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ORIGINAL ARTICLE

Effect of polyester fiber reinforcement on the mechanical properties of interim fixed partial dentures

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KEYWORDS

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Abstract *Background:* Different reinforcements currently available for interim fixed partial denture (FPD) materials do not provide the ideal strength for long-term use. Therefore, the aim of this investigation was to develop a more ideal provisional material for long-term use with better mechanical properties. This study evaluated the effectiveness of polyester fiber reinforcement on different interim FPD materials.

Methods: Thirty resin-bonded FPDs were constructed from three provisional interim FPD materials. Specimens were tested with a universal testing machine (UTM). The modulus of elasticity and flexural strength were recorded in MPa. The compressive strength and degree of deflection were calculated from the obtained values, and a two-way analysis of variance (ANOVA) was used to determine the significance.

Results: The polyester fiber reinforcement increased the mechanical properties. The modulus of elasticity for heat-polymerized polymethyl methacrylate (PMMA) was 624 MPa, compared to 700.2 MPa for the reinforced heat-cured sample. The flexural strengths of the bis-acrylic and cold-polymerized reinforced samples increased significantly to 2807 MPa and 979.86 MPa, respectively, compared to the nonreinforced samples. The mean compressive strength of the reinforced cold-polymerized PMMA samples was 439.17 MPa; and for the reinforced heat-polymerized PMMA samples, it was 1117.41 MPa. The degree of deflection was significantly greater ($P < 0.05$) in the reinforced bis-acrylic sample (5.03 MPa), compared with the nonreinforced bis-acrylic sample (2.95 MPa).

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Conclusion: Within the limitations of this study, polyester fiber reinforcements improved the mechanical properties of heat-polymerized PMMA, cold-polymerized PMMA, and bis-acrylic provisional FPD materials.

1. Introduction

Provisional restorations are imperative for treatment with fixed prosthodontics. They provide an important diagnostic function, protect the prepared teeth, and facilitate biological and biomechanical refinement before fabricating the definitive restoration (Christensen, 1996; Gratton and Aquilino, 2004). Traditional acrylic materials and techniques have insufficient strength and unfavorable esthetics for long-term use (Federick, 1975; Vahidi, 1987). Numerous materials and technical advancements have been proposed to improve the properties of the materials (Haselton et al., 2002; Ireland et al., 1998; Nejatidanesh et al., 2006; Young et al., 2001). The new materials include polymethyl methacrylate (PMMA), polyvinyl ethyl methacrylate, bis-phenol A glycidyl dimethacrylate, and polyurethane (Rosentritt et al., 2004). These materials can be reinforced with traditional stainless steel wire or reinforcement fibers (Chung et al., 1998; Jagger et al., 1998). The various fibers used for reinforcement include polyethylene, glass, aramide, and carbon fibers (Amin, 1995; Geerts et al., 2008; Hamaza et al., 2004; Lang et al., 2003; Larson et al., 1991; Panyayong et al., 2002; Powell et al., 1994; Saygili et al., 2003; Stipho, 1998; Vallittu, 1998). Although sufficient improvements of properties and materials have been obtained, it is still desired to derive a more ideal material with increased strength and improved esthetics that is amenable to long-term provisional usage. Therefore, the objective of this study was to evaluate the mechanical properties of polyester fiber reinforcement to heat-polymerized PMMA, cold-polymerized PMMA, and bis-acrylic provisional fixed partial denture (FPD) materials. The flexural strength, modulus of elasticity, compressive strength, and degree of deflection of these three different provisional materials and their polyester fiber reinforcements were evaluated and compared in this study.

2. Materials and methods

This study was approved by the institutional ethics committee. A CAD-CAM (MTAB XL MILL, MTAB Engineers Private Limited, Chennai, India) die was made to simulate the partially edentulous condition of a three-unit maxillary, posterior FPD (Nejatidanesh et al., 2006). Nonanatomic patterns of 7.5 mm in height and 5 mm in diameter as well as 6 mm in height and 8 mm in diameter were made to replicate prepared teeth of the maxillary second premolar and maxillary molar, respectively. The prepared teeth simulation had a two-degree taper and supragingival chamfer finish line. A gap of 8 mm in height and 10 mm in width placed between the two teeth simulated the pontic space for the maxillary first molar. The precision of the anatomical form of the clinical tooth preparation could not be simulated in this study due to limitations in the use of the sample in the universal testing machine (UTM). The designed die had a rectangular platform (50 cm × 25 cm × 14 cm) to facilitate holding of the aluminum dies in the UTM (Fig. 1).

The materials tested were as follows: heat-polymerized PMMA (A), heat-polymerized PMMA reinforced with polyether fibers (B), cold-polymerized PMMA (C), cold-polymerized PMMA reinforced with polyether fibers (D), cold-polymerized bis-acrylic (E), and cold-polymerized bis-acrylic reinforced with polyether fibers (F). Thirty samples were fabricated (five samples in each group) to analyze the flexural strength and modulus of elasticity of the different materials used in the manufacture of the provisional restoration of the interim FPDs.

A wax pattern (*Krohenwachs*® – Bego) of a definite size, shape, and lesser anatomic details of a three-unit resin-bonded FPD consisting of the second premolar (8 mm in length × 7.5 mm in mesio-distal width × 7 mm in bucco-lingual width), first molar (7.5 mm × 11 mm × 9 mm), and second molar (7 mm × 10.5 mm × 10 mm) was made on the aluminum die. An impression of the wax pattern was made with polyvinyl siloxane (putty consistency; *Virtual Refill*®, Ivoclar Vivadent). Type 4 stone cast (*Ultrarock*®, Kalabhai, India) was made from the impression. The cast obtained was used to make a vacuum-formed template using a pressure molding machine (Biostar®, SCHEU-DENTAL GmbH) (Fig. 2). The vacuum-formed template was used to standardize the specimen size and shape (Fig. 3). The materials were manipulated in accordance with the manufacturer's instructions.

Heat-cured polymerized PMMA specimens A and B were processed by an indirect technique. Impression of the CAD CAM die was made with polyvinyl siloxane (putty consistency; *Virtual Refill*®, Ivoclar Vivadent). Type 4 stone cast (*Ultrarock*®, Kalabhai, India) was made from the impression. The cast obtained was used to make the wax patterns. The wax patterns were made over the cast using the template. The fabricated wax patterns were processed by a compression molding

Figure 1 CAD CAM die simulating fixed partial dentures.

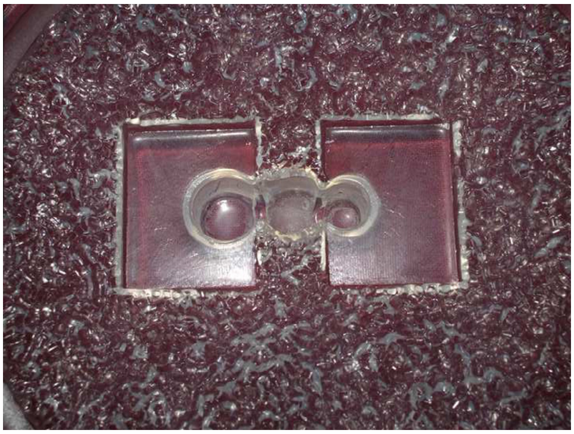

Figure 2 Template used to make the wax pattern of the test specimen.

Figure 3 Wax pattern of the sample on the die stone cast.

technique, according to the manufacturer's instructions for the materials.

Specimens C, D, E, and F were fabricated by a direct technique. The template was loaded with either a dough or paste consistency of the material and pressed over the CAD CAM die. The entire unit was held under firm hand pressure until the materials had set.

The specimens were evaluated for defects. The defective specimens were discarded. The chosen specimens of all groups were trimmed and finished with abrasive stones and 300-grit sandpaper. The specimens were polished with a pumice/water mixture and finished with diamond polishing paste. The entire procedure was performed by the same person for standardization (Figs. 4 and 5).

Specimens B, D, and F were made with polyester fiber reinforcement (particle size of 100 μm, Industrial use, Indian Institute of Technology, Chennai). The fibers were presilanated with methacryloxypropyltrimethoxysilane by the manufacturer to enhance adhesion with resin materials. The polyester fibers were added to the polymer or base paste of the provisional materials in a ratio of 1:10 (2% of the specimen by weight) (Kamble and Parkhedkar, 2012). The weight of the fibers was measured using an electronic machine and transferred to the polymer or base paste of the provisional FPD materials to

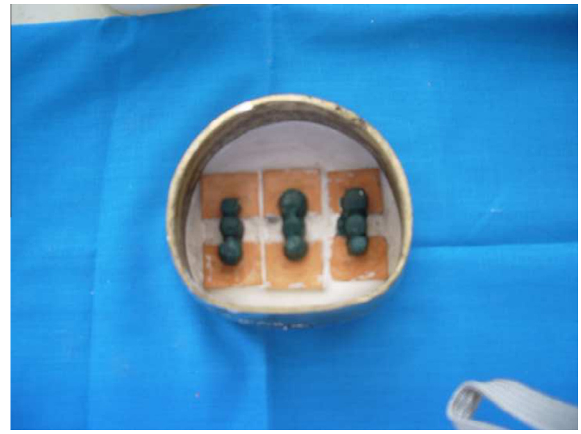

Figure 4 Flasking of specimen.

Figure 5 Post curing of specimen.

Figure 6 Specimens of different groups.

prepare specimens B, D, and F. These specimens were then prepared in a similar manner as specimens A, C, and E. In total, 30 specimens (5 samples per group) were fabricated for this study (Fig. 6). The materials, code, and lot numbers of the materials used in this study are summarized in Table 1.

Before analysis, the specimens were stored at 37 °C for 24 h and air dried for 1 day at room temperature. The fabricated

Table 1 Evaluated materials.

Code	Material	Manufacturer	Batch or lot number	Mixing ratio	Processing technique
A	Heat-activated PMMA	*DPI heat cure*®, India	Batch no. 134:2008	Powder:Liquid = 3:1	Compression molding technique – 74 °C, 90 min
B	Heat activated PMMA + polyester fibers	Custom made with *DPI heat cure*®, India	Customized with Batch no. 134:2008	Fibers added to polymer, Powder: Liquid = 3:1	Compression molding technique – 74 °C, 90 min
C	Chemical activated PMMA	*DPI-RR cold cure*®, India	Batch no. 1945:2008	Powder:Liquid = 3:1	Fluid resin technique
D	Chemical activated PMMA + polyester Fibers	Custom made with *DPI-RR Cold cure*®, India	Customized with Batch no. 1945:2008	Fibers added to polymer, Powder: Liquid = 3:1	Fluid resin technique
E	Bis-acrylic	Bis-acrylic resin – *Unifast Trad*® – GC Corporation, Tokyo, Japan	Lot no: 0602132	Powder:Liquid = 2:1	Fluid resin technique
F	Bis-acrylic polyester fibers	Custom made with *Unifast Trad*® – GC Corporation, Tokyo, Japan	Customized with Lot no: 0602132	Fibers added to polymer, Powder: Liquid = 2:1	Fluid resin technique

Figure 7 Specimen during UTM analysis.

Figure 8 Specimen post UTM analysis.

specimens were tested in the UTM (LR 100 K, Lloyd; U.K., CIPET, Guindy, India) with a cell load of 5 kN. The specimens were positioned and stabilized on the testing platform with a span length of 5 mm, and they were loaded compressively at the mid-pontic region with a cross head speed of 0.5 mm/min (Fig. 7). Failure was marked by a perceptible crack and reconfirmed by the abrupt decrease in the recorded load–deflection curve. Fracture load and deflection were documented for all specimens (Fig. 8). The other mechanical properties were derived using formulae. The load–deflection curves were recorded using computer software (NEXYGEN™ MT).

$$FS = 3/2PL/bd^2$$

where, P = compressive load; L = length in mm; b = width in mm; d = specimen thickness (diameter); FS = flexural strength; $P = (FS \times bd^2)/(3/2 \times L)$; compressive strength (CS) = compressive load/cross-sectional area; cross-sectional area = $\pi \cdot D^2/4$; $\pi = 22/7$; and D = diameter of the sample analyzed.

Collected data were tabulated and analyzed using descriptive and inferential statistics with the statistical software SPSS 17.0® (SPSS, Inc., Chicago, IL) for Windows.

3. Results

The mean values and standard deviation of modulus of elasticity, flexural strength, compressive strength, and degree of deflection for the six different materials were calculated and compared (Table 2). A two-way analysis of variance (ANOVA) test was done to study the effect of the variables, and the inferential statistical technique analyzed the effect of the variables (Table 3).

The results indicated that the flexural strength, degree of deflection, compressive strength, and modulus of elasticity improved significantly when the specimens were reinforced with polyester fibers. Thus, the polyester materials that were reinforced had better properties than the nonreinforced specimens (Fig. 9).

4. Discussion

Numerous reinforcements have been used and tested to improve the properties of interim FPDs (Eisenburger et al.,

Table 2 Mean values and standard deviations of mechanical properties for the tested materials.

Specimen	Modulus of elasticity		Flexural strength		Compressive strength		Degree of deflection	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
A	624	0.013038405	981.01	0.083628942	439.6	0.178969271	3.03	0.096953597
B	700.2	0.020746441	2493.01	0.075365775	1117.41	0.033911650	4.78	0.439454207
C	218.02	0.021213203	592	0.104785495	265.3	0.075503333	0.72	0.078612976
D	594.03	0.032403703	979.86	0.114697268	439.17	0.495530019	2.85	0.144844744
E	680.98	0.048785244	1800.06	0.083366666	806.82	0.045055521	2.95	0.108074090
F	707.99	0.052915026	2807	0.112605551	1258.13	0.049193496	5.03	0.111713920

Table 3 Effect of variables by two-way ANOVA.

Variables	Source of variation	Type 3 sum of squares	df	Mean squares	Frequency	Significance
Modulus of elasticity	Material	0.001	4	0	0.172	0.951
	Reinforcement	1077437.148	6	179572.858	1.1	0.02*
Flexural strength	Material	0.706	4	0.177	0.824	0.523
	Reinforcement	22995634.47	6	3832605.744	2.3	0.01*
Compressive strength	Material	0.109	4	0.027	0.619	0.653
	Reinforcement	1620002.085	6	770000.347	2.6	0.01*
Degree of deflection	Material	0.021	4	0.005	0.764	0.559
	Reinforcement	66.818	6	11.136	1.7	0.01*

* Statistically significant $P < 0.05$.

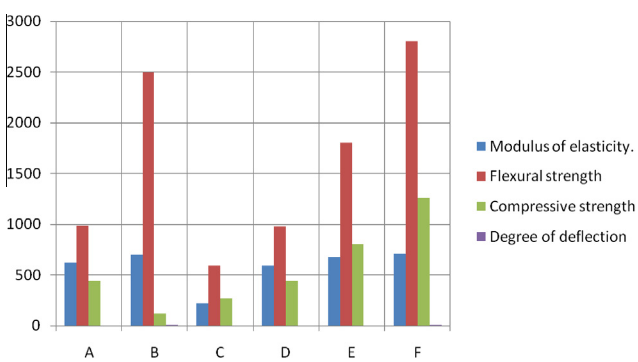

Figure 9 Mean values of various mechanical properties of the specimens.

2008; Geerts et al., 2008; Nohrström et al., 2000; Samadzadeh et al., 1997; Stipho, 1998). However, no previous methods or techniques have improved the materials to achieve desirable mechanical, biological, or esthetic properties for long-term use. Therefore, this study evaluated the use of polyester fiber reinforcement in provisional FPD materials.

Polyester fibers have greater strength, heat resistance, and color stability as well as less corrosion and fewer problems with bonding to acrylic, compared to other fibers (Blanchemain et al., 2011; Grant et al., 2013; Moreno et al., 2011; Takahashi et al., 2012). In this study, polyester fibers were used as the reinforcement material in regular interim FPD materials including heat-polymerized PMMA, cold-polymerized PMMA, and bis-acrylic.

Material strength is an important factor that must be analyzed in selecting provisional materials (Hamza et al., 2006; Haselton et al., 2002). The evaluation of flexural strength, modulus of elasticity, compressive strength, and degree of deflection plays a greater role in the durability of the restoration (Jagger et al., 1998; Vahidi, 1987). These properties were considered because it was anticipated that the chance of mechanical failure of the provisional FPD was great due to masticatory forces.

PMMA is strong, has a high wear strength, is easy to repair, and has good esthetics. However, the material has the following limitations: allergenicity, color instability, and odor (Federick, 1975; Gratton and Aquilino, 2004). This study demonstrated that the heat-polymerized PMMA and the heat-polymerized PMMA reinforced with polyester fibers samples had better strength than the cold-polymerized PMMA and the cold-polymerized PMMA reinforced with polyester fibers samples. The results showed that the method of polymerization also affected the strength of the material. Specimens A and B (heat-polymerized) were stronger and showed better wear resistance than specimens C and D (cold-polymerized). In addition, the polyester fiber reinforcement of cold-polymerized acrylic improved the strength significantly; however, it has a few limitations that must be considered during clinical handling. For example, the process may cause decreased polymerization, liberation of heat during setting will affect the pulp, and the free monomer can cause pulp and gingival damage (Jagger et al., 1998). The cold-polymerized PMMA sample (specimen C) had the least flexural strength and modulus when compared to other materials. However, it is still widely used in the clinic because it is simple to use, easy to finish and polish, and less time is needed to fabricate the provisional FPD (Christensen, 1996; Gratton and Aquilino, 2004). The normal range of functional forces is approximately 150–200 MPa, which is within the tolerable limits of cold-polymerized PMMA. Being a provisional restoration that is used for a short period of time, the limitations of the cold-polymerized PMMA material are tolerable.

Bis-acrylic materials shrink less, liberate less energy, and result in a better marginal fit, compared to PMMA materials.

This study indicated that the bis-acrylic material with polyester fiber reinforcement had superior mechanical properties. Even though the material is stronger, it is less esthetically pleasing when compared to other materials. It stains easily if the unpolymerized surface layer is not removed. However, the mechanical properties of the material make it ideal for use as a long-term provisional FPD (Geerts et al., 2008; Gratton and Aquilino, 2004; Kamble and Parkhedkar, 2012; Nejatidanesh et al., 2009; Saygili et al., 2003; Vahidi, 1987). The results of this study showed that the specimens with polyester reinforcement had better mechanical properties than the nonreinforced specimens. In the nonreinforced category, the bis-acrylic sample had better mechanical properties than the PMMA materials. Although the materials were tested for mechanical stability, they should also be analyzed for other clinical parameters necessary for biological applications.

Within the limitations of the study, the results showed that polyester fiber reinforcement of the provisional materials improved the strength significantly. The bis-acrylic provisional material was the strongest (flexural strength, compressive strength, degree of deflection, and elastic modulus), followed by heat-polymerized PMMA and cold-polymerized PMMA. The study was in accordance with many different studies regarding polymer reinforcement with fibers (Colán Guzmán et al., 2008; Didia et al., 2010; Eisenburger et al., 2008; Fahmy and Sharawi, 2009; Geerts et al., 2008; Hamaza et al., 2004; Kamble and Parkhedkar, 2012; Uzun et al., 1999; Zortuk et al., 2008). This study also correlated with many previous studies of nonreinforced interim FPDs showing that polyester fibers significantly improved the mechanical properties of the material (Haselton et al., 2002; Nejatidanesh et al., 2006; Rosentritt et al., 2004).

This study was an *in vitro* study and cannot be compared to clinical situations because of biological variables. Therefore, a long-term clinical study is warranted. Newer reinforcement materials also should be evaluated for long-term biological and esthetic properties.

5. Conclusion

Polyester fiber reinforcements improved the mechanical properties of heat-polymerized PMMA, cold-polymerized PMMA, and bis-acrylic provisional FPD materials.

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Conflict of interest statement

The authors do not have any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

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