

In Vitro Study of Transverse Strength of Fiber Reinforced Composites

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Abstract:

Objective: Reinforcement with fiber is an effective method for considerable improvement in flexural properties of indirect composite resin restorations. The aim of this in-vitro study was to compare the transverse strength of composite resin bars reinforced with pre-impregnated and non-impregnated fibers.

Materials and Methods: Thirty six bar type composite resin specimens (3×2×25 mm) were constructed in three groups. The first group was the control group (C) without any fiber reinforcement. The specimens in the second group (P) were reinforced with pre-impregnated fibers and the third group (N) with non-impregnated fibers. These specimens were tested by the three-point bending method to measure primary transverse strength. Data were statistically analyzed with one way ANOVA and Tukey's tests.

Results: There was a significant difference among the mean primary transverse strength in the three groups ($P < 0.001$). The post-hoc (Tukey) test showed that there was a significant difference between the pre-impregnated and control groups in their primary transverse strength ($P < 0.001$). Regarding deflection, there was also a significant difference among the three groups ($P = 0.001$). There were significant differences among the mean deflection of the control group and two other groups ($P_{C\&N} < .001$ and $P_{C\&P} = .004$), but there was no significant difference between the non- and pre-impregnated groups ($P_{N\&P} = .813$).

Conclusion: Within the limitations of this study, it was concluded that reinforcement with fiber considerably increased the transverse strength of composite resin specimens, but impregnation of the fiber used implemented no significant difference in the transverse strength of composite resin samples.

Key Words: Fiber Reinforced Composites; Pre-Impregnated Fibers; Non-Impregnated Fibers; Transverse Strength; Deflection

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INTRODUCTION

Fiber-reinforced composite fixed partial dentures (FPDs) are an alternative to metal-ceramic adhesive FPDs [1-4]. Investigations regarding fiber-reinforced composites (FRC) in dentistry have continued over three decades [5]. FRC structures are composed of both fibers and composite matrix and may produce some special properties that cannot be

achieved with either of these elements alone [6, 7]. Factors affecting mechanical properties of FRCs include position and quantity of fibers, impregnation and adhesion of fibers to the FRC matrix, properties of fibers and polymer matrix and water absorption of the FRC matrix [7]. The clinical behavior of FRC restorations is influenced by some different variables. The flexural strength of these restora-

tions is affected by the composition of the overlying veneering composite resin [8]. On the other hand, the material composition applied for fiber impregnation also has a definitive effect on the flexural strength of FRC restorations [9]. Many authors have investigated the effect of fiber impregnation on the bonding properties to the matrix because poor impregnation creates problems in using FRCs [4, 10-13].

Fiber reinforcement is only successful if the loading force can be transferred from the matrix to the fiber. Incomplete impregnation of fibers with coupling agents results in creating some voids in FRC structures that increase water absorption and decrease mechanical properties of these restorations [10, 11, 14-18] because these voids and cracks in the veneering composite resin allow water to enter. Pfeiffer [19] has reported that the highest fracture resistance occurred in FPDs reinforced with pre-impregnated fibers and that fracture resistance of FPDs reinforced with pre-impregnated fibers was not affected by the pontic span.

The aim of this in-vitro study was to compare the transverse strength of composite resin bars reinforced with two types of pre-impregnated and non-impregnated fibers.

Materials and Methods

A Plexiglas split mold was constructed with an inner volume of $25 \times 3 \times 2$ mm³. This volume represented a framework of a fixed partial denture. This clear mold was designed so it would be possible to open and close; therefore, no force was required to remove the cured bars. Thirty six specimens were constructed in the following three groups:

Control group (C): This was a composite resin control group without any fiber reinforcement. First a layer of composite resin (dialog™, dentine materials DA2, Schutz Dental, Rosbach, Germany) with a thickness of 1 mm was placed in the mold, well-packed and light cured for 40 seconds by means of a hand light-

curing unit (Monitex 'BlueX, GT1200', Monitex Industrial Co., Taiwan) with an irradiation time of 40 s from both sides. Then another one millimeter thickness layer of composite resin was placed on the first one. Its surface was packed by a plate of Plexiglas and cured for another 40 seconds in the same manner. Pre-impregnated group (P): After putting a layer of composite resin (dialog™, Schutz Dental) with a thickness of 1 mm in the mold and curing it with a hand light-curing unit, the pre-impregnated fiber (Fibrex.Ribbon, Angelus Dental Solution, Londrina, Brazil) was placed. The ribbon was light-cured for 20 second intervals along its entire length.

Finally, another layer of composite resin was placed on the fiber. Its surface was packed by a plate of Plexiglas and was again cured for 40 sec. Polymerization of the specimens was made by a hand light-curing unit (Monitex 'BlueX, GT1200', Monitex Industrial Co.) with an irradiation time of 40 s from both sides.

Non-impregnated group (N): Construction of the specimens in Group C was as for B except that the reinforcement ribbon (Fiber-braid, NSI Dental PTY., Australia) was carefully impregnated with composite resin primer (dialog™ Bonding Fluid, Schutz Dental). When the ribbon became transparent in appearance indicating saturation by unfilled resin, it was gently placed over the first composite resin (dialog™, Schutz Dental) layer in the same way as group B.

The light intensity of the hand-curing unit, verified by a radiometer (Optilux Radiometer Model 100, Kerr Sybron, Danbury, CA, USA) was 700 mW/cm². The specimens were then polymerized for 20 minutes in a light-curing oven (Spektra™ LED, Schutz Dental).

After the final polymerization, the specimens were finished using a paper disc. The dimensions of specimens were again measured with a digital caliper (Electronic Digital Caliper, Minova Co., Osaka, Japan). The specimens that did not correspond with the standard crite-

ria (maximum 0.1 mm dimensional difference) were omitted and once again manufactured.

In making bar type fiber reinforced specimens, the fiber volume fraction is said to be set lower than 15-20% which is calculated using density values. The specimens of all groups were stored in distilled water at 37°C for 7 days. One hour after removal of the specimens from the incubator (to allow the specimens to return to room temperature) they were tested dry at room temperature.

A three-point bending test was performed to measure fracture load of the specimens using 20 mm span size and 1.0 mm/min crosshead speed. All the specimens were tested in a universal material testing machine (TLCLO, Dartec series, England). Force was applied perpendicular to the center of the composite resin bars. The center was marked at the midpoint of the specimens.

The beginning of the specimen damage was classified as the initial failure (IF). In order to minimize errors in misidentifying changes in the elastic modulus of the specimens' viscoelastic matrices failure criteria were established. IF was denoted if at least two of the following conditions were present: 1- A sharp decline in the load/displacement curve, called a knee or corner, 2- Visible signs of fracture, 3- Audible emissions caused by the generation of elastic waves by crack formation and/or progression [20]. The amount of bending and maximum force (N) at fracture was recorded by the testing machine. The resulted numbers were then placed in the following formula, so that the transverse strength would be evaluated in MPa [14]:

$S = 3FL/2bd^2$ in which F is the force, L the length, b the width and d the thickness. Statistical analysis of mean transverse strength s was carried out with One-way ANOVA and Tukey post-hoc tests and comparison for mean deflection of specimens was done with Kruskal-Wallis test and Bonferroni correction ($\alpha = .05$) by means of SPSS 11.5 for Windows

(SPSS Inc., Chicago, Illinois).

Result

For each specimen, the data recorded included the force measured at the time of primary transverse strength (MPa). The mean primary transverse strength of the pre-impregnated group (32.58 ± 5.79 MPa) was higher than the other groups (20.79 ± 4.41 MPa for the control group and 26.57 ± 5.78 MPa for the non-impregnated group). The results of one way ANOVA indicated significant differences among the groups ($P < 0.001$). The post-hoc (Tukey) test showed that there was a significant difference between the pre-impregnated and control group in their primary fractures ($P < 0.001$) but there was no significant differences between the other two groups ($P > 0.05$).

Regarding specimens' deflection at the point of initial fracture, the Kruskal-Wallis test showed that there was a significant difference among the three groups ($P = 0.001$). The Bonferroni correction was used to establish differences among the three groups.

Analysis of the results indicated that there was no significant difference between the control group and the non-impregnated group ($P_{C\&N} = .95$), but there were significant differences among the pre-impregnated group and the other two groups ($P_{N\&P} = .007$ and $P_{C\&P} = .023$).

DISCUSSION

In this in-vitro study, the transverse strength of bar type composite resin specimens reinforced with two types of pre-impregnated and non-impregnated fibers and the non-reinforced control specimens were compared.

Three-point bending test is a simple method that can be used for comparison of the load bearing capacity of different unidirectional FRC beams [14].

The transverse strength of pre-impregnated and non-impregnated groups were significantly higher than the control group ($P < 0.001$) which was well in consistence with other stu-

dies [2, 7, 14, 19-21] which have demonstrated that placement of reinforcing fibers improved the flexural strength of composite resins in comparison with the unreinforced control specimens [7, 8, 22].

Pfeiffer [19] concluded that the impregnated fibers (Vectris) have higher flexural strength than non-impregnated fibers (Ribbon). Nevertheless, in the present study, the results achieved with pre-impregnated fibers were higher than non-impregnated fibers and the control group.

It has been demonstrated that flexural strength of FRC restorations is affected by the composition of the overlying composite resin [8, 21] and fiber impregnation material also have a significant effect on the flexural strength of these restorations [9, 19, 23].

So the higher values measured in the non-impregnated group might be related to the coordination of the type of resin used for impregnating the fibers with the type of composite resin in our study.

Therefore, reinforcing the fiber system under recommended materials and methods by the corresponding manufacturers should be done [19]. In our investigation, the fiber content was lower than reported by Goldberg [12] for the FibreKor system that was about 40 vol%. For manual adapted fiber reinforcement, other authors observed a fiber volume content of 10-15%, Mullarky 9.4 vol% [24], Ruyter 13.2 vol% [25], Yazdanie 14.8 vol% [26] or Vallitu 12.4-13.1 vol% [13,27]. Some studies reported that placing reinforcing fibers on the tension side of the FRC specimens can improve the flexural strength of a low fiber volume fraction FRC construction [20]. However, in this study, fiber reinforcement was placed in the middle of the test specimen. This was done because making such narrow specimens with middle placement of reinforcing fibers was easier and there was no difference among the three groups from this point of view. The values measured for deflection in

the pre-impregnated group were significantly higher than the control and pre-impregnated groups ($P_{N\&P}=0.007$ and $P_{C\&P}=0.23$). However, there was no significant difference between the control group and the non-impregnated group ($P_{C\&N}=0.95$).

The higher deflection value in pre-impregnated fiber reinforced groups could be a result of better reinforcement of the specimens with these types of fibers. As mentioned earlier, the mean primary transverse strength of the pre-impregnated group was higher than the other groups and the transverse strength of pre-impregnated and non-impregnated groups was significantly higher than the control group. It may be concluded that using pre-impregnated fibers increases bending behaviors of the fiber reinforced specimens under fracture load.

It is important to note the limitations of in vitro studies.

These types of studies conducted in static loading conditions on artificial geometric specimens will not address in vivo conditions or replace clinical studies.

However, when done well, in vitro testing may be valuable before clinical trials by inexpensively testing a high number of experimental groups, screening poor design variations and testing a single variable without the confounding variables associated with a highly dynamic system [28].

Another limitation of this study was the non-inclusion of an artificial aging process, such as thermo-cycling, which could have simulated this negative effect on transverse strength.

CONCLUSION

Within the limitations of this study, it may be concluded that reinforcement of composite resin with fiber considerably increases the transverse strength of composite resin specimens, but impregnation of the fiber used implemented no significant difference in transverse strength of composite resin specimens.

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