Original Article

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Dentistry Section

Comparative Evaluation of the Impact Strength of Polymethyl Methacrylate Heat-cure Acrylic Denture Base Resin Reinforced with Aramid Fibres and Glass Fibres: An In-vitro Study

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ABSTRACT

Introduction: Polymethyl Methacrylate (PMMA) is widely used as the material of choice for denture base fabrication due to its favourable handling properties, aesthetics, and cost-effectiveness. However, its low fracture and impact resistance remains a major clinical limitation, often leading to denture failure. Reinforcement of PMMA with fibres such as aramid and glass has been proposed to enhance its mechanical properties.

Aim: To compare the impact strength of conventional heat-cure PMMA denture base resin, PMMA-reinforced with aramid fibres, and PMMA-reinforced with glass fibres.

Materials and Methods: This in-vitro experimental study was conducted at the Department of Prosthodontics, Maratha Mandal's Nathajirao G. Halgekar Institute of Dental Sciences and Research Centre, Belagavi, Karnataka, India from a period of 6 month from June 2025 to December 2025. A total of 30 rectangular test specimens were prepared using preformed stainless-steel metal dies (50×10×3 mm) with a 45-degree notch at the center. The specimens were divided into three groups (n=10 each): Group A: Conventional heat-cure PMMA (control), n=10, Group B: PMMA-reinforced with aramid fibres (1% by weight) n=10, Group C: PMMA-reinforced with glass fibres, n=10. A monomer-polymer ratio of 1:2 by weight was used. After reaching the dough stage, the material was packed, processed at 73°C for 30 minutes, bench-cooled, and deflasked. The specimens were tested using an Izod impact strength testing machine with a load of 2.9 joules/m. Impact strength was recorded in joules and kJ/m². Statistical analysis was performed using One-way Analysis of Variance (ANOVA) for overall comparison and the Bonferroni Post-hoc test for intergroup comparison with $p \leq 0.05$ was considered statistically significant.

Results: The highest impact strength was observed in Group B (aramid fiber reinforced PMMA), followed by Group C (glass fiber reinforced PMMA), and lowest in Group A (control). Statistically significant differences were observed between Group B and Group C ($p<0.001$) and between Group C and Group A ($p=0.021$). However, the difference between Group B and Group A was statistically insignificant ($p = 0.199$).

Conclusion: Within the limitations of this in-vitro study, incorporation of 1% by weight aramid fibres into heat-cure PMMA significantly improved the impact strength compared to conventional PMMA. Fiber reinforcement, particularly with aramid fibres, can be considered a promising approach to enhance the fracture resistance of denture base resins.

Keywords: Acrylic resins, Aromatic polyamides, Dental stress analysis, Elastic modulus, Fracture resistance

INTRODUCTION

Dentures physically fill the gap between tooth loss and oral functionality by rehabilitating masticatory function. In terms of psychology, they promote greater self-confidence and better social interactions. In terms of functionality, dentures improve speech clarity and articulation, facilitating efficient communication [1]. Poly methyl methacrylate is the preferred material for fabrication of denture bases. It is still being used due to its agreeable working characteristics, superior aesthetics, ease of use, precise fit, stability in the oral environment that too with the use of inexpensive equipment. Despite such distinctive properties, the fracture resistance of PMMA needs to be improved [2]. The denture bases undergo different types of stresses, which can be either from physical or chemical degradation [3,4]. Hence, numerous polymers have been developed which can be used as denture bases that will overpower the mechanical discrepancies [5,6]. To increase the impact strength, one method is to incorporate a rubber phase into the bead polymer [7].

Another technique is to use fibres to strengthen acrylic resin dentures. Fibres can be used in three different ways: chopped, continuous parallel, and woven [6]. Fibres like glass and aramid are used to strengthen acrylic due to their higher transparency and light hue which in turn does not have any major effect on the colour stability glass fibres are beneficial for use in light-curing resin for denture base polymers. Moreover, glass fiber can easily be cut. Polymer pre-impregnation addresses this problem [8,9].

Aramid fibres are a class of heat-resistant and strong synthetic fibres, chemically known as aromatic polyamides, characterised by their high strength-to-weight ratio and high resistance to impact they also possess high strength and rigidity, exhibiting a tensile strength ranging from 3.6 to 4.1 GPa and an elastic modulus of 131 GPa. These fibres are utilised in applications such as bulletproof vests, aircraft wings and various other materials.

Studies indicate that aramid fibres greatly improve the impact strength of PMMA resin and enhance the fracture resistance [10]. Research on micro structural behaviour and morphology, and fracture initiation sites is crucuial to identify the reasons behind the fracture [11,12]. Hence, the thrust of the present study is to evaluate the aramid and glass fiber reinforcements in heat-cure PMMA under standardised conditions.

MATERIALS AND METHODS

This in-vitro experimental study was conducted at the Department of Prosthodontics, Maratha Mandal's Nathajirao G. Halgekar Institute of Dental Sciences Belagavi, Karnataka, India over a period of 6-months from June 2025 to December 2025. The impact testing procedure was conducted at Praj Laboratory, Pune. After obtaining Institutional Ethical Committee clearance (IEC no 108/15/05/2025), the study was conducted on 30 rectangular test specimens prepared using preformed stainless-steel metal dies with a 45-degree notch at the center.

Sample size calculation

$n = (Z1\text{-}\alpha\text{-}Z\beta)^2 * \sigma/\delta$

$Z1\text{-}\alpha = 1.96$ at 95 % confidence interval

$Z\beta = -0.84$ at 80 % power of the study

δ error = 0.5

n = 10 in each group

Total sample size was divided into three groups each consisting of 10 samples [Table/Fig-1] [1].

Groups	Material	Samples
Group A	PMMA without additives	10
Group B	PMMA with aramid fibres 1% by wt (5 mm length (KK packaging company, Mumbai)	10
Group C	PMMA with glass fibres 1% by wt (5 mm length (KK packaging company, Mumbai)	10
Total		30

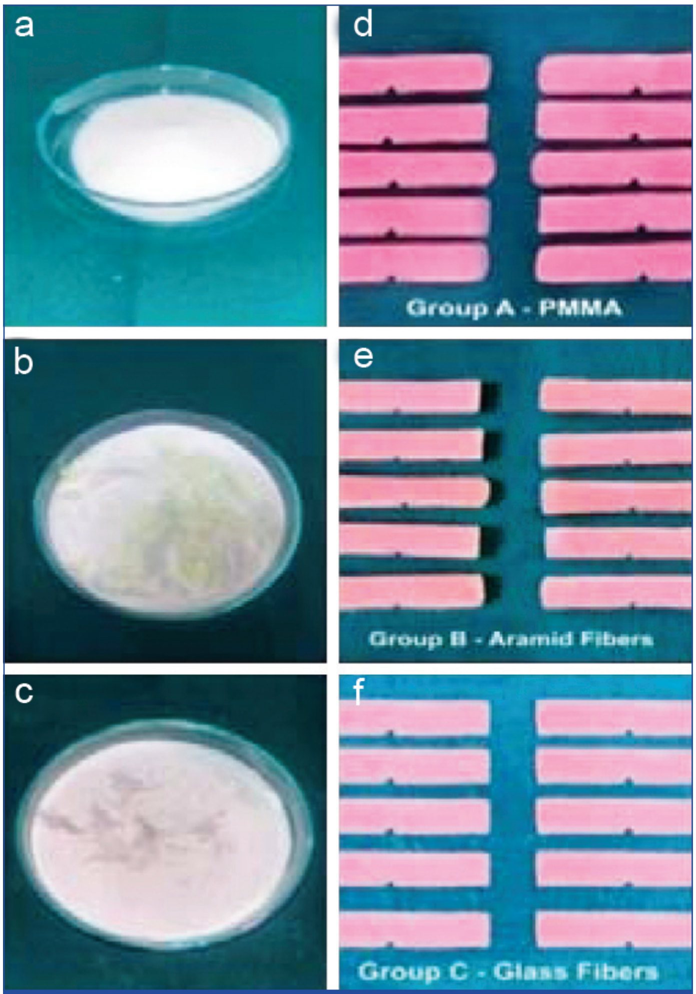
[Table/Fig-1]: Total sample size.

Study Procedure

The sample dimensions selected according to ISO 20795-1(2008), that are 50x10x3 mm. Thirty dental stone moulds were prepared in dental flasks with preformed stainless steel metal dies [Table/Fig-2].

[Table/Fig-2]: Stainless steel die.

Each die was coated with a thin layer of petroleum jelly before being invested in dental stone. After the final set of the dental stone, flask were opened. The master die had a 450 notch in the center. The prepared moulds were then immersed in hot water to remove impurities and to facilitate the application of separating medium. The mould cavities obtained were used for packing acrylic resin. Group A specimens made with PMMA heat cure acrylic denture base resin (A mixture of monomer and polymer in the ratio 1:2 by weight was allowed to reach dough stage, then kneaded and placed in the mould. The flask was clamped and low pressure maintained for 30 minutes. The flask was then immersed in water in an acryliser at room temperature. The temperature was slowly raised to 73°C and maintained for half hour. After completion of short polymerisation cycle, flask was cooled before deflasking. The specimens were retrieved, finished and polished. The remaining two groups consisted of same dimensions only PMMA was reinforced with commercially available aramid fibres (Group B) and glass fibres (Group C) [Table/Fig-3a-f]. Once the specimens were obtained a notch was made in the top center of each specimen so as to apply load under the Izod Impact testing machine.



[Table/Fig-3]: Photograph showing the distribution of the finished test specimens for the three study groups A - PMMA without additives B - PMMA + Aramid fibres C - PMMA + glass fibres , placed in petri dishes for identification. D - PMMA Samples E - PMMA + Aramid fibre samples F - PMMA + glass fibres samples, n=10 in each group.

The specimens were subsequently evaluated using the Izod impact testing machine (see) to determine their impact strength at a load of 2.9 joules/m [Table/Fig-4].

[Table/Fig-4]: Izod Impact testing machine.

The Izod impact test is a standardised method used to measure a material's resistance to sudden impact or shock loading. In this test, each specimen is vertically clamped in the testing machine, typically with a pre-made notch facing the pendulum striker. The pendulum is released from a fixed height, striking the specimen at the notch. The energy absorbed by the material during fracture is calculated based on the difference between the initial and final height of the pendulum after impact. For this experiment, the applied impact energy was 2.9 J/m, indicating the energy absorbed per unit length of the specimen. This value reflects the material's toughness and its ability to withstand sudden applied loads without catastrophic failure. Higher impact strength values generally correspond to greater resistance to brittle fracture, while lower values indicate a more brittle material behaviour.

STATISTICAL ANALYSIS

All analysis performed using International Business Machine (IBM) Statistical Package of Social Sciences (SPSS) software version 21.0. The One-way Analysis of Variance (ANOVA) test was used to compare data overall, with a significance level of 0.05. The Bonferroni test was used for intergroup comparison.

RESULTS

The comparison of mean impact strength values among the three groups. The Aramid fiber–reinforced group has been depicted in [Table/Fig-5]. (Group B) exhibited the highest mean impact strength (3.2850±0.59291), followed by the glass fiber–reinforced group (Group C) with a mean value of 2.9310±0.35161, while the PMMA control group (Group A) showed the lowest mean value (2.3910±0.19638). The 95% confidence intervals indicate that the Aramid group had a wider range compared to the other groups. Statistical analysis revealed a highly significant difference among the groups ($F=11.836$, $p<0.001$), indicating that fiber reinforcement significantly influenced the impact strength.

Groups	n	Mean±SD kJ/m^2	95% CI for mean		F	p-value
			Lower bound	Upper bound		
Aramid (Group B)	10	3.2850±0.59291	2.8609	3.7091	11.836	<0.001**
Glass (Group C)	10	2.9310±0.35161	2.6795	3.1825		
PMMA (Group A)	10	2.3910±0.19638	2.2505	2.5315		
Total	30	2.8690±0.54701	2.6647	3.0733		

[Table/Fig-5]: Comparison of Izod Impact strength (kJ/m^2) in all the groups.
$p<0.05$, One-way ANOVA; SD:Standard deviation; CI: Confidence interval

The Bonferroni post-hoc test for intergroup comparison revealed a statistically significant difference in impact strength between Group B (Aramid) and Group C (Glass) $p<0.001$). Similarly, the difference between Group C (Glass) and Group A (Control) was significant ($p=0.021$). However, the pair-wise comparison between Group B (Aramid) and Group A (Control) was statistically insignificant ($p=0.199$) [Table/Fig-6].

Group	Group	Mean difference (I-J)	Std. error	p-value	95% CI	
					Lower bound	Upper bound
Group B	Group A	0.35400	0.18507	0.199	-0.1184	0.8264
	Group C	0.89400*	0.18507	<0.001**	0.4216	1.3664
Group C	Group A	0.54000*	0.18507	0.021	0.0676	1.0124

[Table/Fig-6]: Intergroup comparison was performed using the Bonferroni post-hoc (pairwise) comparison test to identify specific differences between the three study groups.

DISCUSSION

The present in-vitro study was conducted to evaluate and compare the impact strength of conventional PMMA denture base resin with PMMA-reinforced using glass fibres and aramid fibres. The results demonstrated that fiber reinforcement significantly improved the impact strength of PMMA denture base resin. Among the experimental groups, Group B (aramid fiber-reinforced PMMA) exhibited the highest mean impact strength (3.28 J), followed by Group C (glass fiber–reinforced PMMA), while Group A (conventional PMMA) showed the lowest impact strength. Statistical analysis revealed a significant difference among the groups ($p<0.05$), indicating that incorporation of reinforcing fibres improves the resistance of denture base resin to sudden impact forces. These findings are consistent with the study conducted by Grave AM et al., who evaluated denture base acrylic resin reinforced with high modulus fibres and reported a significant improvement in fracture resistance compared with conventional PMMA ($p<0.05$) [13]. The authors suggested that reinforcing fibres improve stress distribution within the acrylic resin matrix and prevent crack propagation, thereby increasing the durability of denture base materials. Similarly, Vallittu PK investigated the adhesion between reinforcing fibres and acrylic denture base material using different silane coupling agents and reported improved bonding between fibres and the PMMA matrix, which significantly enhanced the mechanical properties of the denture base resin ($p<0.01$) [14]. Adequate bonding between the reinforcing fibres and resin matrix plays a critical role in transferring stress effectively and improving fracture resistance. Comparable findings were reported by Chen SY et al., who evaluated the reinforcement of acrylic denture base resin using various fibres and found that fiber incorporation significantly improved the mechanical properties of PMMA, including impact and flexural strength ($p<0.05$) [15]. The authors suggested that fibres function as crack arresters within the resin matrix and increase the energy required for crack propagation, thereby enhancing the strength and fracture resistance of denture base materials. In the present study, aramid fiber-reinforced PMMA demonstrated the highest impact strength among the tested groups. Aramid fibres are aromatic polyamide fibres known for their high tensile strength, thermal stability, and chemical resistance. Their unique molecular structure, composed of highly oriented aromatic chains arranged in sheet-like formations, allows them to absorb and dissipate impact energy effectively, thereby increasing resistance to sudden forces.

However, findings reported by Kanie T et al., demonstrated that glass fiber-reinforced PMMA exhibited significantly greater flexural strength compared with aramid and nylon fiber reinforcement ($p<0.05$) [8]. The authors attributed this to the higher modulus of elasticity and better adhesion characteristics of glass fibres with the PMMA matrix. These findings indicate that different reinforcing fibres may influence mechanical properties differently, although both glass and aramid fibres contribute to improving the strength of denture base materials. Similarly, Karacaer O et al., reported that increasing the length and concentration of glass fibres significantly improved the mechanical properties of injection-compression moulded denture base polymers ($p<0.05$) [9]. Their study emphasised that fiber reinforcement enhances the load-bearing capacity of PMMA by distributing stresses more evenly across the resin matrix.

Further supporting these observations, Yu SH et al., compared denture base resin reinforced with polyaromatic polyamide fibres of different orientations and found that fiber orientation significantly influenced mechanical properties such as impact strength and fracture resistance ($p<0.05$) [10]. The authors concluded that proper fiber alignment enhances stress distribution and reduces crack propagation within the denture base material.

Additionally, Faot F et al., evaluated the impact strength and fracture morphology of denture acrylic resins and reported that reinforced acrylic resins demonstrated greater resistance to fracture compared with conventional PMMA ($p<0.05$) [16]. Their findings indicated that fiber reinforcement alters fracture patterns and increases the amount of energy required for crack propagation.

Similarly, Zappini G et al., compared fracture resistance of denture base materials and observed that reinforced materials demonstrated significantly improved fracture toughness and resistance to crack propagation compared with conventional acrylic resin [17]. These findings further support the results of the present study.

In addition, Ranganath LM et al., evaluated the dimensional stability of fiber-reinforced PMMA and reported that incorporation of reinforcing fibres did not significantly affect dimensional changes of denture base resin after processing and water immersion ($p>0.05$) [18]. This finding indicates that fiber reinforcement can enhance mechanical properties without adversely affecting dimensional stability of the denture base material.

Recent investigations have also highlighted the importance of reinforcing agents in improving denture base materials. Alhotan A et al., evaluated PMMA-reinforced with nanoparticles and fibres and reported improved fracture toughness and impact strength compared with conventional PMMA ($p<0.05$) [12]. Similarly, Yerliyurt K et al., demonstrated that fiber-reinforced PMMA resins exhibited improved flexural properties and mechanical performance compared with unreinforced materials [3].

The findings of the present investigation are also supported by Dudhe SP et al., who compared the flexural strength of PMMA-reinforced with glass fibres and aluminum oxide and reported significant improvement in mechanical strength following reinforcement ($p<0.05$) [4]. Furthermore, Aparoopa A et al., in a systematic review concluded that fiber reinforcement significantly improves both flexural and impact strength of denture base resins and enhances the longevity of prostheses [5].

Based on the findings of the present study and previously published literature, incorporation of reinforcing fibres into PMMA denture base resin significantly improves its impact resistance. Among the tested groups, aramid fiber reinforcement demonstrated the highest impact strength, followed by glass fiber reinforcement, while conventional PMMA exhibited the lowest resistance to impact forces. These findings suggest that reinforcing PMMA with glass or aramid fibres may enhance the mechanical performance and fracture resistance of denture base materials used for complete dentures and distal extension removable partial dentures.

Limitation(s)

Being an in-vitro investigation, the findings may not fully replicate the complex conditions of the oral environment, including temperature variations, moisture, pH fluctuations, and masticatory forces. Fatigue loading, thermocycling, and long-term water storage were not performed, which could influence the durability and fiber–matrix bonding over time. The sample size was relatively small, and only impact strength was evaluated, without assessing other important mechanical properties such as flexural strength, fracture toughness, or water sorption. Additionally, variations in fiber length, orientation, and surface treatment were not extensively analysed, which may affect the overall reinforcing efficiency.

CONCLUSION(S)

Based on the findings of present study it can be concluded that the reinforcement of PMMA denture base resin with aramid fibres resulted in the highest impact strength among the groups tested. This suggests that incorporating aramid fibres may be an effective approach to enhance the impact resistance of PMMA denture bases.

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