Effect of fiber reinforcement on flexural strength and impact strength of conventional denture base resin: A systematic review.

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ABSTRACT

Polymethyl methacrylate (PMMA) as a denture base material is having a significant pitfall in terms of deficient mechanical properties. Most of the studies reveal that, the superiority through inclusion of various fiber reinforcement materials in Polymethyl methacrylate concerning the flexural strength (FS) and impact strength (IS), whereas none of them demonstrates compendium and juxtaposition of all.This study was systematically review the present data to compare and assess the effect of various fiber reinforcement materials on FS and IS of heat-cured acrylic resin. Online database like PubMed, Ebscohost, and Google Scholar were explored comparing the mechanical properties like FS and IS of fiber reinforced denture base resin with unmodified denture base resin. Year of publication, Title, Author, Study category, Type of reinforcement strategy, assessment methods, sampling scale, FS value for conventional and fiber reinforced PMMA, Impact strength for conventional and fiber reinforced group, and result. All the data provided in the table were extracted by two independent reviewers. The results reveals that the reinforcement done with 2% by weight of glass fiber, polyethylene fiber and polypropylene fiber considerably improved the impact strength of acrylic resin whereas fiber reinforced groups, i.e., the 5.3% Glass fiber (GL), 5.3% polyamide (PA), and 5.3% PE (polyethylene) showed substantially higher FS. The meta-analysis couldn't be performed due to the heterogeneity of the studies. The present systematic review showed that fiber reinforcement of PMMA can notably improves the Flexural Strength and Impact Strength. Hence, it can be blended in clinical practice.

KEY WORDS: *PMMA, Flexural strength, Impact strength, Fiber reinforced denture base resin. Poly Methyl Methacrylate PMMA*

INTRODUCTION.

PMMA evaluated as optimal material for denture base fabrication due toeconomy, simple processing technique, stable colours, optical properties, adequate strength. However, the fracture of dentures is an extensive clinical issue which usually occurs due to heavy occlusal forces or accidental damage [1]. The modes of failure may be flexural fatigue failure caused by occlusal biting forces and impact force failures caused by dropping the denture. The midline fracture in a denture is result of alteration of stress distribution on the denture while performing various function intraorally leads to flexural fatigue. Impact failures usually occur outside the mouth when denture dropson rigid surface [2, 3]. Numerous modifications have already been proposed to conquer these limitations.

Reinforcing denture with fiber is an excellent technique. These reinforcement materials have been under development since the 1960s [4]. In the last 20 years, a pronounced escalation in the utilization of fiber-

reinforced denture base materials with various fiber like E-glass [5] , aramid [6] , carbon [7], nylon [8] , whiskers [9, 10] are the newer materials incorporated for heightened physical and mechanical properties of heat cure acrylic resins. Fiber reinforced PMMA has advantages over other methods of reinforcement that includes superior aesthetics, improved bonding to the resin matrix, and the simplicity to repair [11, 12].

The fiber reinforcement can be done using as a braided material or inclusion of single fiber meticulously in vulnerable area of acrylic resin.These reinforcements can be defined as "total fiber reinforcement (TFR) and partial fiber reinforcement (PFR), respectively [12].

With the availability of several fiber reinforced materials, the possible strategy for clinician has become daunting. Therefore, an evidence- based research is needed to apprehend the impact of fiber-strengthened polymethyl methacrylate on Flexural strength as well as Impact strength.

The purpose of this systematic review is to critically examine and assemble the literatures incorporating several fiber reinforced denture base resins as well as to discover the effect of these denture base materials on FS as well as IS of Polymethyl Methacrylate.

METHODS

This study was designed as a systematic review of in vitro publications. The study was registered in the PROSPERO database with registration number CRD42021247754. The database search strategy was rooted in PICO, i.e., Population/problem (heat polymerized PMMA), intervention (various fiber reinforced PMMA denture base resin), comparison (conventional PMMA with fiber reinforced PMMA) and outcome (flexural strength and impact strength). The following terms were used in the search, Heat cure PMMA, fiber reinforced, IS of PMMA, FS of PMMA, PMMA mechanical property.Criteria for study selection:

The following inclusion criteria were carried out. In vivo, in vitro and laboratory studies, review of literature, full text article only in the English language was included and literature should be published in between 2010 and 2020.

Two independent reviewers (Annanya and Abhijita) screened the titles and abstracts as per the inclusion criteria mentioned earlier. The full text of those articles was retrieved which were selected after abstract screening. Through independent screening, the full text of all included articles for this systematic review was scrutinized by both reviewers for final selection, and any disagreement was resolved with the third reviewer GKC.

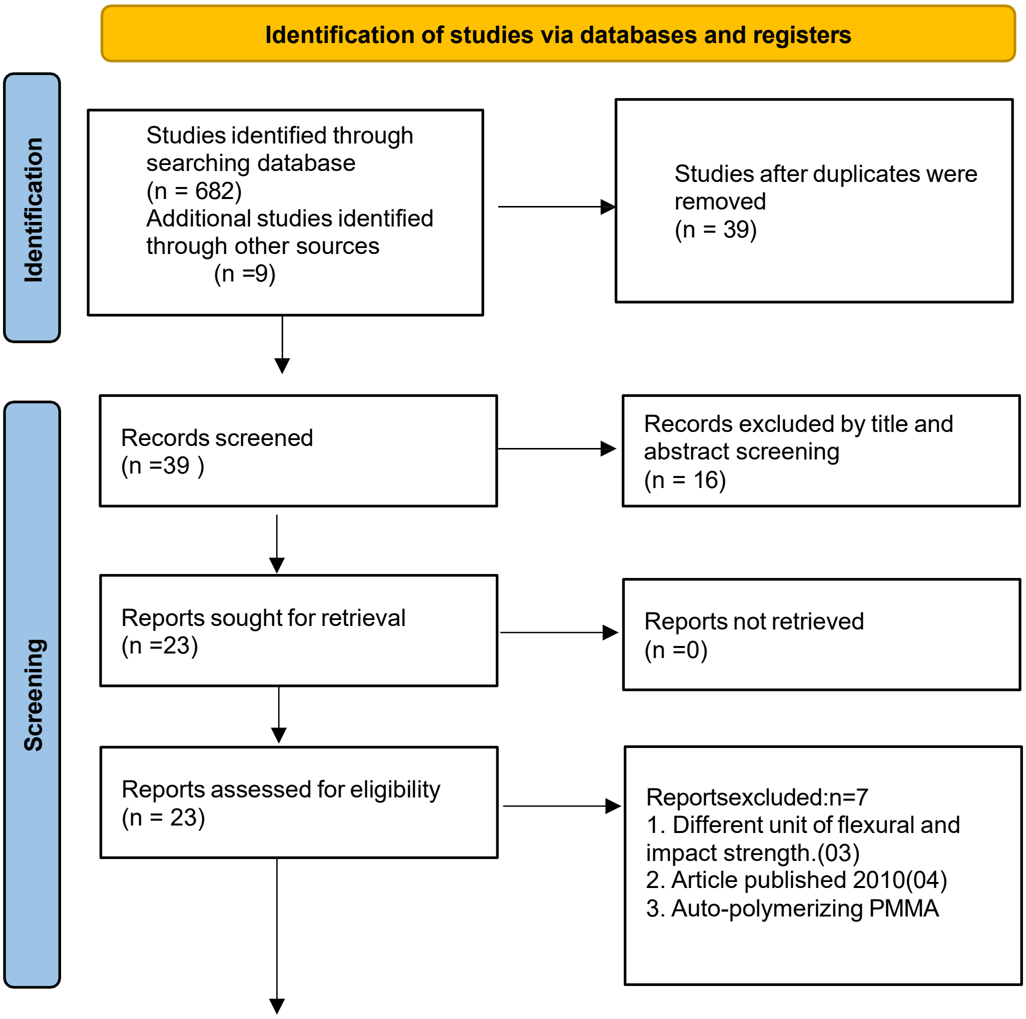
All the data provided in the table were extracted by two independent reviewers. The data were extracted under the following headings: Year of publication, Title, Author, Study category, Type of reinforcementstrategy, assessment methods, sampling scale, FS value for conventional and fiber reinforced PMMA, Impact strength for conventional and fiber reinforced group, and Result. The articles in which data were not distinct were eliminated from the data extraction table. All these data were reevaluated by another reviewer (AM) independently.

RISK OF BIAS

The quality assessment of the included studies was done by two independent reviewers. Cochrane collaboration tool for risk of bias with Review Manager 5.4 was used to gauge the risk of bias in all included studies following the CRIS Guidelines. The tools contain two parts, addressing the seven specific subjects (namely sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective outcome reporting, and other issues). An estimated risk of bias (low, medium, or high) was assigned to each of the included studies by the reviewers. Any disagreement addressed and settled by another reviewer [13].

RESULTS

A total of 682 articles were found from the database searching (PubMed). Additional data were collected from Google scholar and manual searches. Out of the 682 articles, 643 articles were excluded on the basis of title screening because they were not relevant, the required data were not available or the full text was unavailable. From the remaining 39 articles, 16 articles were eliminated because not included in the study: testing materials was auto-polymerizing PMMA, denture relining materials, other kinds of reinforcements such as metal oxides or metallic wire were used. 23 full-text articles which were selected for impact strength and/or flexural strength, 7 full-text articles were not included since the primary values were in different units, which cannotanalyzed. This study was included in the qualitative analysis but not in the quantitative analysis. Finally, 16 studies were incorporated in our systematic review [**Figure 1**].



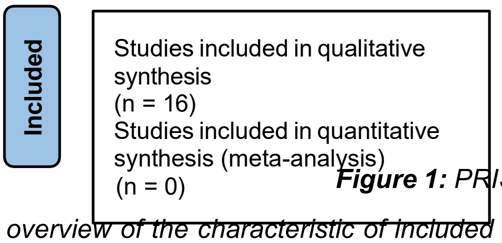


Figure 1: *PRISMA flowchart for literature search*

*A overview of the characteristic of included studies are illustrated in [**Table 1]**.The result was obtained from extracted data shows that the reinforcement done with 2% by weight of glass fibers, polyethylene fibers and polypropylene fibers considerably improved the IS of acrylic resin whereas in terms of FS, the fiber reinforced groups, i.e., the 5.3% Glass fiber (GL), 7.9% GL, 5.3% polyamide (PA), and 5.3% PE (polyethylene) showed substantially higher FS [14].*

Table 1: *Characteristics of included studies.*

Author / year	Type of reinforcement	Sample size	Flexural	Strength	Impact	Strength	Result
			Pmma	Reinforced pmma	Pmma	Reinforced pmma	
Makarem A. Jaber. et al., 2011 [15] Komal Ladha, Dipti Shah et al., 2011 [16]	I. Metal wire; ii. Glass fiber Grp B stick (S) and Grp C Stick Net(SN) glass fiber Grp D =Nylon	45 40	N/A "Dry-86.446 Mpa 2; Wet-83.553 Mpa	N/A Dry condition - (S)=117.876MPa (SN)=95.712MPa; Nylon=83.06MPa; Wet condition - (S)-113.75MPa (SN)-92.77MPa; Nylon-80.120MPa	14.396 MPa N/A	86.94MPa N/A	The IS glass-fibers > ire." Both S and SN reinforcements have increased the flexural strength of acrylic resin but the increase is more evident with S reinforcement. Nylon fibers have reduced flexural strength under dry as well as wet conditions
Tushar Krishnarao.Mowade .et al., 2012 [17]	Glassfiber,polyethylene Polypropylene, Silane impregnated fiber, plasma treated polyethylene and plasma treated	70	N/A	N/A	41.629 MPa	Group B-56.48MPa; Group C-74.334 MPa; Group D-85.219 MPa7 Group Bt-63.233 MPa	reinforcement with 2% by weight of glass, polyethylene and polypropylene fibers substantially increased the impact strength of PMMA resin and the surface treatment of the fibers

	polypropylene					Group Ct- 89.201 MPa Group Dt- 90.505 MPa	further increased the impact strength significantly.
Sang-Hui YU, Yoon LEE, et al., 2012 [18]	Glass (GL), polyaromatic polyamide (PA) and ultra-high molecular weight polyethylene (PE) fibers	25	99.4±3.0 MPa	GL- 203.8±21.3 MPa PA- 192.7±29.0 MPa PE- 183.0±25.6 MPa"	N/A	" N/A	In the single fiber reinforced composite groups, the 5.3% GL, 7.9% GL, 5.3% PA, and 5.3% PE showed significantly higher flexural strengths than the other groups.
fiberJie Xu, Yan Li, Tao Yu, Lei Cong"2013 [24]	short vegetable fiber(Ramie fibers)	31	90.5 Mpa	78.7 MPa	N/A	N/A	By addition of short ramie fiber the flexural strength decreases.
"Idil Dikbas, OzlemGurbuz, 2013 [19]	E-glass fibers With differet concentration like 2.5%, 3%, 4%, 5% by volume)	84	N/A	N/A	100.12 ± 0.37 MPa	198.6± 0.67 MPa	"the 5% glass-fiber showed the highest mean impact strength.
"Koray Soygun, Giray Bolayire et al., 2013 [20]	"E-glass fibers, Nylon 6, Nylon 6.6, Valplast	35	92.00 ± 11.13 Mpa	"E-glass-108.54 ± 10.33 Mpa; N6= 92.72 ± 11.36 Mpa; N6.6= 83.36 ± 4.25 Mpa; Valplast= 117.22 ± 37.80 Mpa"	0.44 ± 0.15 Kn	E-glass= 5.98± 1.274MPa N6= 4.51 ± 1.47MPa N6.6= 4.31 ± 1.274MPa Valplast = 7.45 ± 0.2941 MPa	"The highest values (FS andIS)were seen in the group containing valplast.

"Jacob John, Shani et al., 2014 [21]	*oil palm empty fruit bunch (OPEFB) fiber"*	*50*	*NA*	*A(conventional PMMA=79.15Mpa" B(High impact acrylic resin) 88.03 MPa CConventional PMMA with OPEFB fiber (0.5mm thickness); = 94.96 MPa DConventional PMMA with OPEFB fiber (2mm thickness); = 81.37 MPa EConventional PMMA with OPEFB Cellulose = 95.60 Mpa*	*N/A*	*N/A*	*FS of E>C>B>D>A* *The flexural strength of high-impact acrylic resin (group B), though higher than the control (group A), was not statistically Significant. For flexural strength, acrylic resin reinforced with OPEFB cellulose had the highest value, while conventional acrylic resin had the lowest strengths.* *Two of the OPEFB (E and C) groups had better flexural properties compared to the high-impact acrylic resin (group B).*
"R. Arun Jaikumar et al., 2015 [22] *Bijan Heidari, et al., 2015 [23]*	*glass fiber* *Glass fiber, Polyethelene*	*30* *80*	*NA* *1.8±0.202Mpa* *90.64 Mpa*	*Group1conventional PMMA101.18Mpa Group2 high impact= 121.50 Mpa; Group3Glass reinforced PMMA]= 144.45 Mpa* *Group HG (repaired*	*N/A* *N/A*	*N/A* *N/A*	*FS of grp3> grp2>grp1* *"The Strength observed in control group was 1.8±0.202 MPa. The Group repaired with heat-cured acrylic resin reinforced with glass fiber and group repaired with cold-cured acrylic resin*

Tony C Thomas, Aswini Kumar K, et al., 2015 [25] *Ronak H. Choksi, et al., 2016 [26]*	*group 2- carbon fibres, group 3- glass fibres, group 4 – polyethylene, group 5- Kevlar* *Group 1 - poly (methyl methacrylate) (PMMA) (Trevalon), Group 2 - Trevalon HI, Group 3 -5% glass flake +95% PMMA (Trevalon), Group 4 -10% glass flake +90% PMMA (Trevalon), and Group 5 -20% glass flake +80% PMMA (Trevalon*	*50* *50*	*Group 1= 108.6862 Mpa*	*with heat-cured acrylic resin reinforced with glass fiber)= 2.17±0.32 Mpa; group CP (repaired with cold-cured acrylic resin rein-forced with polyethylene)= 0.55±0.15 Mpa* *Group 2= 102.58 MPa; group 3= 100.79 MPa; group 4= 94.13 MPa; group 5= 96.43 Mpa* *Group 2= 92.8688 Mpa; Group 3= 88.5784 Mpa; Group 4 = 78.4884 Mpa;*	*N/A*	*N/A*	*reinforced with polyethylene revealed highest (2.17±0.32 MPa) and lowest (0.55±0.15 MPa) flexural strength readings, respectively.”* *“Scheffe’s post hoc test indicated that the flexural strength reading of Polymethyl methacrylate + carbon, was considerably different from plain PMMA. Hence the carbon fibre reinforced specimen shows highest flexural strength as well as highest flexural modulus, although the compressive strength stays unchanged.”*

				Group 5 = 64.8136 Mpa			
"Gautam VS Kumar, et all 2016 [27] *Haitham Agha, et al., 2016 [28]*	*Glass, Polyaramid, and Nylon Fibers* *Eglass fiber*	*40* *40*	*group III- 66.87 Mpa* *Total- 40 (n=10); [Group FN- No fiber reinforcement; group FM- fiber in the middle at the no-stress neutral axis; group FC- fiber close to the surface on the compressive stress side; group FT- fiber close to the surface on the tensile stress side]*	*Group I- 67.82 Mpa; Group II- 59.47 Mpa; Group IV- 66.47 Mpa."* *group FM: 102.83 Mpa; group FC: 107.68 Mpa; group FT: 141.46 Mpa*	*N/A*	*N/A*	*The following order of transverse strength in different groups was observed: Group II < Group IV < Group III < Group I. It was4% wt. of polyaramid fibers in random distribution also significantly increased the transverse strength of denture base PMMA."* *FT>FC>FM*

"Tomohiro Kawaguchi et al., 2020 [29]	*cellulose nanofibrils (CNF)"*	*60*	*49.4Mpa*	*CNF-23= 96.8 Mpa; CNF-15=72.0 Mpa; CNF-10=63.5 MPa; CNF-5= 56.4 Mpa*	*N/A*	*N/A*	*CNF-reinforcement improves the flexural strength and modulus of a model PMMA denture base materials prepared via injection molding.*

However, the FS of reinforced denture base with short ramie fiber decreases because of the delicate interfacial adhesion. The control group had 90.5 MPa flexural strength while the reinforced group reduced the flexural strength to 78.7 MPa. As the acrylic resin is highly viscous at the processing phase, it is difficult for the material for penetrating into the fibers. It mayinitiatevoids and porosity in the material which markedly decline its strength in most of the cases. Moreover, the PMMA resin under pressure can move the soaked fibers apart due to even higher viscosity, results varied dispersion of fibers in the matrix [30].

DISCUSSION

PMMA is the most commonly used denture base material in the field of Prosthodontics. It has pulled through the advent of several alternative substances like polycarbonates as well as polyamides. Fracture of denture is the most common worries in removable partial denture due to accidental dropping, routine exposure of masticatory load, wear and tear every time etc. There are two primary cause of denture fracture is flexural fatigue which happen to be inside mouth and impact failure occur outside the mouth.The ability tohold up against dynamicocclusal loads is an integral requirement for a denture base material [31].

Numerous strategies were brought to enhance the PMMA dentures. Earlier metal inserts were used withinside as wires, metallic oxides, meshes, and plates etc. However, incorporation of metal into the denture base resin will impart a dark color to it which results in denture with inferior aesthetics. Hence, to enhance the esthetic characteristics, fiber reinforcement came into the picture. Also, it is evident from the studies conducted by various researchers that fiber reinforcement improves the FSand IS of the conventional denture base resin considerably [32].

Fiber reinforcement can help in load distribution effectively in homogenous polymer matrix by absorbing the complete load along its length by virtue of shear force at junction of polymer matrix and reinforced fiber. Thisresults reduced localized stress concentration and potential failure.These fiber used as load bearing elements and matrix form a bulk phase to surround and clasp the fiber in place [33].

Reinforcement of glass fiber showed betterment in both IS and FS, while polythene fiber showed only increase in IS contrast conventional PMMA. The ability of fiber to reinforce the denture base depends upon quantity of fibers, arrangement of fibers and bonding of fibers to the polymer matrix [34].

Ladha and Shah et al., stated that sufficient impregnation of reinforcing composite fibers and its chemical bonding to the acrylic resin matrix was the difficult task which was resolved to impressive magnitude with the *utilization of a distinct glass fiber reinforcement system (Stick and Stick Net) tested in their study. Each of S (stick glass fiber) and SN (stick net glass fiber) reinforcements beneath dry and wet state improved the FS of acrylic resin. Nylon fibers reduced flexural strength beneath dry and wet conditions [35].*

According to Mowade et al., the reinforced fiber absorbs energy along its length in sole direction in polymer matrix which results its strength stiffness to the specimen in compare to unreinforced resin polymer.IS of polyethylene and polypropylene fibers was superior than glass fiber due to the intrinsic breakable property of glass [36].

Many factors like quantity of glass fibers in polymer matrix, good wetting, adhesion of fibers to polymer contribute higher IS of glass fiber compare to the metal wire. Hence, glass fibers are highly advice in patient with excessive biting pressure like bruxism or when FS of denture base resin is of great concern [37].

Sang-hui et al., compared the reinforcing effects of hybrid Fiber-reinforced Composites (amalgamation of different fiber like glass fiber, aramide fiber or polyethene fiber) with that of single fiber-reinforced composites at concentrations of 5.3% and 7.9%.He concluded that the FS increased significantly in hybrid fiber reinforced composite, to that of glass, aramid, when added individually [38].

In the study conducted by jie xu, 1.5 mm ramie fibers (vegetable fiber) when reinforced with PMMA due to good dispersion of fibers, FS of PMMA enhanced appreciably with fiber content approaching 10% by volume. Though the addition of 3.0-millimeter fibers enhanced the flexural modulus markedly up to 4% by volume, however modulus is diminished at higher concentration due to agglomeration.

According to John et al, specimens reinforced with oil palm empty fruit bunch (OPEFB) had higher flexural strength than the conventional specimens [39].

CONCLUSION

Within the limitation of this systematic review, following speculation can constructed by assembling comprehensive information on FS and IS of reinforced PMMA we concluded that:

1. *Incorporation of glass fibers, aramid fibers, polyethylene fibers to the denture base resin increased the FS of the unreinforced group significantly.*
2. *Oil Palm Empty Fruit Bunch Fibers (OPEFB) incorporation into the conventional denture base resin improved its flexural properties. However, it is uncertain whether it can significantly improve the impact strength.*
3. *Glass fibers are preferred to metal wire for reinforcement of PMMA because of its superior esthetic characteristics.*
4. *It was largely advised that the concentration of added fibers should be limited within a low portion i.e 4% by mass for homogenous dispersion.*

Hence, to increase the clinical competence of PMMA, these reinforcement materials can be taken into account according to clinician, patient and Laboratory personnel requirement.

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