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Evaluation of Flexural Strength of Conventional Acrylic Denture Bases Reinforced with Various Forms of Polyethylene Fibers with High Impact Acrylic Resins: An Invitro Study

Pavani Lukka[1]* M. Sujesh[2] C. Ravi Kumar[3] Srujana Zakkula[4] Sunitha Kollu[5]

[1]Assistant Professor, Department of Prosthodontics, Mamata Dental College, Mamata Dental College, Khammam, Telangana, India.
[2]Professor, Department of Prosthodontics, Mamata Dental College, Mamata Dental College, Khammam, Telangana, India.
[3]Professor and Head, Department of Prosthodontics, Mamata Dental College, Mamata Dental College, Khammam, Telangana, India.
[4]Reader, Department of Prosthodontics, Mamata Dental College, Mamata Dental College, Khammam, Telangana, India.
[5]Reader, Department of Prosthodontics, Mamata Dental College, Mamata Dental College, Khammam, Telangana, India.

ABSTRACT

Background: The purpose of this study was to compare the flexural strength of polyethylene fiber-reinforced denture base resins with conventional and high impact resins.

Materials and methods: A total of 100 specimens were divided into five experimental groups, each group containing 20 samples. Group A- unmodified Poly (methylmethacrylate) (PMMA), Group B- the addition of 2% filamentous polyethylene fibers to PMMA, Group C- the addition of 2% chopped polyethylene fibers to PMMA, Group D- the addition of woven form of polyethylene fibers to PMMA, Group E- high-impact PMMA. Flexural strength was evaluated with a three-point bending test. Multiple comparisons within different study groups were made using Tukey's HSD Post hoc Analysis.

Results: All reinforced specimens showed better flexural strength than the conventional and hi-impact acrylic resin. Specimens reinforced with the woven form of polyethylene fibers showed the highest flexural strength followed by specimens reinforced with the chopped and filamentous form of polyethylene fibers.

Conclusion: Within the limitations of this study, the flexural strength of heat polymerized PMMA denture resin was improved after reinforcement with the woven form of polyethylene fibers.

Keywords: Flexural Strength, Polyethylene Fibers, Resin Reinforcement, high-impact denture base resin.

INTRODUCTION

In the year 1937, Dr. Walter wright clinically evaluated poly(methyl methacrylate)PMMA and found that it fulfilled all the requirements of an ideal denture base material. Such as its favorable working characteristics, processing ease, accurate fit, stability in the oral environment, excellent color stability, superior esthetics, and use with inexpensive equipment. [1]

Despite its exceptional properties, the Poly (methylmethacrylate) (PMMA) has few disadvantages, such as low impact strength, low fatigue resistance, low thermal conductivity, and ease of microbial adhesion to intaglio surface. Among these, the most common is the frequent fracture of dentures because of fatigue and chemical degradation of the base material.

Most fractures of the dentures occur inside the mouth during function, primarily because of resin fatigue. [2] Flexural fatigue occurs after repeated flexing of a material; it is a fracture mode whereby a

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*__Correspondence Dr. Pavani Lukka.__
Department of Prosthodontics, Mamata Dental College, Mamata Dental College, Khammam, Telangana, India.
Email: pavani.chitturi82@gmail.com
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structure eventually fails after being repeatedly subjected to small loads that are not detrimental to the component individually. [3]

Several experiments have been conducted to overcome these shortcomings, such as the introduction of various substitutes for Poly (methyl methacrylate) such as nylon, polycarbonates, and polyamides, incorporation of fibers, metal inserts, or beads.[4] Reinforcement of Poly (methyl methacrylate) has been approached through a chemical modification to produce graft copolymer (butadiene-styrene rubber) of rubber methacrylate, known as high impact resin. Although the material is clinically successful, the cost restricted its use. [5]

Also, fiber reinforcement has advantages when compared with other reinforcement methods, including improved esthetics, enhanced bonding to the resin matrix, and ease of repair. Fiber reinforcement has been used to overcome the mechanical limitations of the denture base polymer. [6] Recently, various types of fibers, such as carbon fiber, aramid fiber, and ultra-high molecular weight polyethylene fibers, have been investigated as reinforcing materials. However, carbon fiber has a sparing nature in handling and is less aesthetic than any other fiber. Aramid fiber also displays some disadvantages like poor aesthetics and difficulty in polishing.

Earlier in vitro studies have been done using rectangular strips of denture base resin as per the ADA specification. Still, very few studies simulate the maxillary arch configuration. The present study was carried out to evaluate and compare the flexural strength of denture bases made of conventional heat cure resin, denture bases made of conventional heat cure resin reinforced with a filamentous, chopped, and woven form of polyethylene fibers, and denture bases made of high impact acrylic resin.

MATERIALS AND METHODS

In this study, the flexural strength of denture base resins modified with three different forms of Polyethylene fibers was compared to the high impact denture base resin.

The three forms of Polyethylene fibres are chopped, filamentous, and woven forms, which were incorporated into the polymer of the conventional denture base resin.

Master denture base fabrication

An edentulous maxillary cast was obtained by pouring dental stone in silicone maxillary edentulous mould by using manufacturer recommended water powder ratio. The baseplate wax was uniformly adapted over the cast by softening it in a controlled water bath. The thickness of the baseplate wax is confirmed to two mm using the calibrated periodontal probe. Then the denture base was acrylised using the conventional method. After finishing and polishing, the thickness of the master denture base was verified for standardization using a measuring gauge.

Specimen fabrication

To ensure better bonding, polyethylene fibers were immersed in monomer for ten minutes, then removed, and excess liquid was allowed to dry. The fibers were mixed thoroughly in the resin for proper dispersion. Using the master denture base as standard, all other modified denture base specimens were fabricated. If the samples revealed, exposed fibers at the peripheral border, trimming was performed with diamond burs to avoid delamination of the reinforcement, and fine abrasive was used without altering the specimen surfaces and dimensions.

A total of 100 specimens were fabricated for the study, which was divided into five groups of 20 specimens each.

Group A: Control group PMMA (TREVALON)

Group B: 2% Filamentous polyethylene fibers + PMMA (TREVALON)

Group C: 2% Chopped polyethylene fibers + PMMA (TREVALON)

Group D: 2% Woven polyethylene fibers + PMMA (TREVALON)

Group E: HI impact acrylic resin (TREVALON HI)

All the samples were preserved in the water at room temperature for one week (Figure. 1) and are later tested for their flexural strengths.

Testing of prepared specimens

All the groups were subjected to flexural loading using a universal testing machine, and flexural strength was evaluated. Before the samples were tested for flexural strength, they were measured for length and breadth with digital vernier caliper

a) Length: measured from labial notch to center of posterior palatal seal area, which was 48mm.

b) Breadth: measured from left buccal notch to right buccal notch which was 45mm

c) Thickness was two mm uniformly.

All the specimens were tested in a similar manner with a load cell having 250 kilo Newton capacity, and a vertical force was applied at the middle of the specimen, by a chisel, at a crosshead speed of five mm/min and a span length of 40 mm, until fracture of the specimen occurred with flexural loading.

Fracture of the specimen was indicated by a sharp crackling sound accompanied by a sudden drop in the digital signal. The amount of load required to induce failure was recorded in MPa (N/mm2). The results are recorded through the three-point bending test.

Flexural strength is calculated as follows:

S=3FL/2bd2

S - Stress

F - Load/Break at heat (N)

L – length between the supports

b - Width of specimen

d - Thickness of specimen

Statistical Analysis:

The obtained data were subjected to the Shapiro Wilk normality test, which showed the data was normally distributed.

Therefore, the statistical analysis was carried out using parametric tests. The mean & standard deviation scores of the flexural strength were obtained and compared with different study groups using ANOVA Test. Multiple comparisons within different study groups were done using Tukey's HSD Post hoc Analysis. The statistical significance [P-value] was fixed at P<0.001.

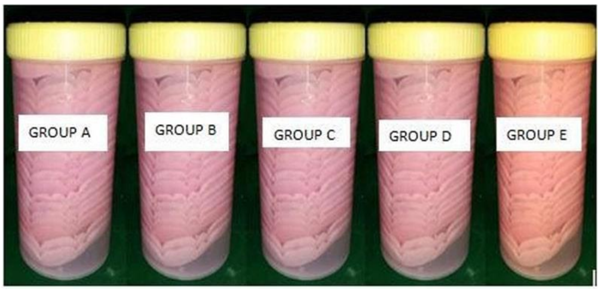

Fig 1: storage of denture base specimen in distilled water.

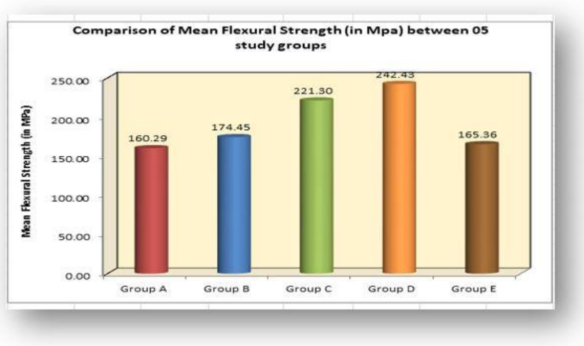

Fig 2: Comparison of mean flexural strength among 05 study groups.

RESULTS

When a comparison was made among the groups, (Figure.2) mean flexural strength of Group D (242.42 Mpa) is more than Mean flexural strength value of Group A (160.29Mpa) Group B (174.45Mpa), Group C (221.30Mpa), Group E (165.36 Mpa) mean flexural strength values measured between the groups were statistically significant (P<0.001)

Further comparative analysis was done among the tested groups by using Tukey's HSD Post Hoc analysis. (Table.1)

There was statistically significant difference with mean values between group A and group B samples, group A and group C samples, group A and group D, group A and group E, group B and group C samples, group B and group D, group B and group E samples, group C and group D, group C and group E samples, group D and group E samples(P <0.001) comparison of mean flexural strength among 5 study groups shown in (Table.2)

DISCUSSION

The denture base resins were 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 frena, sharp changes at the contours of the denture base, deep scratches, and induced processing stresses.[7] To overcome these shortcomings, various attempts were made to Poly (methyl methacrylate) in order to improve the mechanical properties, especially flexural strength by chemical modification and mechanical reinforcement. The graft copolymers of rubber methacrylate produced by chemical modifications were known to resist fracture. The most common method of strengthening denture base polymers has been adding reinforcements, such as metal wires and plates, to the denture base polymer. However, metal reinforcing materials were problematic because their bonds with the resin matrix were weak. In addition, metal is unacceptable clinically because of its low aesthetic properties. Another method that has been used to reinforce the polymethyl methacrylate is adding various types of fiber reinforcements. Effective fiber reinforcement depends on many variables, including the type of fiber, the percentage of fiber in the matrix, the modulus and distribution of the fibers, fiber length, orientation, form, and interfacial bond. [8]

In the present study, polyethylene fibers were preferred when compared to other fibers due to their high biocompatibility, low density, low cost, a high degree of toughness, strength, and fibers appear to be transparent.[9,10] Braden M et al., in 1988[11] stated that surface modification must be done to improve chemical bonding between fibers and resin matrix. Some of the techniques followed are silane treatment, monomer treatment, microwave treatment, and plasma treatment. Heat cure Acrylic resin material preferred as a material of choice. Even though cold cure Acrylic resin material can be used as denture base materials, it differed from heat-cure Acrylic resin in its properties like increased residual monomer content, incomplete polymerization leading to inferior mechanical properties and compromised biocompatibility.[12] The present study deals with the comparative evaluation of flexural strength of conventional heat cure denture base resin, various forms (filamentous, chopped, woven) of polyethylene fibers reinforced conventional heat cure denture base resin and hi-impact heat cure denture base resins. The amount of polyethylene fibers used in the present study was restricted to 2wt%. Gutteridge in 1988[13] stated that the use of fiber 4% by weight is difficult to pack, and resultant dough becomes dry. In the present study, the resins were processed by the conventional water bath technique.

To yield an even layer of acrylic resin on the surface of fibers, the polymerization shrinkage inside the fiber should be minimal. Polymerization shrinkage can be minimized by adding Polymethyl methacrylate powder to Methyl methacrylate liquid that was supported by Aydin C, Yilmaz H, and Caglar A in 2002.[14]Powder and the liquid was mixed according to manufactures recommendations so that proper polymer to monomer balance achieved. The resin was processed by a short curing cycle.[15] Prior to mixing the fibers with polymer and monomer, the fibers were immersed in a beaker with monomer liquid for better adhesion with the resin matrix.[16] Mixing was done incrementally for thorough dispersion of fibers. Once the mix reached the dough consistency, it was kneaded by hand to increase its homogenicity and integrity and then packed in the mould.

All samples were saturated by storing in distilled water at room temperature to maintain 100% humidity. The water uptake varies with time for the different denture base material, but they are usually saturated after seven days. Before the samples were tested for flexural strength, they were measured in three dimensions with a digital vernier calliper.[17]. These dimensions enable the samples to be tested on the Universal testing machine (three-point bending apparatus) for measuring flexural strength. Flexural strength tests were undertaken as these were considered relevant to the loading characteristics of a denture base in a clinical situation. The strength of a material in bending, expressed as the stress on the outermost fibers of a bent test specimen, at the instant of failure.[18]

A three-point bending test was performed on a universal testing machine at a crosshead speed of 5mm/min.[19]. The samples of permanent denture bases were kept with the non tissue side that is the polished surface towards the chisel head of the universal testing machine. According to Ramos V, Runyan DA, and Christensen le in 1996[20] span of the three-point flexural test were 40mm. This dimension represents the space between maxillary molars in a complete denture. The load was applied to the centre of the sample until the fracture occurred.

The orientation of fibers in the polymer matrix also influences the mechanical properties of fiber composite. The fibers oriented perpendicular to the direction of applied forces offer the greatest potential for improvement of flexural fatigue and bending properties of denture base resins. It was known that when the directional orientation of the fiber is with their long axis perpendicular to an applied force. It has been shown that voids of poorly impregnated fiber composite were oxygen reserves to allow oxygen to inhibit radical polymerization of the acrylic resin inside the composite. This can lead to higher residual monomer content of fiber composite and reduced strength of fiber composite.

All the specimens were tested for flexural strength, and obtained results showed that flexural strength was increased by adding woven form of polyethylene fibers to polymethyl methacrylate. The highest flexural strength was observed for Group D (242.43) followed by Group C (221.30), Group B (174.45), Group E (165.36), Group A (160.2). There was a statistical difference between the obtained values at $P<0.001$.

Further observations revealed that specimens reinforced with a woven form of polyethylene fibers (Group D) showed highest flexural strength values followed by specimens reinforced with a chopped form of polyethylene fibers (Group c) and filamentous form of polyethylene fibers (Group B), specimens made of hi-impact acrylic resin (Trevalon-HI), specimens made of conventional acrylic denture base resins.

An increase in flexural strength on the reinforcement of acrylic resin with plasma etched ultrahigh modulus polyethylene fibers was reported by Gutteridge. Ladizesky in 1993 has observed that incorporation of woven high-density polyethylene fibers substantially increased the impact strength of acrylic denture base resins. This was because they observed that the fiber/ resin integration within the denture was excellent, suggesting that increasing the number of reinforcing layers should be a feasible possibility. An increase in flexural strength with the incorporation of polyethylene fibers was due to a good interfacial bond between the fibers and the acrylic resins.

The woven reinforcement is very effective in arresting crack propagation. The interesting outcomes of this experiment were that the denture bases reinforced with the woven form of polyethylene fibers have shown the crack on the tension side but would not propagate through to the compression point. The embedded fiber could not be stretched enough for the crack in the resin to continue. The fiber appears to hold the two pieces together. Some fibers may be located perpendicular to the midline of the denture would be useful to prevent midline fractures of the dentures through flexural loading.

Even though High impact denture base resins had better mechanical properties when compared with conventional heat cure resins, they were economically not viable. To overcome this, in this study, the comparison of flexural strength was done between the specimens made of conventional heat cure denture base resins, conventional heat cure denture base resin reinforced with various forms of polyethylene fibers, and high impact acrylic resin.

In this study, the mean flexural strength of samples fabricated from the hi-impact acrylic resin was slightly higher compared to that of unreinforced conventional denture base resin and lower than the conventional denture bases reinforced with various(filamentous, chopped, woven) forms of polyethylene fibers, which was statistically significant.

The limitations of the study were

1. The clinical conditions were not simulated.
2. Even though the dimensions of the specimens were standardized, the strength of the reinforced Poly (methyl methacrylate) orally in the presence of the saliva cannot be anticipated.

3. Major difficulties in using fibers with polymers include the difficult handling of the fibers due to the fraying and spreading of the fibers to undesired regions of the denture.

In spite of limitations mentioned earlier, if the protocol of this study is followed, the flexural strength of Poly (methyl methacrylate) added with the woven form of polyethylene fibers showed higher values compared to other groups.

Since commercially available high impact resins were expensive and polyethylene fibers were proved to be economically viable, and their colour is neutral, fabrication of complete denture can be done with the incorporation of the woven form of polyethylene fibers.

1. Further studies can be conducted by using microwave polymerization instead of conventional polymerization.
2. A further study is needed to investigate the nature of the reinforcement afforded by the fiber.
3. The effect of long term immersion in water on the fiber/ resin interface and on mechanical properties is of particular importance.
4. Other factors to be considered are the effect of the fibers on the oral mucosa, whether or not they project from the resin following wear and how various cleaning or polishing procedures affect the surface.

CONCLUSION

Within the limitations of the study, it can be concluded that the addition of the woven form of polyethylene fibers to the denture base enhances flexural strength over other forms of fiber-reinforced and conventional dentures.

CONFLICTS OF INTEREST

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

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