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Statistical evaluation of impact of fiber reinforcement on mechanical characteristics of restorative resin using one-way ANOVA

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Abstract
Background: *The purpose of present study was to compare the reinforcing effect of the glass, polyethylene and carbon fibers on mechanical characteristics such as flexural strength, fracture toughness and abrasive resistance of restorative acrylic resins; PMMA (Travelon) and PMMA (DPI).*
Materials and Methods: *A total of 240 rectangular specimens (10 each from 24 groups) were fabricated and tested for flexural strength, fracture toughness and abrasive resistance. The unreinforced group served as the control.*
Results: *The data pertaining to flexural strengths, fracture toughness and abrasive resistance were compared by one way ANOVA followed by Bonferroni post hoc test, using a significance level of 0.05. The flexural strength of specimens of PMMA (Travelon) and PMMA (DPI) reinforced with carbon, polyethylene and glass fibers were significantly higher than their respective control group. Incorporation of carbon fiber in specimens of PMMA (Travelon) and PMMA (DPI) results in significantly higher flexural strength, followed by polyethylene and glass fiber. Mean value of fracture resistance was significantly increased in specimens of reinforced with carbon fiber. Mean values on abrasive resistance in specimens of PMMA (Travelon) and PMMA (DPI) reinforced with carbon fiber were significantly lowered when compared to control group.*
Conclusion: *Within the limitations of this study, it may be concluded that reinforcement of PMMA (Travelon) and PMMA (DPI) resins by non metallic fibers like glass, polyethylene, carbon fibers results in significant increase in flexural strength, fracture toughness and decrease in abrasive resistance of provisional restorative resin materials. It may be possible to apply these findings to distal extension partial and complete denture bases.*
Keywords: *Polymethyl methacrylate (PMMA), fiber, flexural strength, fracture toughness, abrasive resistance.*

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I. Introduction

Polymethyl methacrylate (PMMA) resins have been frequently used in removable prosthetic restorations due to its favorable characteristics such as biocompatibility, aesthetic appearance, chemical inertness, dimensional stability, processing ease, good color stability and compatibility with oral tissues[1,2]. Considering the major drawbacks of PMMA which include low fatigue resistance and thermal conductivity, susceptibility to fracture and low impact strength result in the poor clinical life of prostheses coupled with increased patient's visits and also the cost factor[3,4,5].

Dentures are known to undergo various failures such as fractures and de-bonding of the teeth, and other types of failures in complete or partial dentures[6]. Outside the mouth, fracture occurs due to impact of falling. Study on acrylic resin dentures (68%) break within a few years after fabrication primarily due to impact failure as reported by Johnston et.al.[7] considering the high incidence of fractures, numerous studies have been attempted on individual reinforcement techniques to improve the strength of the provisional restoration[8]. Various modifications have been reported to overcome these disadvantages such as chemical modifications of polymer with copolymerization and use of cross-linking agents of resin materials[9,10,11].

Different polymerization and reinforcement techniques have been attempted to enhance the mechanical characteristics of denture base acrylic resins. Various types of fibers such as carbon, aramid, woven polyethylene, and glass fibers have been reinforced with the polymer materials to improve their mechanical characteristics[12,13,14,15].

We conducted in-vitro experimentations to evaluate the flexural strength, fracture toughness and abrasive resistance of acrylic synthetic resins such as PMMA (Travelon) and PMMA (DPI) following reinforcement with glass fiber, polyethylene fiber and carbon fiber[16,17]. The purpose of this study was to compare the impact of reinforcement with glass, polyethylene and carbon fibres on flexural strength, fracture toughness and abrasive resistance of synthetic acrylic resins such as PMMA (Travelon) and PMMA (DPI) utilizing one-way ANOVA.

II. Materials & Methods

Chemicals: The acrylic synthetic resins namely PMMA (Travelon) and PMMA (DPI) were procured from M/s Densply India Private Limited, India and M/s Dental Products of India, Mumbai, India respectively. Silano (Silane coupling agent) was obtained from M/s Angelus, Londrina, PR, Brazil.

Preparation of specimens: A total of 240 rectangular specimens (10 each from 24 groups) having dimension (65 x 10 x 3.3 mm^3) of PMMA (Travelon) and PMMA (DPI) were prepared as defined in Table 1. The preparation of the specimens of control groups and respective experimental groups reinforced with glass fiber, polyethylene fiber and carbon fiber for flexural strength, fracture toughness, abrasive resistance and incorporation of fibers was described as earlier[16].

Table no 1: Data related to various groups and respective sample size.

S. No.	Synthetic Resin	Mechanical Characteristics	Groups		Number of specimens
1	PMMA (Travelon)	Flexural strength	Control group	A	10
			Reinforced with glass fiber	A1	10
			Reinforced with polyethylene fiber	A2	10
			Reinforced with carbon fiber	A3	10
		Fracture toughness	Control group	B	10
			Reinforced with glass fiber	B1	10
			Reinforced with polyethylene fiber	B2	10
			Reinforced with carbon fiber	B3	10
		Abrasive resistance	Control group	C	10
			Reinforced with glass fiber	C1	10
			Reinforced with polyethylene fiber	C2	10
			Reinforced with carbon fiber	C3	10
2	PMMA (DPI)	Flexural strength	Control group	D	10
			Reinforced with glass fiber	D1	10
			Reinforced with polyethylene fiber	D2	10
			Reinforced with carbon fiber	D3	10
		Fracture toughness	Control group	E	10
			Reinforced with glass fiber	E1	10
			Reinforced with polyethylene fiber	E2	10
			Reinforced with carbon fiber	E3	10
		Abrasive resistance	Control group	F	10
			Reinforced with glass fiber	F1	10
			Reinforced with polyethylene fiber	F2	10
			Reinforced with carbon fiber	F3	10

Statistical analysis: All the data were coded and entered Microsoft Excel 2007 and then transferred into IBM SPSS version 26 for graphical representation and analysis of it. Basic descriptive statistics were performed on all important variables and checked by both graphical method (using a histogram) and Shapiro-Wilk test. After analyzing the data distribution and homogeneity of variance by Levene's test, one-way ANOVA was employed to determine the significance of difference among the mean values of the different group, followed by Bonferroni post-hoc test and Games Howell test for multiple comparisons. All statistical tests in the analysis assumed two sided P values and the alpha error (α) was considered 5% (0.05).

III. Results

The data pertaining to flexural strength of control group of PMMA (Travelon) and PMMA (DPI) and their respective experimental groups reinforced with 5% each of glass, polyethylene and carbon fiber were reflected in Figure 1. The mean value of flexural strength of PMMA (Travelon) was maximum in group A3 (80.99 N/mm^2) followed by A2 (76.52 N/mm^2), A1 (73.8 N/mm^2) and A (67.86 N/mm^2). One way ANOVA on flexural strength of PMMA (Travelon) in control group (A) and its experimental groups (A1, A2 and A3) revealed that there was a statistically significant difference in average value of flexural strength between at least two groups (F=9.235, p=0.001). Data in Table 2 indicate Games Howell test for multiple comparison of flexural strength indicated significant difference between A and A1 (p=0.021), A and A2 (p=0.047), A and A3 (p=0.001) and A1 and A3 (p=0.021). However, no significant difference was noticed in average flexural strength between A1 and A2 (p=0.809) and A2 and A3 (p=0.503). Figure 1 represents mean value of flexural strength of PMMA

(DPI) which was maximum in group B3 (71.94 N/mm^2) followed by B2 (70.18 N/mm^2), B1 (69.29 N/mm^2) and B (61.89 N/mm^2). One way ANOVA revealed that there was a statistically significant difference in average value of flexural strength between at least two groups (F=12.262, p=0.001). Data in Table 3 indicate results on Bonferroni *post hoc* test for multiple comparison of mean value of flexural strength and significant difference was noticed between B and B1 (p=0.001), B and B2 (p=0.001), B and B3 (p=0.001). Albeit, no significance was noticed between B1 and B2 (p=1.00), B1 and B3 (p=0.889), and B2 and B3 (p=1.00).

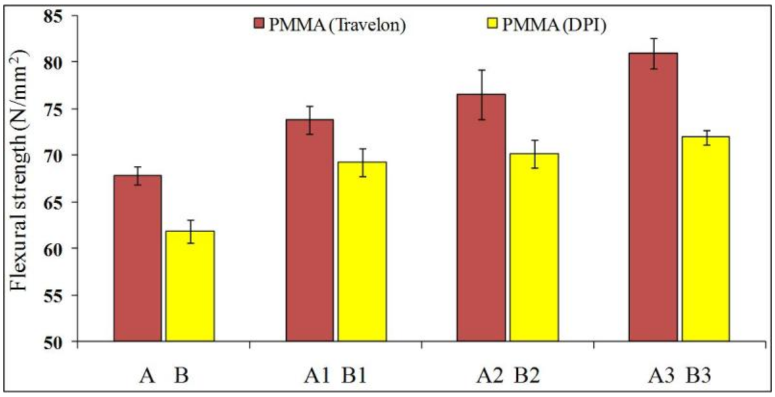

Figure 1: Data on flexural strength of PMMA (Travelon) in control group (A) and reinforced experimental groups (A1, A2 and A3) and PMMA (DPI) in control group (B) and reinforced experimental groups (B1, B2 and B3). Data represented as mean ± SD.

Table 2: Games Howell *post hoc* analysis of flexural strength for intergroup comparison of PMMA (Travelon)

Groups	95% CI	p
A versus A1	-11.07, -0.764	0.021
A versus A2	-17.19, -0.120	0.047
A versus A3	-18.71, -7.552	0.001
A1 versus A3	-13.44, -0.945	0.021
A1 versus A2	-11.58, 6.145	0.809
A2 versus A3	-13.51, 4.56	0.503

p value (significant if ≤ 0.05)

Table 3: Bonferroni *post hoc* analysis of flexural strength for intergroup comparison of PMMA (DPI)

Groups	95% CI	p
B versus B1	-12.39, -2.408	0.01
B versus B2	-13.28, -3.29	0.001
B versus B3	-15.04, -05.05	0.001
B1 versus B2	-5.87, 4.11	1.00
B1 versus B3	-7.64, 2.34	0.88
B2 versus B3	-3.22, 6.76	1.00

p value (significant if ≤ 0.05)

The mean value of fracture toughness in control group of PMMA (Travelon) and PMMA (DPI) and their respective experimental groups reinforced with 5% each of glass, polyethylene and carbon fiber were shown in Figure 2. It was maximum in group C3 (1.82 MPa.m$^{1/2}$) followed by C2 (1.69 MPa.m$^{1/2}$), C1 (1.33 MPa.m$^{1/2}$) and C (1.32 MPa.m$^{1/2}$). One way ANOVA indicated significant difference in average value of fracture toughness between at least two groups (F=6.507, p=0.001). Data in Table 4 showed Bonferroni *post hoc* test for multiple comparison of fracture toughness values which were significant between C and C3 (p=0.007) and group C1 and C3 (p=0.008). However, no difference was observed between C and C1 (p=1.00), C and C2 (p=.079), C1 and C2 (p=0.091), C2 and C3 (p=1.00). The mean value of fracture toughness of PMMA (DPI) were reflected in Figure 2 and it was maximum in group D3 (2.02 MPa.m$^{1/2}$) followed by D2 (1.87 MPa.m$^{1/2}$), D1 (1.52 MPa.m$^{1/2}$) and D (1.24 MPa.m$^{1/2}$). One way ANOVA revealed a statistically significant difference in average value of fracture toughness between at least two groups (F=8.575, p=0.001). Results on Bonferroni *post hoc* test for multiple comparison of fracture toughness were given in Table 5. Statistically significant difference was recorded between D and D2 (p=0.004), D and D2 (p=0.001) and group D1 and D3 (p=0.03). There were no statistically significant difference in average value of fracture toughness between D and D1 (p=0.595), D1 and

D2 (p=0.293) and D2 and D3 (p=1.00).

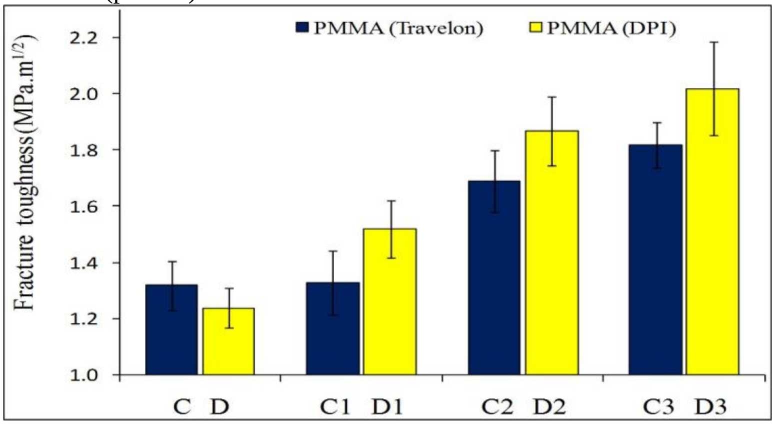

Figure 2: Data on fracture toughness of PMMA (Travelon) in control group (C) and reinforced experimental groups (C1, C2 and C3) and PMMA (DPI) in control group (D) and reinforced experimental groups (D1, D2 and D3). Data represented as mean ± SD.

Table 4: Bonferroni *post hoc* analysis of fracture toughness for intergroup comparison of PMMA (Travelon)

Groups	95% CI	p
C versus C3	-0.892, -0.107	0.007
C1 versus C3	-0.884, -21.099	0.008
C versus C1	-0.401, 0.384	1.00
C versus C2	-0.759, 0.025	0.079
C1 versus C2	-0.751, 0.033	0.09
C2 versus C3	-5.259, 0.259	1.00

p value (significant if ≤ 0.05)

Table 5: Bonferroni *post hoc* analysis of fracture toughness for intergroup comparison of PMMA (DPI)

Groups	95% CI	p
D versus D2	-1.11, -0.16	0.004
D versus D3	-1.259, -0.309	0.001
D1 versus D3	-0.971, -0.021	0.036
D versus D1	-0.763, 0.183	0.595
D1 versus D2	-0.822, 0.128	0.293
D2 versus D3	-0.624, -0.329	1.00

p value (significant if ≤ 0.05)

The data related to abrasive resistance in control group of PMMA (Travelon) and PMMA (DPI) and their respective experimental groups reinforced with 5% each of glass, polyethylene and carbon fiber were reflected in Figure 3. The mean value of abrasive resistance of PMMA (Travelon) was maximum in group E (1.1 mm) followed by E2 (1.05 mm), E1 (0.98 mm) and E3 (0.92 mm). One way ANOVA revealed that there was a statistically significant difference in average value of abrasive resistance between at least two groups (F=25.963, p=0.001). Data in Table 6 indicated the multiple comparison using Bonferroni test on mean values of abrasive resistance and significant difference was noticed between E and E1 (p=0.001), E and E3 (p=0.001) and E2 and E3 (p=0.001). However, no difference in mean values of abrasive resistance between E and E2 (p=0.159), E1 and E2 (p=0.019) and E1 and E3 (p=0.054) were recorded. The mean value of abrasive resistance of PMMA (DPI) was maximum in group F (1.28 mm) followed by F2 (1.26 mm), F1 (1.17 mm) and E3 (1.1 mm). One way ANOVA indicated statistically significant difference in average value abrasive resistance between at least two groups (F=25.639, p=0.001). Data in Table 7 mentions multiple comparison employing Bonferroni test and significant difference was observed between F and F1 (p=0.001), F and F3 (p=0.001), F1 and F2 (p=0.003), F1 and F3 (p=0.043) and F2 and F3 (p=0.001). There were no significant difference in average value of abrasive resistance between F and F2 (p=1.00).

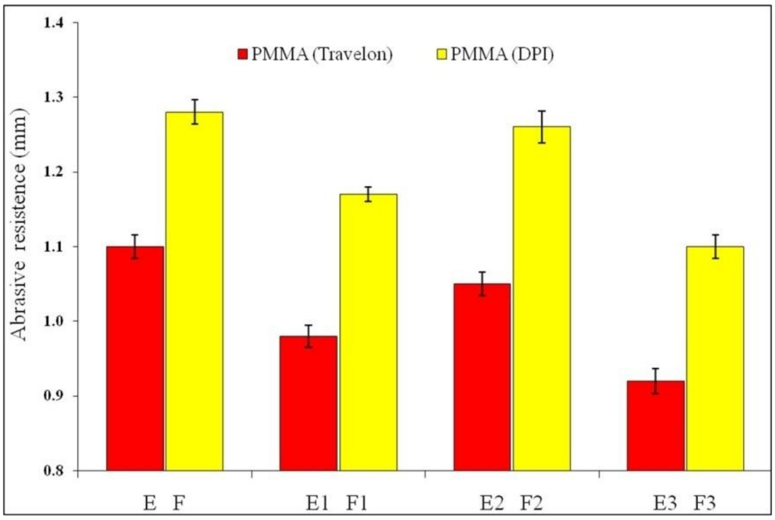

Figure 3: Data on abrasive resistance of PMMA (Travelon) in control group (E) and reinforced experimental groups (E1, E2 & E3) and PMMA (DPI) in control group (F) and reinforced experimental groups (F1, F2 & F3). Data represented as mean ± SD.

Table 6: Bonferroni *post hoc* analysis of abrasive resistance for intergroup comparison of PMMA (Travelon)

Groups	95% CI	p
E versus E1	0.060, 0.1857	0.001
E versus E3	0.122, 0.247	0.001
E2 versus E3	0.070, 0.195	0.001
E1 versus E2	-0.137, -0.008	0.019
E versus E2	-0.010, 0.114	0.159
E1 versus E3	0.007, 0.124	0.054

p value (significant if ≤ 0.05)

Table 7: Bonferroni *post hoc* analysis of abrasive resistance for intergroup comparison of PMMA (DPI)

Groups	95% CI	p
F versus F1	0.0503, 0.179	0.001
F versus F3	0.116, 0.245	0.001
F1 versus F2	-0.152, -0.023	0.003
F1 versus F3	0.001, 0.130	0.043
F2 versus F3	0.008, 0.218	0.001
F versus F2	-0.037, 0.179	1.00

p value (significant if ≤ 0.05

IV. Discussion

The major cause of clinical failure of acrylic dentures were reported to be fatigue failure, midline failure and impact failure due to the low flexural strength and impact strength of acrylic material which necessitated the need for the denture strengthening[18]. The interim restorations should possess adequate flexural strength to withstand the masticatory forces. Our results indicated that reinforcement of PMMA (Travelon) and PMMA (DPI) with glass, polyethylene and carbon fibers increased the flexural strength and fracture toughness, but lowered the abrasive resistance. The orientation of the fibers in fact increased the flexural strength of the material, which in turn prevent the midline fracture of the denture clinically. Among the fibers, carbon showed maximum strengthening effect. In another study, there was 50% increase in transverse strength of acrylic resin when surface treated carbon fibers were incorporated[19]. Albeit, the primary disadvantage by the use of carbon fiber was the unaesthetic appearance due to black color.

The adhesion between fibers and polymers matrix implicates a defining role in transferring the stress from the matrix to the fibers. The site of placement of fibers is also crucial for strength of the restoration. Problem constantly faced with the fiber reinforcement of acrylic resin is to achieve adequate impregnation of reinforcing fibers with resin; which is a perquisite for proper binding of fibers to the polymer matrix and thus for the strength of composite[20]. Other factors affecting the strength of fiber composites are the quantity and orientation of fibers to the polymer matrix. In addition, the chemical bond between the polymer and fibers should ideally be of a covalent nature. Silane coupling agents have been used successfully to improve the adhesion between polymers and glass fibers[21].

The fabrication of provisional restoration is important for a happy patient life and functionally it must satisfy optimal interim restoration such as biological and esthetics considerations to provide pulpal protection by preventing the conduction of temperatures through the outer surface of the enamel into inter-pulpal tissues. In this context, considering their mechanical characteristics, the fracturing of the restoration occurs from a large transitory force caused by an accident or a small force during repeated chewing and bruxing[22,23].

Flexural strength of denture base resin is considered primary mode of clinical failure and regarded as the highest stress defined within the material at its moment of rapture[24]. Fracture toughness is a quantitative way of defining a material's resistance to crack propagation; the standard values for a given material are generally available and may more accurately determine the likelihood of fracture of a provisional restoration in practice.

Studies indicated that experiments pertaining to reinforcement with different types of fibers as a method of improving the fracture strength of provisional restorations seems promising which may be explained due to the transfer of stress from weak polymer matrix to the fibers that have high tensile strength resulting stronger adhesion between the fiber and the matrix[25,26,27]. Experimental evidences indicate that the position, quantity, direction and degree of adhesion between the fibers and polymer matrix affect the degree of reinforcement[28,29,30].

The improvement in the flexural characteristics to achieve the requirements of clinical use would be desirable as they indicate the stiffness of denture base resin and resistance to a force that may develop in oral environment. Albeit, the sample size may be considered as a limitation of the study, but the clinical implications of the findings may reflect a promise of potentially practical tool in regard to strengthening provisional fixed partial dentures.

V. Conclusions

Within the limitations of this study, it may be concluded that reinforcement of PMMA (Travelon) and PMMA (DPI) resins by non metallic fibers like glass, polyethylene, carbon fibers results in significant increase in flexural strength, fracture toughness and decrease in abrasive resistance of provisional restorative resin materials. It may be possible to apply these findings to distal extension partial and complete denture bases.

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