IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 22, Issue 6 Ser.7 (June. 2023), PP 24-31
www.iosrjournals.org

Comparative Evaluation Of Flexural Strength And Hardness Of Heat-Cure PMMA When Reinforced With Kevlar Fibers, Nylon Fibers, Metal Mesh, And Fiberglass Mesh – In Vitro Study.

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Abstract:
Aim and objectives:*The purpose of the study is to evaluate & compare the flexural strength and hardness of heat-polymerized PMMA when reinforced with Kevlar fibers, nylon fibers, metal mesh, and fiberglass mesh.*
Materials and methods:*A total of 50 rectangular specimens of similar dimensions of heat-cured acrylic resin, 10 specimens of each group were fabricated according to ISO standardization. Group I (control group) consisted of specimens with no reinforcement. Specimens in group II were reinforced with nylon fibers. Group III specimens were reinforced with Kevlar fibers. Specimens in group IV were reinforced with metal mesh. Specimens in Group V were reinforced with glass fiber mesh. FS was evaluated with a three‑ point bending test and hardness using the Rockwell hardness test. The results were analyzed with a one‑ way analysis of variance.*
Results:*All reinforced specimens showed better FS than the conventional acrylic resin. Specimens reinforced with glass fiber mesh showed the highest FS, followed by metal mesh. The hardness of kevlarfibers decreased slightly compared to the control group.*
Conclusion:*Within the limitations of this study, the FS of heat‑ polymerized PMMA denture resin was improved after reinforcement with glass fiber mesh and metal mesh, whereas the hardness of Kevlar fibers decreased slightly.*
Key word: *Kevlar fibers, nylon fibers, metal mesh, fiberglass mesh.*

Date of Submission: 02-06-2023 Date of Acceptance: 12-06-2023

I. Introduction

Loss of tooth is common phenomenon which is most significant among geriatric population. Owing to the advances with continuous improvements in medical domain, rapid increase in specialization and treatment modalities are observed in practice. So, it is realized that these improvements prolonged the life span of the human and drastically increased the life expectancy of elderly people within past few decades. Denture base material plays an important role in the construction of complete denture and removable partial denture prostheses. Several materials have been tried as denture base which includes wood, swaged metal, plastic, vulcanite, bakelite, etc. For the past few decades, polymethylmethacrylate is successfully used and it has been accepted as the material of choice for denture base fabrication.Polymethylmethacrylate (PMMA) is the most commonly used denture base material. PMMA remained the most preferred material of choice for the fabrication of complete as well as partial denture prostheses. Its biocompatibility, ease of handling, dimensional stability in oral conditions, low density, ability to repair, and low cost of production made it popular. The major drawback of PMMA is its inadequate mechanical and physical properties such as low flexural strength (FS), low impact strength (IS), low thermal conductivity, low elastic modulus, and low surface hardness which leads to the reduced clinical performance of the denture. With use, the denture base is subjected to many different influences such as biting forces, thermal changes, exposure to saliva, food, and water, and mechanical blows, which may result in denture failure.Several studies have been conducted to enhance the properties of PMMA by using different curing methods and/or incorporating fillers/fibers in its composition.The addition of fibers and mesh to PMMA is a commonly used method to improve both its physical and mechanical properties. This in vitro study was performed to evaluate and compare the flexural strength and hardness of commonly used heat cure acrylic resin, heat cure acrylic resin reinforced with different fibers and different mesh.

II. Materials And Methods

The denture base resin used in the present study was heat-cured polymethyl methacrylate (DPI limited, Mumbai, India). Kevlar fibers (Ceat Ltd, Calcutta, India), nylon fibers (Ceat Ltd, Calcutta, India), metal mesh (Crown dental depo, Visakhapatnam, India), and glass fiber mesh (Ceat Ltd, Calcutta, India) were used for reinforcement.

Preparation of gypsum molds to obtain the acrylic specimen:

Wax patterns (65 mm x 10 mm x 3 mm) were prepared using modelling wax and invested in the dental flask in the conventional manner using model plaster. After an hour of investing, the flask was kept for dewaxing. Any wax residue was removed by washing the mold with hot water. They were cleaned and allowed to dry. The mold was then ready to be used for the preparation of acrylic specimens.

Preparation of PMMA resin specimens:

The test specimens were fabricated with dimensions of 65 mm x 10 mm x 3mm (according to the American dental association specification no. 12). This enables the specimens to be tested for hardness on Rockwell hardness tester and flexural strength on Instron Universal Testing Machine.

A total of 50 specimens were fabricated for this study, which were divided into five groups, 10 specimens of each.

Group 1 - Control [unreinforced] specimens.
Group 2 - PMMA resin reinforced with Kevlar fibers.
Group 3 - PMMA resin reinforced with Nylon fibers.
Group 4 - PMMA resin reinforced with Metal mesh.
Group 5 - PMMA resin reinforced with Glass fiber mesh.

Group I: The control group test specimens were made with conventional heat-polymerized acrylic resin. A mixture of monomer and polymer in the ratio of 1:2.4 by weight was allowed to reach the dough stage, then kneaded and placed in the mold space. After completion of the polymerization cycle, the flask was allowed to cool in the water bath to room temperature before deflasking. The acrylic specimens were then retrieved, finished, and polished.

Group II and group III: Consisted of heat cure acrylic resin specimens of the same dimensions reinforced with Nylon and Kevlar fibers respectively. The fibers had a thickness of 10 to 15 µm and were cut to 5 mm in length. These 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 were mixed thoroughly to disperse the fibers. The mixture was kneaded and packed into the mold space upon reaching the dough stage. The specimens were allowed for polymerization and retrieved as followed in the control group.

After deflasking, if the specimens revealed exposed fibers at the peripheral border, trimming was performed with diamond burs to avoid delamination of the reinforcement. The specimens were then finished and polished.

Groups IV and V: Consisted of heat cure acrylic resin specimens of the same dimensions reinforced with metal and glass fiber mesh. These mesh had a thickness of 0.5mm and were positioned along the length of the specimen.

Testing of Hardness

The load was applied on the test specimen by a diamond or ball indenter for a specified dwell time. After the load was released, the final depth of indentation was recorded. Load position was measured which was converted to the Rockwell hardness number.

HR = N - (d/s)

- N and S were scale factors depending on the scale of test being used.
- D - The penetration depth measured from zero points (in mm).

Testing of flexural strength

The specimens were subjected to a three-point bending test with universal testing machine (model 3366, Instron). The test was conducted at a crosshead speed of 2mm/min. The span of this 3-point deflection test was 50 mm with a load of 250 kg applied at the center of the specimen. The peak load at fracture was noted. FS values were automatically calculated by the software and the results were recorded. The breaking load was converted to FS by the formula:

$FS = 3FL/2bd^2$

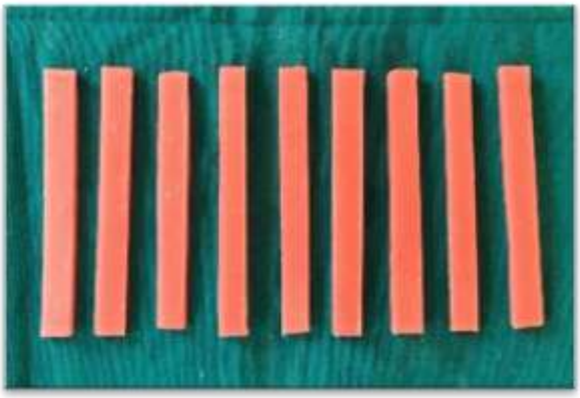
Where FS is flexural strength,

F - Load at fracture,
L - Length between the jig tips (50 mm),
b – Width of test sample,
d - Thickness of the test sample.
After the data collection, the results were analyzed statistically by means of one-way ANOVA to see if there were significant differences among groups.

DPI Heat cure acrylic

NYLON AND KEVLAR FIBERS

METAL AND FIBER MESH

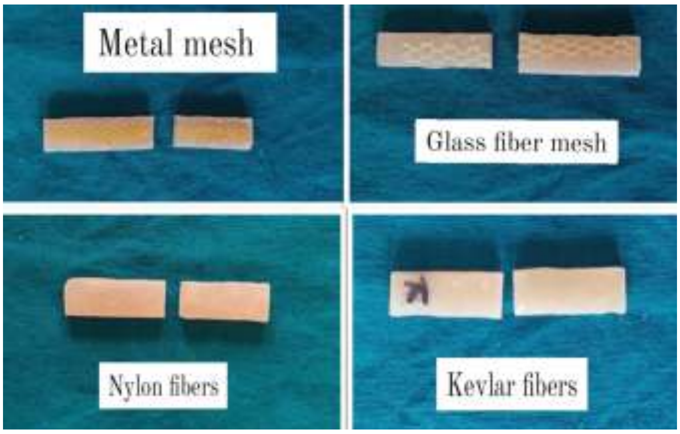


WAX PATTERNS

SPECIMENS

APPLICATION OF LOAD FOR TESTING HARDNESS USING ROCKWELL HARDNESS TESTER

APPLICATION OF LOAD FOR TESTING FLEXURAL STRENGTH USING UNIVERSAL TESTING MACHINE



DEFORMED SAMPLES

III. Results

One-way ANOVA (table-1, 2) showed significant differences in flexural strength among groups. The mean FS of Kevlar fibers group (106.87 MPa) was more than Nylon fibersgroup.A statistically significant difference was found between the FS which indicates that the increase in the FS was due to the addition of the kevlar and nylon fibers.

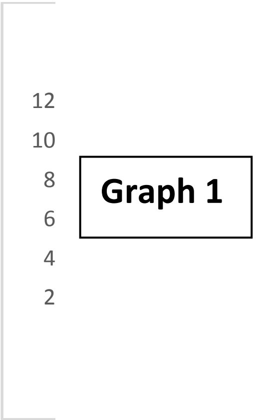
In graph 1, the mean flexural strength of all group were analyzed in which Kevlar group showed higher flexural strength 106.87 (MPa) when compared to other group.

Table 1:

Groups	N	Mean	Std. Deviation	Std. Error
Control	10	76.59	6.06	1.91
Kevlar	10	106.87	3.94	1.24
Nylon	10	104.47	5.28	1.67

Table 2:

Source of variation	Sum of squares	Degree of freedom	Mean square	F - stat	P-value
Between groups	5644.9	2	2822.4	107.1	0
Within groups	711.2	27	2653.3		
Total	6356	29			



Graph 1

When a comparison was made among the mesh-reinforced groups (table 3, 4), the mean FS of the glass fiber mesh group (136.4 Mpa) was more than the metal mesh group (124.3 Mpa).

A statistically significant difference was found between the FS which indicates that the increase in the FS was due to the addition of the glass fiber mesh and metal mesh.

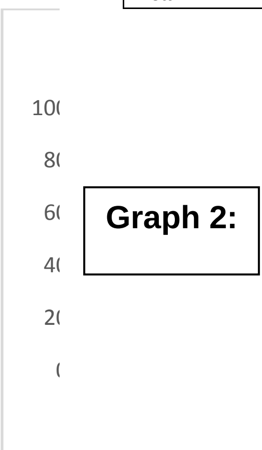
In graph 2, the mean flexural strength of all group were analyzed in which glass fiber mesh group showed higher flexural strength 136.4 (MPa) when compared to other group.

Table 3:

Groups	N	Mean	Std. Deviation	Std. Error
Control	10	76.59	6.06	1.91
Metal mesh	10	124.34	3.36	1.06
Glass fiber	10	136.36	4.26	1.34

Table 4:

Source of variation	Sum of squares	Degree of freedom	Mean square	F - stat	P-value
Between groups	1971.2	2	9880	466.9	0
Within groups	571.3	27	2521.6		
Total	2542	29			



Graph 2:

When a comparison was made among the groups (table 5,6), the mean hardness of the kevlar group (70.3) decreased slightly when compared to the nylon (74.91) and control groups (72.50).

In graph 3, the hardness of all group were analyzed in which nylon fibers group showed higher hardness when compared to other groups.

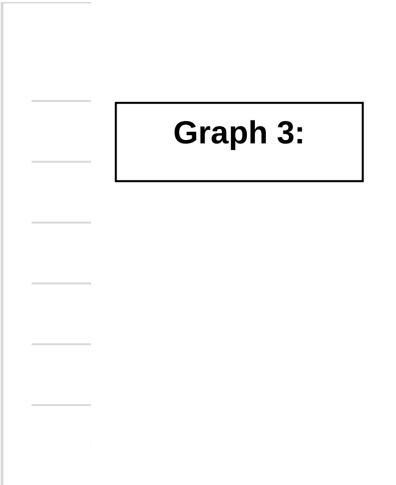
Table 5:

Groups	N	Mean	Std. Deviation	Std. Error
Control	10	72.500	4.26	0.71

Kevlar	10	70.330	3.95	1.97
Nylon	10	74.910	4.32	1.36

Table 6:

Source of variation	Sum of squares	Degree of freedom	Mean square	F - stat	P-value
Between groups	142	2	71.0	3.28	0
Within groups	584	27	21.6		
Total	726	29			



Graph 3:

When comparison was made among the groups (table 7,8), the mean hardness of the glass fiber mesh group (93.6) was more than metal mesh (85.3).

In graph 4, the hardness of all group were analyzed in which glass fiber mesh group showed higher hardness when compared to other groups.

Table 7:

Groups	N	Mean	Std. Deviation	Std. Error
Control	10	66.50	2.26	0.71
Metal mesh	10	85.30	3.18	1.06
Glass fiber	10	93.63	3.84	1.21

Table 8:

Source of variation	Sum of squares	Degree of freedom	Mean square	F - stat	P-value
Between groups	3852	2	1926.4	191.8	0
Within groups	271.1	27	10.042		
Total	4123.9	29			

Graph 4:

The results obtained in this study revealed that all the reinforcement groups namely Kevlar fibers, nylon fibers, metal mesh and glass fiber mesh improved the flexural strength and hardness of heat cured acrylic resin samples except the Kevlar fibers group where its hardness decreased.

IV. Discussion

Polymethylmethacrylate (PMMA) resin is the material of choice for the fabrication of denture bases. The popularity of PMMA in dentistry is due to its ease in processing, less cost, lightweight, aesthetic characteristics, less water sorption, and solubility. However, inferior mechanical strength, low thermal conductivity, brittleness, and a high coefficient of thermal expansion make the material more prone to failure during clinical service. Therefore, many attempts have been made to improve the strength properties of acrylic denture bases. Various fibers such as nylon, and kevlar and different mesh-like metal mesh and glass fiber mesh have been used as reinforcement materials to increase the strength of conventional heat cure PMMA resin. This in vitro study was conducted to compare the effect of reinforcement on the flexural strength and hardness of conventional heat cure denture base resin by reinforcing with kevlarfibers, nylon fibers, glass mesh, and metal mesh and comparing it with the control group.

The study found that the flexural strength and hardness among mesh type group – glass fiber mesh reinforced group exhibited higher flexural strength and hardness followed by metal mesh and control group. This was primarily due to its high specific modulus and specific strength. Because the modulus of elasticity of glass fibers is very high, most of the stresses were received by them without any deformation. It enhances the flexural strength of conventional acrylic due to increased filler content in the matrix that allows wider force dissipation. Thus, glass fiber mesh-reinforced specimens exhibited better flexural strength than the other groups in this study.

Higher surface hardness was caused by the addition of cross-linking material in the acrylic resin. The cross-linking material can enhance surface hardness and reduce the water absorption amount of a denture base.

The study found that the flexural strength – among fibers group – kevlarfiber groups were higher followed by nylon fiber. Aramid (kevlar) is a generic term for wholly aromatic fibers. These fibers are resistant to chemicals, are thermally stable, and have high mechanical stability, melting point, and glass transitional temperature. They also have a pleated structure (molecules are radially arranged in the form of sheets) that makes aramid weak as far as flexural, compression, and abrasion behavior are concerned. Nylon fibers are polyamide fibers and are based primarily on aliphatic chains. The chief advantage of nylon lies in its resistance to shock and repeated stress. In this study, nylon-reinforced specimens bases had a higher fracture resistance than the control PMMA specimens. The decreased surface hardness of the kevlar-reinforced group may be caused by both the effects of the incorporated fibers and the reduced proportion of the resin matrix.

Limitations

1. It was an in-vitro study.
2. An increase in the length of fibers may alter the flexural strength.
3. Changes in the orientation of fibers also alter flexural strength.
4. The Kevlar fibers used in this study could not be used clinically because of their yellow tint.

V. Conclusion

Within the limitations of this study, the reinforcement of denture base resin with different fibers and different mesh improved flexural strength. While hardness was found to be slightly decreased with the kevlarfiber group. Glass fiber mesh exhibited superior flexural strength and hardness when compared to metal mesh and control group. Among the fibers reinforced groups, Kevlar fiber group possessed superior flexural strength but its hardness decreased.

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