Fracture Resistance of Fiber-Reinforced PMMA Interim Fixed Partial Dentures

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Purpose: To compare different fiber reinforcements on fracture toughness of interim polymethyl methacrylate materials and then use the best combination to determine the optimal position for fiber placement in an interim 3-unit fixed partial denture (FPD).

Materials and Methods: In the first stage of the study, five groups of notched fracture toughness specimens were fabricated and loaded to failure (Instron): (1) unreinforced (control); (2) reinforced with pre-impregnated silanized E-glass fibers (Fibrestick); (3) cold plasma-treated woven polyethylene fibers (Ribbond triaxial); (4) pre-impregnated silanized plasma-treated woven polyethylene fibers (Construct); and (5) 1.0-mm-diameter stainless steel wire. In the second stage, the optimal position (occlusal, middle, or cervical third of pontic) for reinforcement with glass fibers (regimen 2) was tested by loading a 3-unit FPD to failure. All groups were compared with analysis of variance ($\alpha < 0.05$).

Results: The fracture toughness (in MPam$^{1/2}$) for each reinforced group (Fibrestick 2.74 $\pm$ 0.12, Construct fibers 2.59 $\pm$ 0.28, Ribbond triaxial 2.13 $\pm$ 0.20, and orthodontic wire 1.66 $\pm$ 0.09) was statistically greater ($p < 0.05$) than for the unreinforced group (control = 1.25 $\pm$ 0.006). Fracture loads for FPDs were greatest when the fiber reinforcements were placed in the cervical third (cervical = 1165 N).

Conclusions: The use of fiber and, to a lesser extent, orthodontic wire is an effective method to reinforce interim restoration resins.

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INDEX WORDS: polymers, fibers, fracture toughness, marginal integrity, fracture resistance

THE INTERIM restoration is an important phase in fixed prosthodontic therapy. It should provide both pulp and periodontal protection and have good esthetics and sufficient durability to withstand the forces of mastication. A fractured interim is damaging to prosthodontic care and may lead to an unscheduled appointment for repair. In addition, the interim restoration should have a well-adapted and well-contoured margin to maintain good gingival health prior to placement of the final restoration. While there is always a microscopic gap at the tooth-restoration interface, this should be as small as possible to facilitate plaque control in this critical area.[1]

Materials commonly used to fabricate interim restorations are polymethyl methacrylate, polyethyl methacrylate, *bis*-acryl composite, and epimine resin.[2-6] In patients with bruxism or those whose treatment plan requires longer-term use of interim restorations, such as when periodontally involved teeth are retained during the osseointegration of an implant,[7] interim restorations with improved physical properties are required. Several attempts have been made to reinforce interim fixed partial dentures (FPDs). These have included the use of metal wire,[8] a lingual cast metal reinforcement, a processed acrylic resin interim restoration,[9] and different types of fibers, e.g., carbon, polyethylene, and glass.[10-25]

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The concept of using fibers to reinforce an interim restoration appears to have an acceptable success rate.[20] With the recent introduction of improved fiber reinforcing materials, this has become increasingly beneficial.

Investigations have shown that carbon fibers produced a significant increase in the flexural strength of polymers;[11-13] however, their black color limits their use for provisionals. Transverse strength was not improved by polyethylene fibers in the absence of surface treatment due to poor adhesion between the fibers and the polymer matrix;[14] however, when plasma-treated polyethylene fibers were used, a significant increase in strength was recorded.[15] Silanized glass fibers are promising due to their good adhesion to the polymer matrix, high esthetic quality, and increased strength of the resulting composite.[16-19] Others have found that the position, quantity, and direction of the fibers and the degree of adhesion between the fibers and the polymer affect the degree of reinforcement.[20-25]

The purpose of this study was to compare the effect of different reinforcement methods on the fracture toughness of interim restoration resin and to determine the influence of reinforcement location on the marginal integrity and the fracture resistance of interim FPDs.

Materials and Methods

Two laboratory tests were used for the study. For fracture toughness, compact test specimens were fabricated. In the second part, interim FPDs with fibers added in three locations were fabricated. The fracture resistance and marginal integrity of these FPDs were measured and compared to control groups.

The fibers used in this study had different configurations and surface treatments. Fibrestick has continuous unidirectional silanized E-glass fibers pre-impregnated with a porous polymer. Ribbond triaxial consists of cold plasma-treated woven polyethylene fibers and Construct has pre-impregnated silanized plasma-treated polyethylene fibers.

In the first stage of the study, compact test specimens were fabricated following ASTM no. E 399-83 recommendations.[26] The specimens were in the form of a double cantilever beam, with a slot that originated from the center of one edge extending along the block's center line to a 60° terminal apex located slightly beyond the midpoint of the block. Two loading holes pierced the block (Fig 1).

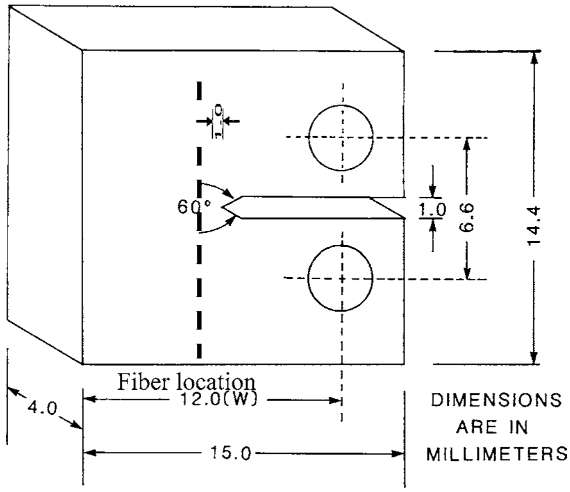

Figure 1. Dimensions of compact test specimens for fracture toughness testing.

Twenty-five compact test specimens were made using a specially designed stainless steel mold. The design of the assembled mold provided three triangular ports, which allowed the escape of excess resin during mold assembly and during polymerization. The specimens were divided into five groups of five specimens each, according to the type of reinforcement [Group 1: unreinforced (control); Group 2: reinforced with silanized continuous unidirectional E-glass fibers pre-impregnated with porous polymer (Fibrestick, lot #2020610-r-0061, Stick Tech Ltd, Helsinki, Finland); Group 3: cold plasma-treated woven polyethylene fibers (Ribbond triaxial, lot # T104, Ribbond, Inc, Seattle, WA); Group 4: pre-impregnated silanized plasma-treated woven polyethylene fibers (Construct, Lot # 30869, Kerr Corp, Orange, CA); and Group 5: 1.0-mm-diameter stainless steel wire (Remanium Feder Hart, Dentaurum, Pforzheim, Germany)].

All specimens were fabricated at room temperature by mixing the polymer and monomer in a clean glass jar with a stainless steel spatula at the 2:1 ratio recommended by the manufacturers. When the mix reached the dough stage, it was slowly packed into the mold cavity to avoid trapping air. The cover and the two circular rods of the mold were placed in position and the entire assembly placed in a hand press and compressed to facilitate complete filling of the mold.

The reinforced specimens were made by precutting the fibers and the stainless steel wire into 12-mm lengths, and wetting the fibers according to the manufacturers' instructions using the polymer–monomer mix. The fiber bundles were approximately 2 mm wide. The mold cavity was filled with the resin, and then the fibers or the metal were placed perpendicular to the end of the slot and 1 mm away from it, aligning the fibers perpendicular to the direction of the crack (Fig 1).

After the resin had completely set, the specimens were separated from the mold and flash removed with a razor blade. The specimens were examined for any voids and defective specimens were discarded. Specimens were stored in 37°C water for 24 hours before testing.

A precrack was placed in the compact test specimens by placing a sharp scalpel at the end of the slot and applying hand pressure. The dimensions of each specimen were determined with a measuring microscope (Nikon Measurescope mm-11, Tokyo, Japan) having an accuracy of $4 + L/25$ μm where L is the length in mm.

The specimens were dried and then tested in tension in a universal testing machine (Instron Corp. 4204, Canton, MA) with the direction of the force perpendicular to the plane of the pre-formed crack. Each specimen was held in a specially designed tension device in the machine, and tension force was applied with a crosshead speed of 5 mm/min.

The peak force (F), which caused fracture of the specimens, was recorded in newtons and used to calculate the fracture toughness (K_{Ic}) in MPam$^{1/2}$ from the following equation:

$$K_{Ic} = \frac{pc}{bw^{1/2} \cdot F(a/w)}$$

where pc is the maximum load prior to crack advance in KN; b is the average specimen thickness in cm; w is the width of the specimen in cm; and

$$F(a/w) = \frac{(2\pm a/w)(0.886\pm 4.64a/w - 13.32a^2/w^2 \pm 14.72a^3/w^3 - 5.6a^4/w^4)}{(1-a/w)^{1/2}}$$

where a is crack length in cm.

In the second stage of the study, fiber-reinforced interim FPDs were fabricated with fiber placed in three locations (occlusal, middle, and cervical third of the pontic). The fracture resistance and marginal integrity of these FPDs were recorded and compared to unreinforced controls. The materials used were the polymethyl methacrylate (PMMA) resin and the silanized preimpregnated E-glass fiber, which yielded the highest mean values in phase one of the study.

A brass master die[19] with the dimensions shown in Figure 2 was made to simulate prepared abutments of a three-unit FPD. The two abutments were 10 mm apart. The mesial abutment simulated a prepared premolar tooth 6 mm wide cervically and 4.9 mm wide occlusally; the distal abutment simulated a prepared molar tooth 8.0 mm wide cervically and 7.6 mm wide occlusally. The finish lines on both abutments were 1 mm wide shoulders.

A poly(vinyl siloxane) impression (Express STD, 3M Dental Products, St Paul, MN) of the master die was made and poured with ADA type-IV die stone (Fujirock, GC Dental Industrial Corp., Tokyo, Japan) to form a

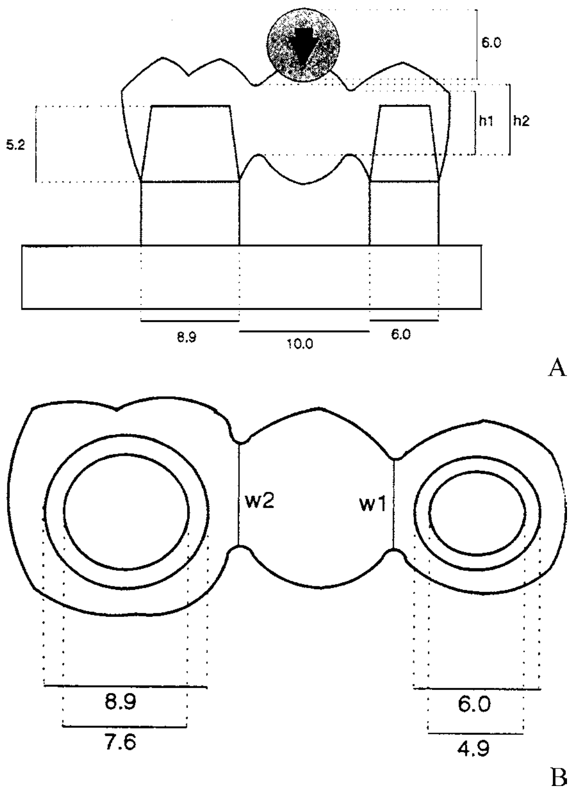

Figure 2. Diagram representing the dimensions of the brass master die. (A) Lateral view of the model and FPD (dimensions in mm). The arrow shows the direction of the occlusal force directed through a steel ball. (B) Occlusal view of the abutments (dimensions in mm). [Reprinted from reference 18, with permission from The Editorial Council of the Journal of Prosthetic Dentistry.]

master cast. A wax pattern of the interim FPD was made on the dental stone. The outer surface of this pattern was duplicated with the poly(vinyl siloxane) impression material to ensure that all interim FPDs had the same dimensions.

For the unreinforced specimens, the polymer and monomer of the PMMA resin were mixed as before in the manufacturer's recommended ratio of 2:1 by weight. The resin was hand mixed for 15 seconds, then the resin mixture was poured into the poly(vinyl siloxane) mold, which was located over the cast of the abutments and left to polymerize for 15 minutes.

For the reinforced groups, the fibers were precut to 10 mm lengths and the procedure described in the unreinforced group was followed except that, immediately after mixing the PMMA powder and liquid, the fibers were wetted with this mixture according to manufacturer recommendations and then placed into the poly(vinyl siloxane) mold in three locations as follows:

Group I: The wetted fiber reinforcement was placed in the mold in the pontic area before the resin mixture was added to fill the mold. This resulted in fibers located in the occlusal third of the pontic.

Group II: The mold was half filled with resin, then the wetted fiber reinforcement was placed in the pontic area and the rest of mold was filled with the resin. This resulted in fibers located in the middle third of the pontic.

Group III: The mold was filled with the resin, and the wetted fiber reinforcement was placed in the pontic area. This resulted in fibers located in the cervical third of the pontic.

In each case, the poly(vinyl siloxane) mold was located over the cast of the abutments and left to polymerize for 15 minutes. Then each FPD was removed from the mold, finished, polished, and stored in 37°C water for 24 hours before testing.

Each FPD was positioned on the brass master die with a 30 N force and the marginal opening measured with a stereo measuring microscope (Nikon Measurescope mm-11) having an accuracy of $4 + L/25\ \mu m$, where L is the length of the measurement. The distance between the finish line of the abutment and the margin of the crown was measured at ten predetermined locations (representing approximately mesio-buccal, mid-buccal, disto-buccal, mesio-lingual, and disto-lingual on each abutment crown) and the mean distance was calculated and recorded.

Using a universal testing machine (Instron Corp. 4204), the FPDs were loaded with a 6-mm diameter steel ball in the region of the central fossa with a crosshead speed of 5 mm/min. The load causing the initial fracture was recorded. The means and standard deviations for each group were determined.

The data were analyzed for differences using one-way analysis of variance, then Tukey's standardized range test (HSD) using a confidence level of 0.05 to determine statistically significant differences between the means.

Results

The mean fracture toughness values are shown in Table 1. The Tukey's standardized range test (HSD) revealed that all reinforced groups had significantly greater fracture toughness than the unreinforced resin controls. Significantly, greater means were found with Fibrestick and Construct reinforcement than Ribbond triaxial, which in turn was significantly greater than orthodontic wire ($p < 0.05$). There was no significant difference between PMMA resin reinforced with Fibrestick and Construct ($p > 0.05$).

Table 1. Fracture Toughness of Fiber-Reinforced PMMA Interim Resins

Type of Fiber Reinforcement	*Mean Fracture Toughness* ($MPa \cdot m^{\frac{1}{2}}$)	*Standard Deviation*	*Tukey Grouping*
Fibrestick	2.74	0.12	a
Construct	2.59	0.28	a
Ribbond triaxial	2.13	0.20	b
Steel wire	1.66	0.09	c
Control	1.25	0.06	d

Groups with different lowercase letters are significantly different ($p < 0.05$).

The fracture resistance testing (Table 2) showed that the placement of the reinforcement in the cervical third of the pontic was significantly higher ($p < 0.05$) than all other locations. However, the use of fiber to reinforce FPDs had no significant effect ($p = 0.99$) on the marginal integrity of the retainers (Table 2).

Discussion

This study compared the effect of fiber and metal reinforcement on the fracture toughness of interim restoration resins.

Laboratory fracture toughness values under static loading may not reflect the intraoral conditions; nevertheless, these values are helpful in comparing materials under controlled situations and may be a useful predictor of clinical performance.

To simulate the clinical conditions, interim FPDs with different locations of fibers were constructed, and then both the fracture resistance and

Table 2. Fracture Resistance and Marginal Gaps Associated with E-glass Fiber-Reinforced PMMA Interim FPDs

Fiber Locations	*Mean Fracture Resistance (N)*	*Marginal Fit* (μm)
Cervical third	1165 ± 88 a	176 ± 4.6 a
Middle third	947 ± 184 b	174 ± 3.5 a
Occlusal third	785 ± 94 b,c	170 ± 4.9 a
No fibers	660 ± 47 c	168 ± 4.2 a

Groups with different lowercase letters are significantly different ($p < 0.05$).

the marginal integrity of these FPDs were evaluated. Because the dimensions of these FPDs were identical, their fracture load values provided preliminary estimates of the effect of reinforcement method on the fracture resistance of a clinical interim restoration.[19]

The method used to test the fracture resistance of interim FPDs was based on the one previously described by Vallittu in 1998.[18] The effect of the interim luting agent on fracture resistance of interim FPDs was not investigated in this study; it is likely that cementing the FPD to the abutments increases the fracture resistance of the FPD by transferring stresses more evenly to the FPD abutment system. Another possible limitation of this study was the difficulty in keeping the fiber in the exact same location in each group; however, the results may provide a rational clinical protocol for the fabrication of fiber-reinforced interim FPDs.

Many investigators have confirmed the reinforcing effect of fibers on different polymer types.[10-18] This was in agreement with the results of this study, which revealed that all tested fibers increased the fracture toughness of interim restoration resins. This increase is due to transfer of stress from the weak polymer matrix to the fibers that have a higher tensile strength.[19] The stronger the adhesion between the fiber and the matrix, the greater the strengthening effect. In fact, the presence of poorly bonded fibers, to which little load is transferred, can be almost equivalent to voids.[21]

One approach to increasing the adhesion of fibers to a polymer matrix is resin impregnation of the fibers prior to application. An effective impregnation process allows fibers fracture toughness; and specimens showed complete separation of the resin to come into contact with the surface of every fiber. Wetting the fibers with monomer has been a commonly used method; however, although the monomer increases adhesion of fibers to the matrix, it may impair other properties due to residual monomer.

In this study, the effect of steel wire as a method of reinforcement was also evaluated. Although it caused a significant increase in the fracture toughness of the interim restoration resin, the effect of fiber was greater, due, presumably, to better adhesion of fibers to the resin.

The results revealed that placing the fibers at the cervical third of the pontic gave the highest fracture resistance values. This can be explained because interim restoration resin, like most brittle materials, has a greater compressive than tensile strength.[24] Therefore, fracture is usually initiated in the tension side of the restoration, which will be in the cervical third of the pontic. By placing fiber in this area, the fracture resistance of the restoration is increased, because the fiber will stop propagation of the initiating fracture through the restoration.[25]

From the clinical perspective, the loads required to fracture the fiber-reinforced interim FPDs were slightly higher than the maximal occlusal biting force in the molar region.[18] This suggested that optimally fabricated fiber-reinforced interim FPDs should have clinical success as long-lasting, higher strength interim restorations.

The results of this study also showed that there was no direct effect of fiber reinforcement on the marginal integrity of the FPDs. This may be attributed to the use pre-impregnated fibers (Fibrestick) in this study. As a result, there is no need to wet the fiber with monomer, which theoretically will increase the polymerization contractions and thus affect the marginal integrity of the restoration.[18]

When using reinforced interim resin materials clinically, it should be beneficial to choose a combination that, although fracturing, is held together by intact fibers. This might prevent catastrophic failure and may decrease patient discomfort and unscheduled appointments.

Further study should investigate the importance of the connector size with and without reinforcement. It is known that increasing the connector size has a major effect on increasing the fracture resistance of FPDs, but this may be undesirable as it could impede access for plaque control. Using fibers to reinforce the connectors may be beneficial in helping prevent fracture in this area.

Conclusion

Within the limitations of the current experiment, the following can be concluded: (1) all reinforcements evaluated produced an increase in fracture toughness ($p < 0.05$), (2) placement of reinforcement in the cervical third of an uncemented FPD produced the greatest fracture resistance ($p < 0.05$), and (3) there was no difference in marginal fit under load for different reinforcement positions ($p > 0.05$).

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