Comparison of Impact Strength of Non-Reinforced Polymethyl Methacrylate Resin, Polymethyl Methacrylate Resin Reinforced with Glass Nanoparticles and Polymethyl Methacrylate Resin Reinforced with Carbon Nanotubes as a Denture Base Material

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Abstract

Background/purpose: Removable dentures are most widely used to replace missing tooth. Poly methyl Methacrylate (PMMA) is the commonly used material to fabricate denture base by heat cure technique. It has the advantage of low cost, a simple fabrication process, light weight, satisfactory aesthetics, colour matching ability and easy to do finishing and polishing. However, it has certain disadvantages like insufficient surface hardness, low strength in thin sections and brittle in nature. Glass nanoparticles and Carbon nanotubes have shown, to have increased strength when used in other various forms in dentistry. In this study, the impact strength of Non-reinforced PMMA denture base material are compared with reinforced PMMA (Glass nanoparticles and Carbon nanotubes). **Materials and methods:** A metal block of dimensions 60mm x 12mm x 3mm(following ASTM standards) were used to form the mould space for acrylisation of samples.[2] For the control specimen non-reinforced PMMA material were used with standard powder to liquid ratio as per manufacturer's instructions. For Glass Fibre specimens (20-80nm Nanoparticles), the heat cure polymer powder (Dpi) were mixed with Glass Fibres of 5% by weight. For Carbon Fibre specimens (2-10μm Nanotubes), the heat cure polymer powder (Dpi) were mixed with Carbon Fibres of 5% by weight. The specimens were then flasked and cured by water bath polymerisation method. Following which, the samples were finished and subjected to IZOD type of impact tester using CEAST impact tester. **Results:** Statistical analysis shows that, the mean ± standard deviation of impact strength of group 1 was 1.91±0.29, for group 2 was 1.14±0.35 and for group 3 was 2.82±0.39 respectively. The difference between the impact strength of the three groups was highly statistically significant (p=0.001). The lower and upper bound for the groups was 1.78 and 2.04 respectively for group 1, 0.98 and 1.29 respectively for group 2 and 2.64 and 2.99 respectively for group 3. The minimum and maximum values for the groups was 1 and 2 respectively for group 1, 1 and 2 respectively for group 2 and 2 and 3 respectively for group 3.**Conclusion:** The results suggest that the PMMA denture resin reinforced with carbon nanotubes has the highest impact strength as compared to non-reinforced PMMA and reinforced with glass nanoparticles. It was also found that PMMA reinforced with glass nanoparticles has less impact strength as compared to non-reinforced PMMA.

Key words: Impact strength, Polymethyl methacrylate resin, Glass nanoparticles, Carbon nanotubes.

Introduction: Removable dentures are most widely used to replace missing tooth. Poly methyl Methacrylate (PMMA) is the commonly used material to fabricate denture base by heat cure technique. It has the advantage of being feasible, simple fabrication process, light weight, satisfactory aesthetics, colour matching ability and ease of finishing and polishing.[1]Despite the advantages the most common problem in acrylic resin dentures is fracture of the prosthesis. The reasons for the same are its unsatisfactory transverse, impact and flexural fatigue strength. The high-strain-rate fracture occurs due to the denture being dropped on the floor, or bent and fractured in cleaning and rarely does a complete denture break in the mouth. Impact strength is a measure of the energy absorbed by a material when a sudden blow strikes it. Ideally, the denture base should have sufficiently high impact strength to prevent breakage on accidental dropping.

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 are problematic because their bonds with the resin matrix are weak. In addition, metal is unacceptable clinically because of its low aesthetic properties.[2,3]As a replacement for metals various types of fibers such as carbon, glass, polyaromatic polyamide (aramid), and ultra-high molecular weight polyethylene (UHMWP) have been studied. Carbon fibers have been effective in reinforcing denture base resin, but their dark color is unaesthetic, and they are difficult to polish[4]. However, glass fibers are aesthetically stable, and improve the flexural and impact strength of denture base resins. As a result, glass fiber is the most commonly used reinforcing fiber with high tensile strength and good aesthetic properties[3,4].

Glass nanoparticles[5] and Carbon nanotubes[6] have shown, to have increased strength when used in other various forms in dentistry.

In this study, the impact strength of Non-reinforced PMMA denture base material will be compared with reinforced PMMA (Glass nanoparticles and Carbon nanotubes).

Materials and methods: The materials used in this research are PMMA powder and liquid (Heat cure denture base resin, DPI, India) Glass nanoparticles (Adnano technologies Pvt Ltd) and Carbon nanotubes (Shilpa pvt Ltd)

Test specimen preparation: Total sample size of 66 was calculated using G*power 3.1.9.2. A metal block of dimensions 60 mm x 12 mm x 3 mm, (Figure: 1a and 1b) as standardized by the American Standards for Testing and Material (ASTM) used to form the mould space for acrylisation of samples (Figure: 2).[2] For the control specimen non-reinforced 0.43 grams of PMMA powder which was estimated through a pilot trial, was required to fabricate a sample with dimensions 60mm x 12mm x 3mm (Figure:3a and 3b). For Glass nanoparticles specimens (20-80nm Nanoparticles), 0.41 grams of PMMA powder (DPI) was mixed with 0.02 grams of Glass nanoparticles i.e, 5% by weight (Figure: 4).[3,5]For Carbon nanotubes specimens (2-10µm Nanotubes), 0.41 grams of PMMA powder (DPI) was mixed with 0.02 grams of Carbon nanotubes i.e., 5% by weight[4] (Figure:5) (Table:1). Each specimen was then flasked and cured by water bath polymerisation method using the long curing cycle which involved polymerization in a constant temperature water bath at 74°C (165°F) for 8 hours with no terminal boiling. The samples recovered from the flasks after polymerization were finished and polished. The finished and polished samples were stored in water at room temperature for 24 hours and subjected to the tests mentioned.

Table 1: Powder mixture component ratio's between Glass nanoparticles and Carbon nanotubes (Fixed at 5 wt%) as fillers in PMMA denture base resins.

Group	% of filler	% of acrylic
A. Control	0	100
B. Glass nanoparticles	5	95
C. Carbon nanotubes	5	95

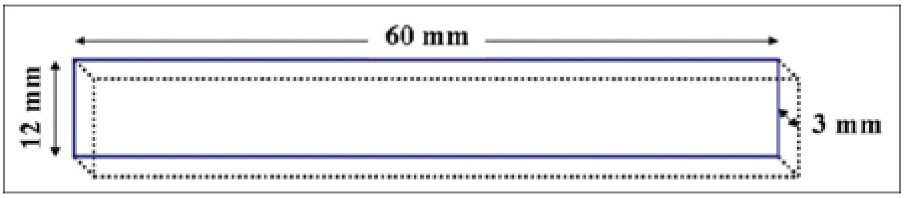

Figure 1a: Schematic representation of specimen dimensions

Figure 1b: Metal strips to create mould space

Figure 2: Base flasking of the metal strips

Figure 3a: Materials used

Figure 3b: Control specimen Non-reinforced PMMA

Figure 4: PMMA Reinforced with Glass nanoparticles (5% by weight).

Figure 5: PMMA Reinforced with Carbon nanotubes (5% by weight).

Testing of the samples: Digital calliper was used to locate the midpoint of each sample and marked using a marking pen. The samples were then subjected to IZOD type of impact tester using CEAST impact tester (Figure: 6). The sample was placed in a metal fixture so that the middle of the sample coincides with the striking pendulum (Figure 7).

The pendulum was made to strike the sample until it fractures. The energy required to break the sample was measured in joules (Figure: 8a and 8b).

Figure 6: IZOD type of impact tester

Figure 7: Sample placed in the metal fixture so that the middle of the sample coincides with the striking pendulum

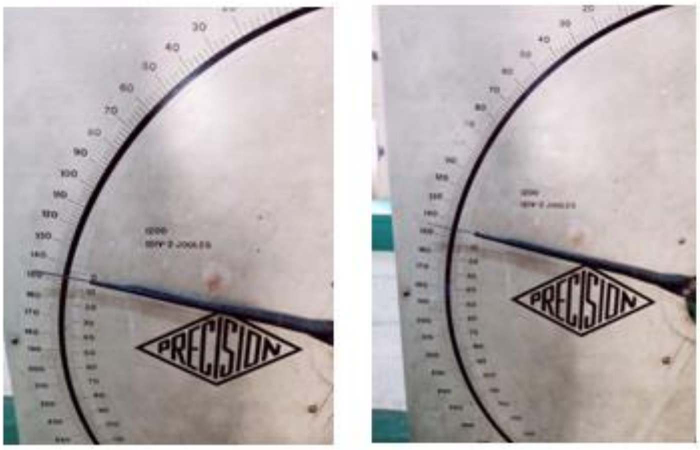

Figure 8a: The energy required to break the sample was measured in joules.

Figure 8b: Fractured samples

Results: The study was carried out to compare the impact strength of non-reinforced polymethyl methacrylate resin, polymethyl methacrylate resin reinforced with glass nanoparticles and polymethyl methacrylate resin reinforced with carbon nanotubes as a denture base material. The data obtained from the IZOD type of impact tester using CEAST impact tester were statistically analysed using SPSS version 14.

The level of significance was fixed at 0.05 and confidence level at 0.95.The data collected was entered into excel sheets and descriptives were generated. The impact strength of specimens in the three groups were compared using parametric ANOVA (One-way ANOVA).

The mean and standard deviation of impact strength of the three groups is tabulated (Table 2 graph 1), accordingly, the mean ± standard deviation of group 1 was 1.91±0.29, for group 2 was 1.14±0.35 and for group 3 was 2.82±0.39 respectively. The difference between the impact strength of the three groups was highly statistically significant (p=0.001). The lower and upper bound for the groups was 1.78 and 2.04 respectively for group 1, 0.98 and 1.29 respectively for group 2 and 2.64 and 2.99 respectively for group 3. The minimum and maximum values for the groups was 1 and 2 respectively for group 1, 1 and 2 respectively for group 2 and 2 and 3 respectively for group 3.

The data of all the three groups were found statistically significant at $p<0.05$. Therefore, Post-hoc test was done (Tukeys HSD test) to do pair-wise comparisons (Table: 3) and checked which group had statistical significance. Group 1 when compared with group 2 and group 3 the mean difference was 0.773 and 0.909 respectively, which showed highly significant difference (p=0.001). Group 2 when compared with group 3 the mean difference was 1.682 and showed highly significant difference (p=0.001).

Table: 2 Comparison of impact strength of three denture base materials consisting of Non-reinforced Polymethyl Methacrylate Resin, Polymethyl Methacrylate resin Reinforced with Glass nanoparticles And Polymethyl Methacrylate resin Reinforced with Carbon nanotubes.

Group	**No. of samples**	**Mean ± SD**	**95% Confidence Interval for Mean**		**Minimum**	**Maximum**	**p**
			Lower Bound	**Upper Bound**			
Non Reinforced PMMA	22	1.91±0.29	1.78	2.04	1	2	.001
PMMA reinforced with glass nanoparticles	22	1.14±0.35	.98	1.29	1	2	
PMMA reinforced with carbon nanotubes	22	2.82±0.39	2.64	2.99	2	3	

Graph 1: Comparison of impact strength of three denture base materials consisting of non-reinforced polymethyl methacrylate resin, polymethyl methacrylate resin reinforced with glass nanoparticles and polymethyl methacrylate resin reinforced with carbon

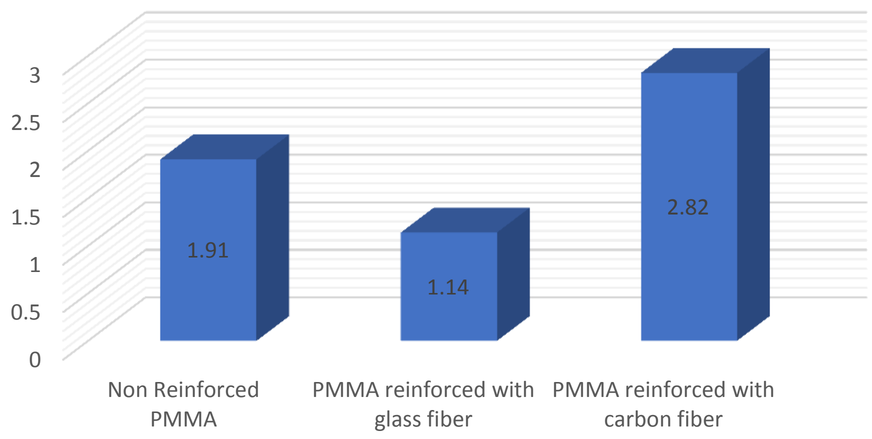

Table 3: Post-hoc test (Tukeys HSD test) for pair-wise comparisons between three denture base materials.

Group(I)	(J) Group	Mean Difference (I-J)	Std. Error	Sig. (p value)	95% Confidence Interval	
					Lower Bound	**Upper Bound**
Non Reinforced PMMA	PMMA reinforced with glass fiber	.773(*)	.105	0.001	.52	1.03
	PMMA reinforced with carbon fiber	-.909(*)	.105	0.001	-1.16	-.66
PMMA reinforced with glass fiber	PMMA reinforced with carbon fiber	-1.682(*)	.105	0.001	-1.93	-1.43

* The mean difference is significant at the .05 level (Post hoc : Tukey HSD)

Discussion: The present study was carried out to compare the impact strength of non-reinforced polymethyl methacrylate resin, polymethyl methacrylate resin reinforced with glass nanoparticles and polymethyl methacrylate resin reinforced with carbon nanotubes as a denture base material.

Since first polymerized by Walter Bauer in 1936, acrylic resin denture base gradually took the place of traditional metal base and became the most commonly used denture base material in clinical fabrication. Until today, there are some scientists still finding it the most suitable denture base material. Heat-polymerized acrylic resin systems include powder consisting of pre-polymerized spheres of poly (methyl methacrylate) and a small amount of benzoyl peroxide termed the initiator and liquid is predominantly non-polymerized methyl methacrylate with small amounts of hydroquinone which acts as an inhibitor. Glycol dimethacrylate is used as crosslinking agent, to form several interconnections between the molecules. A polymer formed in this manner yields a net like structure that provides increased resistance to deformation. As a rule, heat activated denture base resins are shaped via compression moulding. Polymethyl methacrylate is still the most predominantly used denture base material mainly because of its low cost, light weight, insoluble in oral fluid, excellent aesthetic properties and ability to be repaired easily.

Nonetheless, PMMA resin has some negative problems such as polymerization shrinkage, weak flexural, lower impact strength, and low fatigue resistance. Hence there are few methods proposed by Mallikarjuna et al. to improve the properties of PMMA resin such as:

- Using polycarbonates and polyamides as substitutes for PMMA.
- Chemical modification of PMMA by the addition of copolymers, cross-linking agents and rubber substances in the form of butadiene styrene.
- The incorporation of fibres, metal or ceramic inserts into the denture bases act as filler.[7]

Impact strength is defined as the energy required to fracture a material under an impact force. Measured using Charpy impact tester, where a pendulum is released that swings down to fracture the centre of a specimen supported at both ends. A moving object possesses a known kinetic energy. If the struck object is not permanently deformed, it stores the energy of collision in an elastic manner. This ability is due to the resiliency of the material and is measured by the area under the elastic region of the stress-strain curve. Thus a material with low elastic modulus and high tensile strength is more resistant to impact forces. A material with low elastic modulus and low tensile strength has low impact resistance. Acrylic is considered to have low elastic modulus of 3.5Gpa and moderately low tensile strength of about 60 Mpa, therefore less resistance of impact forces.

According to Rajul and Romesh, adding fillers to reinforce PMMA are considered the most cost effective and reasonable method. Different fillers will have different influence toward the properties of the PMMA. Those fillers can be polymer, metal and ceramic base materials. Generally, polymer base fillers, consist of polyethylene fibre and vegetable fibre. Silver, stainless steel, aluminium and copper are example of metal base fillers. Ceramic materials such as glass fibre, carbon fibre, silica, zirconia, alumina and barium titanium oxide are generally used to increase the mechanical, thermal and chemical properties of PMMA. However, improvement of polymer powder property depends on the filler concentration, filler morphology, degree of dispersion, orientation and degree of adhesion with the polymer matrix. Some of the materials from these developments have an excellent balance of impact resistance and flexural properties. However, most are not acceptable to the dental technician because of their processing characteristics. According to various studies most popular material at present for the fabrication of dentures, which has high impact strength, is a rubber modified acrylic polymer whose handling characteristics are more or less identical to conventional PMMA.[7]

In our study two of these materials glass nanoparticles and carbon nanotubes have been incorporated to reinforce PMMA resins in order to check for the improvement in the impact strength.

Carbon fibres were first made commercially by Edison in late 19th century by carbonizing thin bamboo shoots and carbon fibres. Carbon nanotubes (5% by weight) are anisotropic and provide greatest reinforcement of denture base resins in terms of flexural strength & bending properties. Ideally they have to be placed longitudinally (perpendicular to applied forces) but because of difficulty encountered in placing the fibres centrally fibres are placed randomly oriented.[2] Glass fibres and nanoparticles were tested as reinforcement for denture base PMMA since 1960s. The reasons glass nanoparticles were suitable to be used as reinforcing agent for denture base materials is because they had excellent aesthetic appearance, superior mechanical properties and biological compatibility. However, due to the deleterious effect on the doughing properties, the incorporation of glass fibres has to be limited to 20 wt%.[8]

The results in this study indicate that the difference between the impact strength of the three groups, non-reinforced PMMA denture base material, reinforced PMMA with glass nanoparticles and reinforced PMMA with carbon nanotubes was highly statistically significant and also the pair-wise comparisons of the data of all the three groups has highly statistical significant difference. The results of the study can be interpreted to be showing that PMMA reinforced with carbon nanotubes has high impact strength compared to non-reinforced and PMMA reinforced with glass nanoparticles. Whereas PMMA reinforced with glass nanoparticles has less impact strength as compared to non-reinforced PMMA.

Further modifications may be needed for the acrylic denture base resins to improve its physical properties while still exhibiting its beneficial antifungal and antibacterial characteristics. Recently, methods such as applying the concept of nanotechnology to modify the denture base resin are also giving good results. Literature suggests that the surface-charged resins can be further modified to increase its physical strength to achieve both biological and mechanical standards.

Limitations of the study:

1. Silane coupling treatment of the glass nanoparticles and carbon nanotubes was not done in the study, therefore bonding of the reinforcement particles with the PMMA could be lacking affecting the results.
2. Carbon nanotubes are unesthetic because of the black colour and also the polishing is difficult and weakens the finished prosthesis. Although carbon nanotubes is considered to provides significant improvement in mechanical properties of PMMA, its cytotoxic properties make it not suitable in denture application.

Conclusion: Within the limitations of present study, the following conclusions were made; the results suggest that the PMMA denture resin reinforced with carbon nanotubes has the highest impact strength as compared to non-reinforced PMMA and reinforced with glass nanoparticles. It was also found that PMMA reinforced with glass nanoparticles has less impact strength as compared to non-reinforced PMMA. Reinforcing with carbon nanotubes gives the dentures good impact strength along with being light weight but the main disadvantage is the unesthetic colour. Therefore further studies are suggested in order to overcome the disadvantage of carbon nanotubes.

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