a natural bone and quite cost-effective.^[11,15]

In the study by Vosshans *et al.*,^[15] the application of BioHPP in dental restorations showed favorable advantages such as stress-free primary framework, fixedness of prostheses, convenient insertion/removal of the removable prostheses for patients, good hygiene, plaque resistance, color stability, and low weight. In another study, Bechir *et al.*^[11] assessed the properties of BioHPP as a superstructure material in oral implantology. They found that BioHPP possesses favorable features for the fabrication of fixed prosthetic restoration such as superstructure on dental and implant abutments.

One of the major advantages of this material for the implant-based prosthesis is its lower modulus of elasticity compared with metal and its cushion effect

to reduce the forces implemented on the implant.^[16] BioHPP can also be used for the framework of partial dentures, fabrication of removable dentures-obturators, as well as the crowns and bridge restorations.^[14,17,18]

Controversies still exist regarding the effectiveness of metal reinforcement, and no definite solution is known to increase the strength of acrylic resin denture base materials. No study has ever evaluated the effect of BioHPP material on the flexural strength (FS) of PMMA denture base material. Hence, the present study was designed to assess the effect of a novel material called BioHPP and metal reinforcement on the FS of heat-cured PMMA. The null hypothesis was that neither the BioHPP nor the metal reinforcement material could enhance the FS of PMMA denture base material.

MATERIALS AND METHODS

In this experimental study, a stainless steel metal mold (64 mm \times 13 mm \times 3 mm) was prepared based on ASTM D790 (American Society for Testing and Materials) (2010) [Figure 1].^[19] Ten perforated special trays were made by using self-cure acrylic resin (GC Unifast III, GC Corp., Tokyo, Japan). From the metal mold, 30 impressions were made with silicone impression material (Speedex, Coltene, Swiss) and poured with dental stone (Fujirock, GC Dental Industrial Corp., Tokyo, Japan) [Figure 2].

The fabricated stone molds were divided into three groups ($n = 10$) according to the reinforcement material. Two groups of molds were scanned by a digital scanner (Aadva Lab Scan, GC Co, Tokyo, Japan). Then, by using a CAD-CAM system (Myplant, Addtech Co., Seoul, Korea), 10 metal and 10 BioHPP meshes (Bredent, GmbH & Co, Germany) [Figure 3a and b] were prepared with the dimensions of 1 mm \times 8 mm \times 60 mm (thickness \times width \times length)



Figure 1: A stainless steel metal mold.

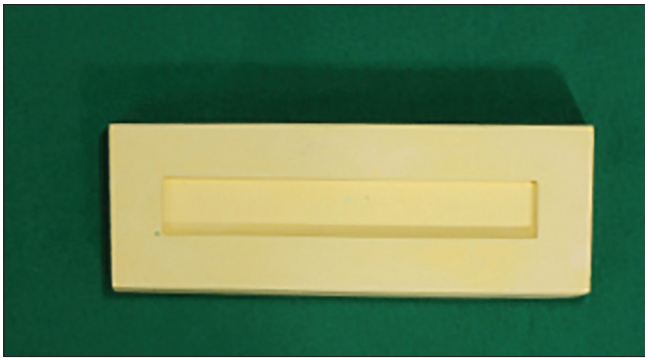


Figure 2: Stone mold.

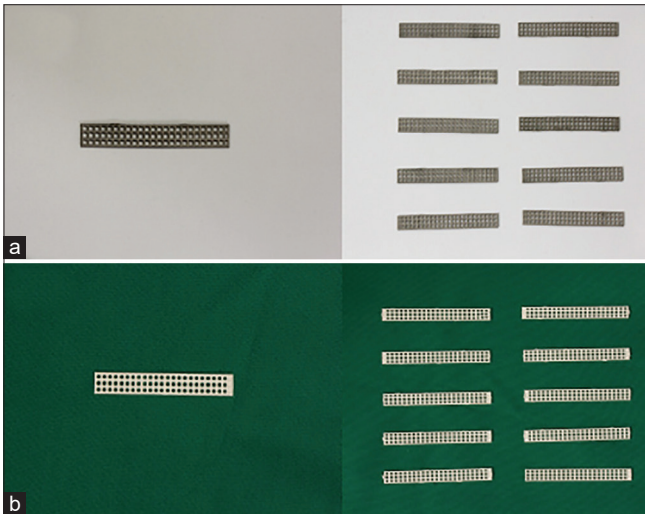


Figure 3: (a) Metal meshes, (b) High-performance polymer meshes.

and 4 stops on four sides of the specimens. No frame was designed for the remaining 10 stone molds serving as the control group. To prepare metal meshes, CAD-CAM wax (Ceramill Mall; Amann Girrbach; Koblach, Austria) was placed into the CAM milling machine to fabricate the wax frames. Then, the wax frames were cast by a casting machine (BEGO; Nautilus CC Plus; Lincoln, NE, USA) using the 4-all metal alloy (4-all, Ivoclar Vivadent, Liechtenstein).

The stone molds were all filled with wax (Delar Corp., Lake Oswego, OR, USA) and flaked. Having burned out the waxes from the flasks, the BioHPP and metal frames were placed in their respective molds ($n = 10$). Heat-cure PMMA (Meliodent, Heraeus, Kulzer GmbH, Germany) was poured in all of the molds. The flasks were closed, pressed, and heated according to the manufacturer's instructions. After deflasking, the acrylic specimens were retrieved, finished, and polished according to the manufacturer's instructions [Figure 4]. Dimensions of the specimens

were measured by using a digital caliper (Fowler High Precision, Newton, Massachusetts, USA) and set to 64 mm × 13 mm × 3 mm.

All the specimens were stored in water at the room temperature for 2 weeks before testing. According to ISO/DIS 1567, the FS of all specimens was measured by using 3-point bending test [Figure 5] with a universal testing machine (Zwisch/Roell Z020, Germany) at a crosshead speed of 2 mm/min.^[20] The FS was calculated with the following formula:

$$FS = 3 \times F \times L/2 \times b \times h^2.$$

Where FS is flexural strength, F is the maximum load applied, L is the span length, b is the sample width, and h is the sample thickness.

The data were statistically analyzed with the SPSS software (SPSS for Windows; version 13.0, SPSS Inc., IL, USA). Kolmogorov–Smirnov and Levene's tests were used to assess the normality assumption and homogeneity of variances, respectively. The median, mean, and standard deviation (SD) values were reported. The FS was compared among the groups using nonparametric Kruskal–Wallis H and Dunn's *post hoc* tests. All analyses were done at the significance level of alpha = 0.05.

RESULTS

Table 1 shows the mean ± SD of the FS values in the study groups. As displayed in Figure 6, the highest FS was observed in the metal-reinforced group, which was significantly higher than that in the BioHPP-reinforced ($P < 0.001$) and control groups ($P < 0.001$). The FS values were not statistically significantly different between the BioHPP-reinforced and the control group ($P = 0.614$).

DISCUSSION

This *in vitro* study evaluated the effect of various reinforcement techniques on the FS of PMMA. The null hypothesis was rejected as the findings revealed significantly higher FS in the metal-reinforced group compared with the BioHPP-reinforced and nonreinforced groups.

Studies have previously examined the effect of various forms of metal reinforcement on the mechanical strength of PMMA.^[9,21] In a study by Vallittu and Lassila,^[9] the thick wires which were subjected to sandblast showed better adhesion to the acryl and

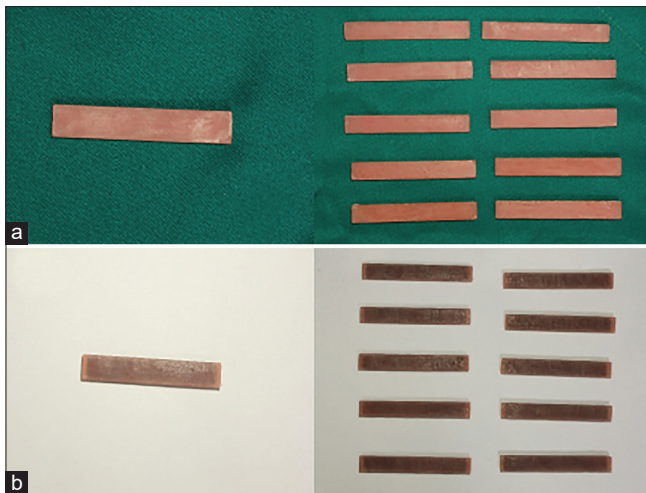


Figure 4: (a) Poly methyl methacrylate specimens reinforced with high-performance polymer mesh, (b) poly methyl methacrylate specimens reinforced with metal mesh.

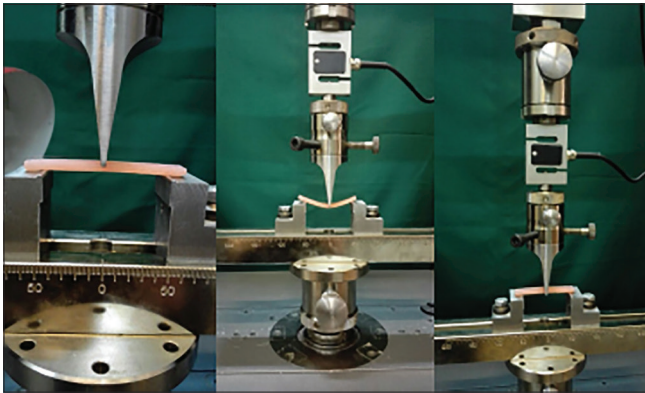


Figure 5: Three-point bending test.

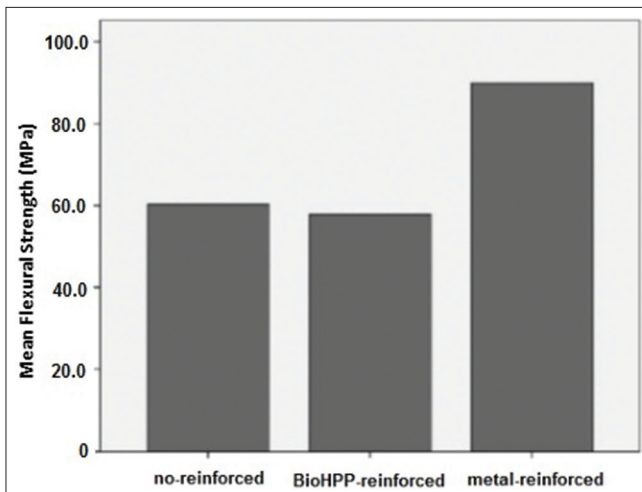


Figure 6: Mean \pm standard deviation of flexural strength of different groups.

significantly increased the resin fracture resistance. In line with the present study, Polyzois concluded that the addition of a metal mesh to PMMA would

increase its fracture strength.^[22] In another study, Lee *et al.*^[23] detected that the incorporation of metal wire in poly (ethyl methacrylate), significantly improved its FS.

The favorable properties of metal reinforcement could be related to the higher modulus of elasticity of the metal mesh compared with the acryl, which results in the force absorption by the metal without any significant deformation. Although the metal could compromise the integrity of the acrylic structure, as a solid foundation, it protects the remaining acrylic structure from deformation and its consequent potential failure.^[21] However, in contrast to our findings, Vallittu^[24] claimed that the stainless steel mesh could not significantly increase the transverse strength of PMMA resin.

Studies on glass fibers have also shown similar promising reinforcement effects. The application of these fibers has been reported to reinforce the acryl, probably due to their high-elastic modulus.^[1] However, most of these investigations did not consider the clinical conditions such as the presence of saliva, body temperature, and the presence of cyclic forces, and they often tested static forces.

A major problem with these metal reinforcements is the dark metal shadow, which is visible from the underlying acryl in the esthetic areas. Therefore, several alternatives of metal such as glass, Aramide, Kelvar, and nylon have been proposed and evaluated; the results of which are quite different and diverse.^[6,25,26]

Concerning the metal-resin-related problems, previous clinical studies reported that BioHPP could be an alternative framework material for full-arch restorations.^[14,16] The present study used this novel substance as an esthetic substitute of metal mesh for strengthening the PMMA. However, the findings revealed that BioHPP could not improve the FS of heat-cured PMMA; thus, it cannot be a suitable alternative to metal reinforcement. A possible reason could be related to the low thickness of BioHPP mesh (1 mm), which results in the bending and fracture of the frame and acryl.

In the present study, three-point bending test was used for measuring the FS of specimens, since this test can precisely simulate the type of force applied on the denture through mastication.^[8] The bending test not only assesses the strength but also gives an estimate of the material rigidity.^[27]

Table 1: Median (mean±standard deviation) values of the flexural strength (MPa) of the study groups

Experimental groups	Flexural strength	Pairwise comparisons
Nonreinforced heat-cure resin	59.20 ^b (60.24±4.28)	1 versus 2 (P=0.614)
BioHPP-reinforced heat-cure resin	57.11 ^b (57.89±9.47)	1 versus 3 (P<0.001)
Metal-reinforced heat-cure resin	87.68 ^a (89.84±13.70)	2 versus 3 (P<0.001)

Different lower case letters indicate significant difference between the groups (alpha=0.05). HPP: High-performance polymer

The limitation of the present study was that the effect of thermomechanical cycling was not measured. Moreover, these reinforcing materials are likely to diminish the mechanical properties of acrylic resins over time, and consequently the denture longevity. Thus, there is an urge to simulate the clinical conditions in further investigations.

CONCLUSION

With respect to the findings of this study, it can be concluded that using metal mesh to reinforce the PMMA, considerably enhances the FS of heat-polymerized denture base resin; while, BioHPP does not have such a significant effect. Accordingly, BioHPP is not a suitable substitute for metal reinforce to enhance the FS of PMMA denture base material.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

REFERENCES

- Somani MV, Khandelwal M, Punia V, Sharma V. The effect of incorporating various reinforcement materials on flexural strength and impact strength of polymethylmethacrylate: A meta-analysis. *J Indian Prosthodont Soc* 2019;19:101-12.
- Gungor H, Gundogdu M, Yesil Duymus Z. Investigation of the effect of different polishing techniques on the surface roughness of denture base and repair materials. *J Prosthet Dent* 2014;112:1271-7.
- Mansour MM, Wagner WC, Chu TM. Effect of mica reinforcement on the flexural strength and microhardness of polymethyl methacrylate denture resin. *J Prosthodont* 2013;22:179-83.
- Praveen B, Babaji HV, Prasanna BG, Rajalbandi SK, Shreeharsha TV, Prashant GM. Comparison of impact strength and fracture morphology of different heat cure denture acrylic resins: An *in vitro* study. *J Int Oral Health* 2014;6:12-6.
- Kanie T, Fujii K, Arikawa H, Inoue K. Flexural properties and impact strength of denture base polymer reinforced with woven glass fibers. *Dent Mater* 2000;16:150-8.
- Doğan OM, Bolayir G, Keskin S, Doğan A, Bek B, Boztuğ A. The effect of esthetic fibers on impact resistance of a conventional heat-cured denture base resin. *Dent Mater J* 2007;26:232-9.
- Foo SH, Lindquist TJ, Aquilino SA, Schneider RL, Williamson DL, Boyer DB. Effect of polyaramid fiber reinforcement on the strength of 3 denture base polymethyl methacrylate resins. *J Prosthodont* 2001;10:148-53.
- Sakaguchi RL, Powers JM. *Craig's Restorative Dental Materials-e-Book*. Saint Louis: Elsevier Health Sciences; 2012.
- Vallittu PK, Lassila VP. Reinforcement of acrylic resin denture base material with metal or fibre strengtheners. *J Oral Rehabil* 1992;19:225-30.
- Georgiev J, Vlahova A, Kissov H, Aleksandrov S, Kazakova R. Possible application of biohpp in prosthetic dentistry: A literature review. *Journal of IMAB* 2018;24:1896-8.
- Bechir ES, Bechir A, Gioga C, Manu R, Burcea A, Dascau IT. The advantages of biohpp polymer as superstructure material in oral implantology. *Mater Plast* 2016;53:394-8.
- Andrikopoulou E, Zoidis P, Artopoulos II, Doukoudakis A. Modified PEEK resin bonded fixed dental prosthesis for a young cleft lip and palate patient. *J Esthet Restor Dent* 2016;28:201-7.
- Cigu AT, Ciobanu C, Covalciuc E, Popovici M, Cărligeanu L, Ardeshir S. Research of biohpp system behavior in the oral cavity. *Int J Med Dent* 2015;19:44-51.
- Zoidis P, Papanthasiou I, Polyzois G. The use of a modified poly-ether-ether-ketone (peek) as an alternative framework material for removable dental prostheses. A clinical report. *J Prosthodont* 2016;25:580-4.
- Vosshans J, Schelhove M, Schnieder F. Biohpp-a metal-free material for prosthetic restorations. *Zahntech Mag* 2013;17:138-43.
- Al-Rabab'ah M, Hamadneh W, Alsalem I, Khraisat A, Abu Karkay A. Use of high performance polymers as dental implant abutments and frameworks: A case series report. *J Prosthodont* 2019;28:365-72.
- Biris C, Bechir ES, Bechir A, Mola FC, Badiu AV, Oltean C, et al. Evaluations of two reinforced polymers used as metal-free substructures in fixed dental restorations. *Mater Plast* 2018;55:33-7.

18. Bolat M, Bosinceanu DG, Sandu IG, Bosinceanu DN, Surlari Z, Balcos C, *et al.* Comparative study on the degree of bacterial biofilm formation of dental bridges made from three types of materials. *Mater Plast* 2019;56:144-7.
19. ASTM I. Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. ASTM D790-07; 2007.
20. Alharez AO, Ahmad ZA. Effect of al₂o₃/zro₂ reinforcement on the mechanical properties of pmma denture base. *J Reinf Plast Comp* 2011;30:86-93.
21. Ruffino AR. Effect of steel strengtheners on fracture resistance of the acrylic resin complete denture base. *J Prosthet Dent* 1985;54:75-8.
22. Polyzois GL. Reinforcement of denture acrylic resin: The effect of metal inserts and denture resin type on fracture resistance. *Eur J Prosthodont Restor Dent* 1995;3:275-8.
23. Lee JI, Jo JY, Yun MJ, Jeon YC, Jeong CM, Huh JB. Comparison of metal wire reinforcement and glass fiber reinforcement in repaired maxillary complete denture. *J Korean Acad Prosthodont* 2013;51:284-91.
24. Vallittu PK. A review of methods used to reinforce polymethyl methacrylate resin. *J Prosthodont* 1995;4:183-7.
25. John J, Gangadhar SA, Shah I. Flexural strength of heat-polymerized polymethyl methacrylate denture resin reinforced with glass, aramid, or nylon fibers. *J Prosthet Dent* 2001;86:424-7.
26. Singh K, Sharma SK, Negi P, Kumar M, Rajpurohit D, Khobre P. Comparative evaluation of flexural strength of heat polymerised denture base resins after reinforcement with glass fibres and nylon fibres: An *in vitro* study. *Adv Hum Biol* 2016;6:91-4.
27. Yunus N, Rashid AA, Azmi LL, Abu-Hassan MI. Some flexural properties of a nylon denture base polymer. *J Oral Rehabil* 2005;32:65-71.