Original Article

In vitro Evaluation and Comparison of Transverse and Impact Strength of Heat Polymerized Acrylic Resin Reinforced with Polyethylene Fibers and Polypropylene fibers

Deepan. N[1], Arun Prakash.C[2], Bharath Rao. K[3], Abhay Sonthalia[4]

[1]Consultant and Prosthodontist, Deepam Multi speciality Dental clinic and hospital, Raja Street, Chengam, Tamil Nadu; [2]Department of Prosthodontics, [3]Department of Oral Biology, Faculty of Dentistry, Melaka Manipal Medical College, Manipal University, Manipal, Karnataka; [4]Consultant Prosthodontist, Smile O Care, No 14, Watkins lane, Gokul Apartment, Howrah

Abstract

Purpose: To evaluate and compare the transverse and impact strength of heat polymerized acrylic resin reinforced with polyethylene fibers and polypropylene fibers in vitro. **Materials and methods:** The specimens were fabricated from the custom made split brass moulds with a dimension of 64X13X3 mm as per ASTM standards. The specimens were tested for transverse bend test and impact test using Lloyd's universal testing machine for 3 point bend test and Izod digital impact tester. The results were compared with the unreinforced control group. **Results:** The results were analyzed with 1- way analysis of variance (ANOVA) using Fisher test. The highest mean impact strength value was obtained for non reinforced Trevalon Hi and the lowest mean impact strength value was obtained for Trevalon reinforced withpolyethylene of all tested groups. When reinforced with polypropylene, Trevalon Hi had the highest impact strength and flexural strength. When reinforced with polyethylene fibers, Travelon Hi showed highest impact strength and flexural strength of both the resins were similar. The highest modulus of elasticity was recorded for polypropylene fiber reinforced Trevalon Hi group. **Conclusion:** Reinforcement with the fiber is an effective method to improve the impact and transverse strength of PMMA denture base resin .The reinforcement of polypropelene fibers in the mesh form can be an effective method to increase the longevity of the dentures made with Trevalon Hi resins.

Key Words: Denture base resin, Transverse strength, Impact strength, Polyethylene fibers.

Corresponding Author: Dr. Arun Prakash.C, Assistant Professor, Department of Prosthodontics, Faculty of Dentistry, Melaka Manipal Medical College, Manipal University, Manipal, Karnataka. Email: arunprakash1980@gmail.com

Received: 30-05-2014 Accepted: 11-06-2014

This article may be cited as: Deepan N, C Prakash A, K Rao B, Sonthalia A. In vitro Evaluation and comparison of transverse and impact strength of heat polymerized acrylic resin reinforced with polyethylene fibers and polypropylene fibers. J Adv Med Dent Scie 2014;2(2):46-56.

Introduction:

Poly (methyl methacrylate) [PMMA] is the most widely used denture base material. Dr. Walter Wright evaluated PMMA and found that it fulfilled most of the requirements of an ideal denture base material.[1] The advantages of heat polymerized acrylic resin includes good esthetics, ease of processing, reparability, favorable physical and mechanical properties, usage with inexpensive

equipments and its limitations being its poor resistance to impact and flexural forces which reduces the life span of the denture.[2] Denture fracture is a most common problem which causes inconvenience to both the dentist and patient. Studies have found that, 68% of dentures break within few years after fabrication due to impact failure and nearly one million dentures were repaired every year and the cause of the fracture includes poor resistance of denture base materials to stresses caused either by flexural or impact forces.[3] Many methods have been adopted to strengthen denture base resins such as incorporating metal wires.[4,5] The primary problem in using metal wire is poor adhesion between the wire and resin matrix. The strength of polymethyl methacrylate can be improved by incorporation of a rubber phase in the bead polymer or by reinforcement with high modulus fibers. This has successfully improved the property of impact resistance but has detrimental effects on the modulus of elasticity and hence the rigidity of denture base.[6,7] Various other modifications of denture base materials include incorporation of glass, sapphire, aramid, carbon and nylon fibers.[8-14] The problem with all these fibers are they break the homogenous matrix of acrylic resin due to poor interface between the fibers and resin which invariably affects the mechanical properties. Reinforcement by polyethylene fibers has shown to increase the mechanical properties of polymethylmethacrylate without affecting its esthetic qualities.[16-19] The polypropylene fibers are widely used to improve the mechanical properties of plastics and concrete materials. [20] It is also used in the field of surgery for hernia repair, because of its improved mechanical properties and the biocompatibility.[21]

This study was conducted to evaluate and compare the impact and flexural strength of two commercially available heat polymerized denture base resins (Trevalon and Trevalon-hi) reinforced with polyethylene and polypropylene fibers.

Materials and Method:

A total of one hundred and twenty rectangular acrylic test specimens were prepared. 60 specimens were used for Trevalon (Group A) and 60 specimens were for Trevalon Hi (Group B). Group A was further sub grouped into A1, A2, and A3 of 20 samples each. A1 specimens were acrylized without any fiber reinforcement, A2 and A3 specimens were acrylized reinforcing with polyethylene and poly propylene fibers respectively. Trevalon Hi (Group B) was sub grouped into B1, B2, and B3 and tested in a similar fashion. (Table I, Figure 1).

Figure 1: Wax patterns invested in the flask

Table I: Grouping Of Specimens

Specimen	Impact strength	Flexural strength	Total No. of specimens
A1	10	10	20
A2	10	10	20
A3	10	10	20
B1	10	10	20
B2	10	10	20
B3	10	10	20
			120

A custom made split brass mold with dimension 64 X 13 X 1.5 mm was used to prepare wax patterns. The two wax patterns were fused together to obtain a sample of dimension 64X13X3 mm as per ASTM standards.[20]

The test specimens were invested using Type III dental stone in the dental flask. The wax pattern was made to flush with stone surface in the lower portion of the flask at its middle half, so that after dewaxing two equal mold spaces are created to facilitate fiber reinforcement in the center. (Figure 2)

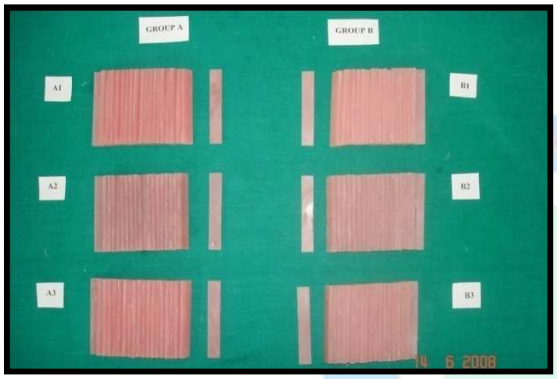


Figure 2: Picture showing all the samples

After dewaxing, the entire mold was then cleaned with a piece of cotton saturated with a solvent (Xylene) and flushed with boiling water. After applying 2 coats of separating media, the acrylic dough was packed into both halves of the flask according to manufacturer's instructions. The flask was positioned in the bench press and subjected to a compression of 1500 psi for trial closure. Then flask was opened flash was carefully removed

Groups A1 and B1 were used as control without any reinforcement. They were directly subjected to final closure. For groups A2 and B2 after trial closure the precut polyethylene fiber mesh of size 60 X 8 mm were dipped/ dried in monomer and then approximately centered on the packed resin for reinforcement (Figure 3). Similarly for groups A3 and B3 polypropylene fiber mesh of similar size was used. Final closure was done under compression of 3500 psi. Bench curing was done for 60 minutes, so that there is uniform distribution of monomer throughout the resin.

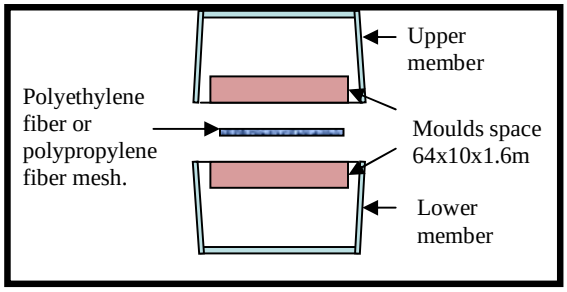


Figure 3: Diagrammatic representation of reinforcement of fibers.

The specimens were acrylized at 74 degree C and held for 2 hours, then raised to 100 degree C and was maintained for 1 hour.[2] Then they were retrieved from the mold and finished to the dimension 64 X 10 X 3 mm with tungsten carbide acrylic trimmers and wet waterproof sandpaper.[23,24] The specimens were then stored in water bath for two weeks at 37° C until fully saturated.

The impact strength test was done when the specimens were dried for 1 hour and was measured using an Izod digital impact tester.[2,7,14] (Figures 4 and 5).

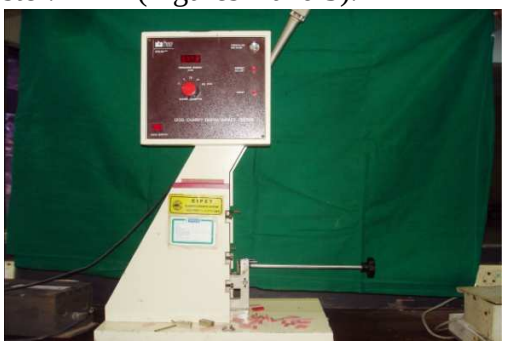


Figure 4: Izod Digital impact tester.

This machine has pendulum type hammer which is standardized, to comply with certain requirements including a fixed height of hammer fall which results in substantially fixed velocity of the hammer

at the moment of impact. The specimens were mounted vertically and longitudinally against the load. The impact test was undertaken in air at 20 ± 2°C. The energy absorbed by the specimen to fracture was measured digitally and expressed in Joules.

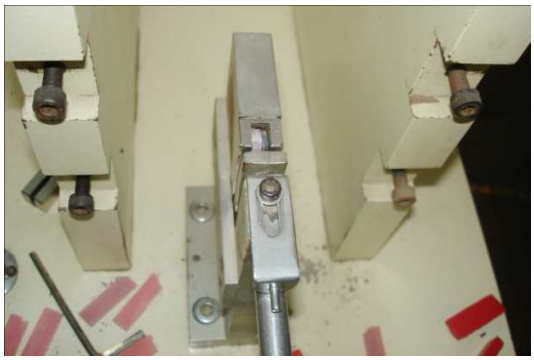


Figure 5: Fractured specimen after impact testing.

The transverse bend test was performed using a three point loading method (Figures 6,7) using Lloyds Universal testing machine with a cross head speed of 5 mm/min with load applied till fracture.[7]

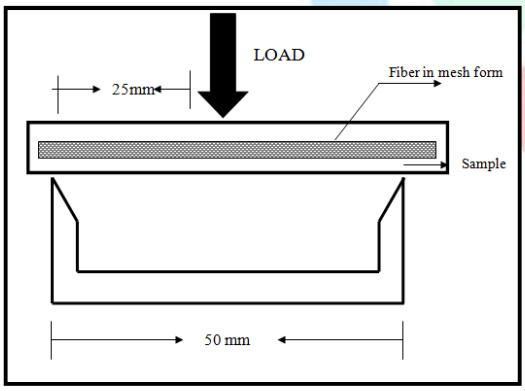


Figure 6: Diagrammatic representation of three point bend principle.

The values were expressed in MPa and is derived from the formula $S=3LP/2WT^2$ where P is fracture load in Newtons, L the distance between the supports (50mm), W is the specimen width (10mm) and T the specimen thickness (3mm). For Young's modulus of elasticity determination, the machine was calibrated so that the deflection of the specimen could be measured.

Figure 7: Lloyd's universal testing machine performing Transverse bend test.

Results:

The results were analyzed with 1- way analysis of variance (ANOVA) using Fisher test. The highest mean impact strength value was obtained for non reinforced Trevalon Hi and the lowest mean impact strength value was obtained for polyethylene reinforced Trevalon (Table II, Graph 1) The reinforcement of Trevalon with polyethylene fiber seems to have no effect on the transverse strength and a slight decrease when reinforced with polypropylene fibers. There was a slight increase in transverse strength of Trevalon Hi when reinforced with polyethylene fibers and very significant increase when reinforced with polypropylene fibers. (Table III, Graph 2.) The highest modulus of elasticity was recorded for polypropylene fiber reinforced high impact resin group. (Table IV, Graph 3).

Discussion:

Acrylic resin has number of advantages such as good esthetics, ease of fabrication, low capital cost, and good surface finish while the disadvantage includes low impact strength, low flexural strength to penalize poor denture design and a short fatigue life.[25] The cause for fracture is multi-factorial and not only the property of the material itself.

Table II: Mean impact strength and their standard deviations analyzed statistically with fisher test.

Groups	N	Mean	Standard Deviation	Minimum	Maximum
Trevalon (A1)	10	0.5020	0.065272	0.382	0.631
Trevalon PE (A2)	10	0.3345	0.122028	0.201	0.586
Trevalon PP (A3)	10	0.4473	0.130555	0.303	0.711
Trevalon Hi (B1)	10	0.6448	0.087682	0.537	0.799
Trevalon Hi PE (B2)	10	0.5662	0.114193	0.423	0.711
Trevalon Hi PP (B3)	10	0.6286	0.125232	0.459	0.878

F=11.49; p=0.001 vhs

Table III: Mean flexural strength with their standard deviations analysed statistically by Fisher test.

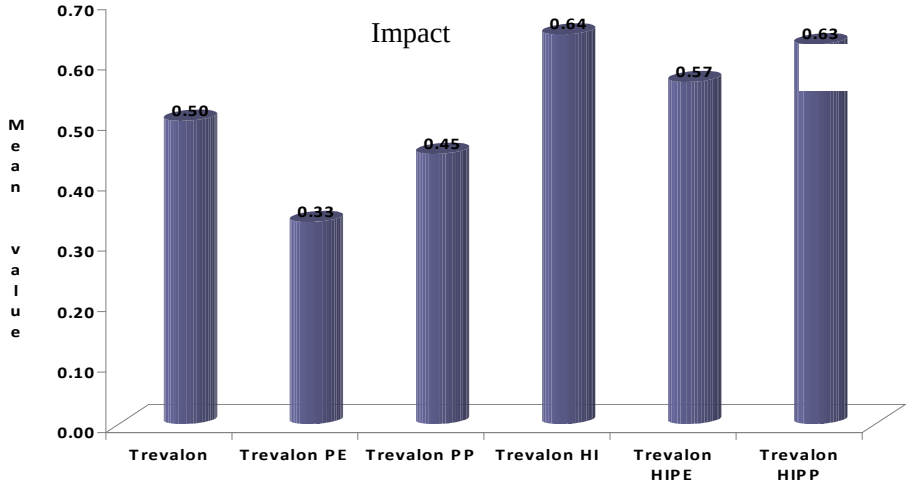
	N	Mean	Std. Deviation	Minimum	Maximum
Trevalon	10	86.3458	2.835024	80.007	89.686
Trevalon PE	10	86.1762	2.255951	82.567	88.794
Trevalon PP	10	84.3402	8.964051	71.553	94.435
Trevalon Hi	10	82.8372	4.122777	77.401	88.211
Trevalon Hi PE	10	85.9424	3.352575	79.487	89.447
Trevalon Hi PP	10	89.4968	2.274012	86.211	92.915

Table IV: Mean of modulus of elasticity and their standard deviations of six groups analysed statistically by Fisher test.

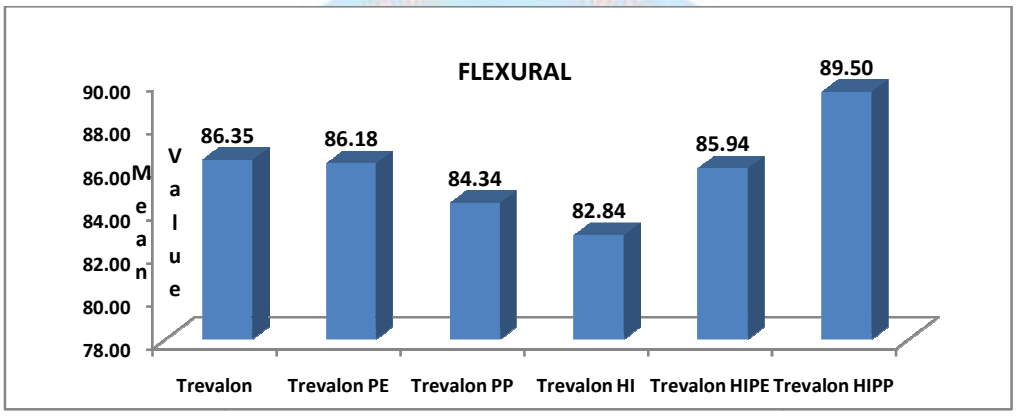
	N	Mean	Std. Deviation	Minimum	Maximum
Trevalon	10	2286	59.217115	2170	2340.000
Trevalon PE	10	2216	91.311433	2090	2340.000
Trevalon PP	10	2266	155.720547	2060	2450.000
Trevalon Hi	10	2170	105.409255	2060	2330.000
Trevalon Hi PE	10	2268	65.455668	2180	2340.000
Trevalon Hi PP	10	2428	56.920998	2330	2490.000

Trevalon PE – Trevalon reinforced with Polyethylene
Trevalon PP- Trevalon reinforced with Polypropylene
Trevalon Hi PE – Trevalon Hi reinforced with Polyethylene
Trevalon Hi PP – Trevalon Hi reinforced with Polypropylene

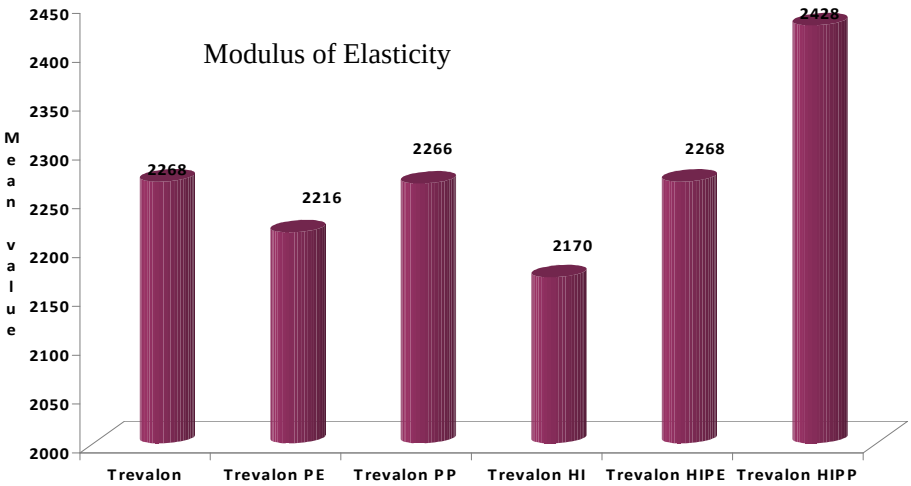
Graph 1: Comparison of mean impact strength of all six groups tested



Graph 2: Comparison of mean transverse strength of all six groups tested.



Graph 3: Comparison of mean modulus of elasticity of all six groups tested.



It may be caused by poor design, defective occlusal pressure, deep frenal notch and sharp changes in the denture base. Other causes includes, denture base foundation that fails to distribute the applied load exactly, failure due to flexural fatigue, and fracture due to accidental dropping of the denture during cleaning, and also poor fit. Improved acrylic resin polymers are being developed to overcome the inherent deficiency of the material and to serve the demands of oral environment. There have been two approaches to strengthen the PMMA. The first is to increase the impact strength and the fatigue life by incorporation a rubber phase into the beads during their suspension polymerization. [6] The rubber remains soluble in the monomer globule until the polymer content of the globule becomes too high and rubber begins to precipitate out. The nature of this precipitation is complicated by the fact that some of the growing chains of PMMA may have become grafted to the butadiene rubber. This results in what is known as phase inversion, resulting in beads that have a core or rubber included polymer covered by an outer shell of conventional polymer to give a more conventional dough formation.[7]

The second approach is reinforcement of (PMMA) acrylic resin denture with high modulus fibers which have a greater strength and mass. [2, 17-19, 26-28] Reinforcing a single cut mat of fiber in the center of specimen is comparatively easier than continuous, parallel, longitudinal placement of fibers. In previous studies, this difficulty was also noted because some fibers spread out laterally in the mold when the acrylic resin was pressed.[16] Because fibers are used to strengthen a polymer material, optimal adhesion between the polymer matrix and the fiber is essential. In our study, surface treatment with monomer liquid was used to improve bond strength and wettability between fibers and PMMA.[24]

During the impact test, all the specimens broke with a sharp fracture. This type of fracture is typical of brittle fracture behavior characterized by a lack of distortion of the broken parts. [7] The results obtained in our study were very highly significant with a definite increase in the impact strength of high impact denture base resin specimens (Travelon Hi) as compared with the conventional denture base resin (Travelon) specimens.

The mean impact strength of Polypropylene fibers reinforced Travelon Hi and Travelon samples were slightly lower than the unreinforced group, but the results were comparable. (Graph 1). The reinforcement with polyethylene fiber in conventional heat cure resin significantly decreased impact strength but reinforcement with polypropylene fiber does not decrease impact strength of both the resins significantly. Polyethylene and polypropylene are the two most common members of the olefin family which is a long chain synthetic polymer composed of 85% of ethylene, propylene or other olefin units. These fibers are very light weight, high strength and modulus, resistant to detioriation by chemicals, abrasion resistant and not brittle. [29]

Jagger and Jagger et al[7] compared impact and transverse strength of five “high strength” denture base acrylic resins with a conventional heat cured resin. Their results demonstrated that there were significant differences between some materials. There was no significant difference between Enigma Hi – Base and Sledgehammer compared with Trevalon. In the present study the high impact resin Trevalon Hi chemically modified with incorporation of butadiene styrene, showed high impact strength than the conventional resin. This

extends to this previous observations made by Rodford et al.[30]

Murphy et al[28] reported a considerable improvement in the impact strength of the rubber reinforced polymers, which is in agreement with our study. The addition of rubber to PMMA produces a resin that consists of a matrix of PMMA within which is dispersed an interpenetrating network of rubber and PMMA. A developing crack will propagate through the PMMA but will decelerate at the rubber interface.[7, 31]

At present there is very little evidence regarding the effect of reinforcement of PMMA with polypropylene fibers in literature. Polypropylene has natural colour, good mechanical properties and excellent biocompatible properties. The reinforcement of conventional and high impact resin groups with polypropylene fibers did not increase the impact strength; however it did decrease the impact strength of the resin. Previous studies have shown marginal improvement in impact strength of denture base resin when reinforced with polyethylene fibers. [16-18] This study showed that the impact strength of polypropylene reinforced groups was higher than the polyethylene fiber reinforced groups.

The transverse (flexural) strength of a material is a measure of stiffness and resistance to fracture. Flexural strength tests were considered the most relevant to the loading characteristics of the denture base in a clinical situation.[7] The reinforcement of Trevalon with polyethylene fiber seems to have no effect on transverse strength and for Travelon Hi, there was an increase in the strength. In our study, Trevalon Hi when reinforced with polypropylene had highest transverse strength (Graph 2) and the non-reinforced high impact resin Trevalon Hi group was the lowest. The increase in transverse strength may be due to the reinforcement of high modulus polypropylene fiber which binds to the resin matrix and work together to resist the load.

The little or no significant effect of any fiber reinforcement on transverse strength of conventional resin group is probably due to the poor adhesion of the fibers to the resin matrix. But in case of high impact resin the polymer itself is chemically modified which probably helps in binding of fibers in the resin matrix. [6,7] Hence there is slight increase in transverse strength when polyethylene fibers were reinforced and significant increase when polypropylene fibers were reinforced. The difference in values between polyethylene and polypropylene may be due to the higher modulus of the polypropylene fiber itself and its ability to bind with the resin matrix.

The results of this investigations indicates that the reinforcement of polyethylene fiber in mesh form decreases the mean transverse strengths of Trevalon specimens and slightly increases the transverse strength of Trevalon Hi specimens, which is in agreement with Gulay Uzun[16] and Dixon and Breeding.[19]

The international standard organization (ISO 1567) (1988) and British standard Specification 1989 (BS2487) [32] for denture base resins have specified that breaking force of acrylic resin should not be less than 55N. In this respect the two different resins used in the study satisfied the requirement as compared to study of Jagger and Jagger. [7] Also for the modulus of elasticity, polypropylene fiber reinforced high impact resin group showed highest value followed by control (Graph 3). The modulus of elasticity increased for even polyethylene fibers incorporated in Trevalon Hi groups. The remaining four tested groups had a modulus of elasticity less than the control.

In literature, very little evidence is available about the effect of reinforcement of polypropylene fibers on the transverse strength and modulus of elasticity of

denture base acrylic. This study showed that the mean transverse strength of Trevalon Hi denture base resin significantly increases with polypropylene fiber reinforcement. This study also showed that the mean transverse strength of Trevalon denture base resin decreases with polypropylene fiber reinforcement, but not significantly. The modulus of elasticity of Trevalon Hi has increased significantly upon fiber reinforcement when compared with the controls used in the study.

It is evident that reinforcement of high impact resin Trevalon Hi with polypropylene fibers significantly increased the transverse strength without significant decrease in impact strength. Hence the polypropylene fibers can be successfully reinforced with denture base resin to improve its mechanical properties in terms of impact and transverse strength and to increase the longevity of removable denture prosthesis. Also better modulus of elasticity indicates better resistance to stress and fracture.

Since it is an in- vitro study, the direction of force on the test specimen may not be similar to force experienced by the denture in the oral cavity. Due to this limitation the correlation of clinical implication of the results obtained in this study is difficult. Further in-vivo studies are needed to get more predictable results in terms of impact and transverse strength.

Conclusion:

Flexural strength and impact strength are the two important properties of denture base resins. The most effective and economical method to increase the fracture resistance in a denture base is fiber reinforcement. Within the limitations of this study we can conclude that without fiber reinforcements, Trevalon Hi has higher impact strength and lower flexural strength when compared to Trevalon. When reinforced with polypropelene fibers Trevalon Hi had good impact strength and better transverse strength and modulus of elasticity and hence can be effectively used in improve the longevity of dentures.

References

1. Peyton FA . History of resins in dentistry. Dent Clin North Am. 1975 Apr; 19(2):211–22.
2. Kenneth J. Anusavice: Phillip's science of dental materials; 11th ed, 2003.
3. Johnston EP, Nicholls JI, and Smith DE. Flexural fatigue of 10 commonly used denture base resins. J.Prosthet Dent 1981; 46 : 478 -483.
4. Ruffino A.R. Effect of steel strengtheners on fracture resistance of acrylic resin complete denture bases: J.Prosthet Dent 1985;54:75-78.
5. Vallittu PK, Lasilla VP . Effect of metal strengthener's surface roughness on fracture resistance of acrylic denture base material. J.Oral Rehab.1992;19:385-391.
6. Sheldon Winkler. Essentials of complete denture prosthodontics. 2nd ed;1996.
7. Jagger DC, Jagger RG,Allen SM, Harrison A. An investigation into the transverse and impact strength of 'high strength' denture base acrylic resins. J Oral Rehabil. 2002 ;29(3): 263-7.
8. Solnit GS. The effect of methyl methacrylate reinforcement with silane-treated and untreated glass fibers. J Prosthet Dent 1991;66(3):310-4.
9. Vallittu PK. Glass fiber reinforcement in repaired acrylic resin removable dentures: preliminary results of a clinical study. Quintessence Int 1997 ;28(1):39-44.
10. Berrong JM, Weed RM, Young JM. Fracture resistance of Kevlar-reinforced poly(methyl methacrylate) resin: a

preliminary study. Int J Prosthodont 1990 ;3(4):391-5.
11. Goldberg AJ, Burstone CJ. The use of continuous fiber reinforcement in dentistry. Dent Mater 1992;8(3):197-202.
12. Vallittu PK, Lassila VP, Lappalainen R. Acrylic resin-fiber composite-Part I: The effect of fiber concentration on fracture resistance. J Prosthet Dent 1994;71(6):607-12.
13. DeBoer J, Vermilyea SG, Brady RE. The effect of carbon fiber orientation on the fatigue resistance and bending properties of two denture resins. J Prosthet Dent 1984;51(1):119-21.
14. Vallittu PK, Vojtkova H, Lassila VP. Impact strength of denture polymethyl methacrylate reinforced with continuous glass fibers or metal wire. Acta Odontol Scand 1995;53(6):392-6.
15. Matthews E, Smith DC. Nylon as a denture base material. Br Dent J 1955;98:231-7
16. Uzun G, Hersek N,Tincer T. Effect of five woven fiber reinforcements on the impact and transverse strength. J Prosthet Dent 1999; 81(5):616-20.
17. Braden M, Davy KW, Parker S, Ladizesky NH. Denture base poly (methylmethacralate) reinforced with ultra high modulus polyethylene fibers. Br Dent J. 1988; 160: 109 – 113.
18. Gutteridge D.L. The effect of including ultra high modulus polyethylene fiber on the impact strength of acrylic resin. Br Dent J. 19; 164(6):177 – 80.
19. Dixon DL, Breeding LC. The transverse strength of three denture base resins reinforced with polyethylene fibers. J Prosthet Dent. 1992; 67(3):417-9.
20. Soroushian P, Khan A, Hsu JW. Mechanical properties of concrete materials Reinforced with polypropylene and polyethylene fibers.ACI Materials Journal.1992; 89(6): 535-40.
21. Scheidbach H, Tamme C, Tannapfel A, Lippert H, Kockerling F. In vivo studies comparing the biocompatibility of various polypropylene meshes and their handling properties during endoscopic total extraperitoneal (TEP) patchplasty: an experimental study in pigs. Surg Endosc. 2004;18(2):211–220
22. ASTM international. Designation. D 4812-99, Standard test method for un-notched cantilever beam impact resistance of plastics (test method under jurisdiction of ASTM committee on plastics D-20). Annual Book of ASTM Standard; March 1999,14:02
23. Williamson DL, Boyer DB, Aquilino SA, Leary JM. Effect of polyethylene fiber reinforcement on the strength of denture base resins polymerized by microwave energy. J Prosthet Dent. 1994;72(6):635-8.
24. John J, Gangadhar SA, Shah I. Flexural strength of heat polymerized PMMA denture resin reinforced with glass, aramid or nylon fibers. J Prosthet Dent. 2001; 86(4): 424 - 7.
25. William J.O.'Brien: Dental materials and their selection 2nd ed Quint pub. 1997
26. Ladizesky NH, Ho CF, Chow TW. Reinforcement of complete denture bases with continuous high performance polyethylene fibers. J Prosthet Dent.1992; 68(6):934-9.
27. Vallittu PK, Lassila VP, Lappalainen R. Acrylic resins-fiber composite – Part I: The effect of fiber concentration on fracture resistance. J Prosthet Dent.1994; 71(6):607-12.
28. Vallittu PK . Acrylic resins-fiber composite – Part II: The effect of polymerization shrinkage of polymethlmethacrylate applied to the fiber roving on transverse strength. J Prosthet Dent.1994;71(6):613-7.
29. Paula E Silva E, Rosa EL, Barbosa SV. Tissue reactions of polypropylene mesh

used in maxillofacial trauma. Braz Dent J.2001; 12(2):121-5.
30. Rodford RA. Further development and evaluation of high impact strength denture base material. J.Dent 1990; 18(3):151-7.
31. Murphy WM, Bates JF, Huggett R, Bright R. A comparative study of three denture base material. Br Dent J 1982; 152(8):273 – 6.
32. British Standard Specifiication for denture base polymers BS2487 (1989), British Standards Institution, London, UK.

Source of support: Nil
Conflict of interest: None declared