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Influence of Different Techniques of Laboratory Construction on the Fracture Resistance of Fiber-Reinforced Composite (FRC) Bridges

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Group A: 1.5 mm square bar of Artglass

Abstract

The aim of the current investigation is to evaluate optimal pontic and retainer fiber positions for Polyethylene fiber-reinforced composite (FRC) restorations. In series I notch disc specimens were used to mimic loading cuspal regions of pontics. Four groups (n=15/group; codes A to D) were prepared from Artglass composite. Groups A to C were reinforced with polyethylene fibers, and group D was an unreinforced control. Fibers were positioned either around (A), beneath the notch (B), or at the disc base (C). Specimens were stored in distilled water at 37˚C for 24 h before testing to failure (CHS=1mm/min) in a universal testing machine. Mean torque to failure values ranked [$P< 0.05$; one-way analysis of variance (ANOVA)] as follows A = B > C = D. In series II five groups of three unit bridges (n =5/group; codes A to E) were prepared from Artglass dental composite without (group A) or with (groups B to E) different Connect fiber reinforcement locations/techniques. Bridges were cemented using 2 bond resin cement to a standardized substructure. After storage, as per series I, bridges were loaded mid-pontic region to failure. One-way ANOVA showed no significant ($P=0.08$) difference between test groups. The research hypothesis was that notched disc and 3 unit bridge test techniques would discriminate equally between fiber-reinforced specimens and an unreinforced composite control was rejected.

Keywords: Reinforced dental composite, three-unit bridge, notched disc, Artglass, bonding agent

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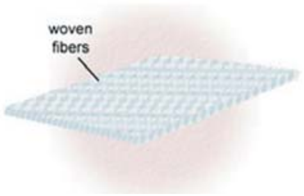
Introduction

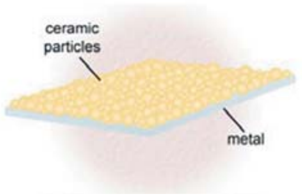
Brown[1] has discussed the current dental applications of fiber reinforcement including dental cements and splints, fibers made into structures for use in direct and indirect composite restorations, and denture bases. The contemporary use of fibers in fixed partial dentures was reviewed, their role in biomedical implants was surveyed and their future potential was forecast.

Fiber-reinforced composite fixed partial dentures (FPDs) are an alternative to metal-ceramic adhesive FPDs.[2,3] There are few clinical reports on fiber reinforced FPDs to date and most are of relatively limited duration.[3-5] Göhring et al.[4] reported on a two year clinical and scanning electron microscopy (SEM) evaluation of glass-fiber-reinforced inlay fixed partial dentures (IFPDs). While glass fiber IFPDs were clinically successful in most criteria, after two years they also reported delaminations of veneering composite from the fiber framework and concluded more research on the framework design was necessary to take full potential of the benefits of glass-fibers before conservative IFPDs can be recommended as a standard treatment. Monaco et al.[5] reported the results of a study of glass-fiber reinforced inlay retained FPDs over a period of one to four years. A conventional (unidirectional pontic fibers only) and a modified (unidirectional + woven frame fibers for bucco-lingual support) framework design were tested. The modified framework design showed a lower (5% versus 16%; $P > 0.05$) fracture rate of the veneering composite. They reported all of the adhesive-cohesive veneering composite fractures occurred in the pontic element of the conventional framework design group.

The clinical performance of fiber-reinforced composite (FRC) materials in dentistry depends not only on their physical properties but also on the handling characteristics of these materials. Relevant handling characteristics of these materials include the stickiness and viscosity of these fibers as related to the technique of their application.



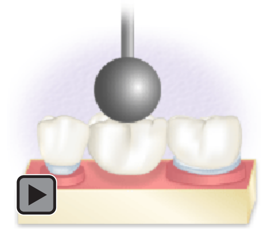
Fiber-reinforced



Metal-ceramic Adhesive

Ellakwa et al.[6,7] have shown the influence of the bonding agent chemistry used to impregnate the fiber and as well as the position of fiber in the restoration on the physical properties of dental composite.

There are different techniques of laying the fiber to fabricate the fiber-reinforced framework before final coverage with the overlying veneering composite. As far as the authors are concerned, very little information has been published about the influence of the technique of fiber framework construction on the potential of clinical performance of FRC bridges.



In the clinical situation the pattern and frequency of loading that occurs on a FRC fixed bridge may vary considerably between patients and this will influence failure rates. Thus, different loading modes are indicated to test the efficacy of fiber reinforcement of dental restorations. In the current *in vitro* investigation two specimen designs and methods of load application were employed to reflect relevant clinical loading scenarios.

The first aim of this *in vitro* current study was to evaluate the influence of three different techniques of laying the ultra high molecular weight polyethylene (UHMWPE) fiber in notched disc samples on their fracture resistance. This method of testing was aimed at assessing the possible influence of fiber reinforcement on the cuspal regions of a FRC restoration.

The second aim of this *in vitro* current study was to evaluate the influence of four different techniques of laying the UHMWPE fiber in the pontic space on the fracture resistance of FRC bridges.

The research hypothesis was that test method (notched disc versus fixed bridge FRC specimen type) would have no bearing on the ranking of fracture resistance (measured by force to failure) of FRC versus unreinforced composite control specimens.

Material and Methods

Series I

The notched disc specimen test technique as described by Ellakwa et al.[8] was used. This method enabled the relative fracture resistance of solid control composite samples and fiber reinforced samples to be determined. The geometry of the final specimen is that of a circle with a deep 60° V notch. The specimen fabrication technique and the equation used for data analysis are described in Ellakwa et al.[8] A cylindrical roller 3 mm in diameter was seated inside the V notch of the disc to allow external force application.

Four groups of 15 samples in each each group were made with Artglass, Three groups were reinforced by the UHMWPE fiber (coded A to C) and the fourth was used as a control (without fiber, group D). The required standardized length of Connect fiber was measured, wetted by D/E adhesive resin, and placed in the mold in different locations as shown in (Figure 1).

Test samples were light cured with a Spectrum light activation unit (serial No 02265/Dentsply GmbH) for 40 seconds each. The fiber reinforcements were arranged in the three reinforced groups of test specimens as follows:

Group A: The fiber was positioned up against the side walls of the central V notch to simulate placement immediately beneathcuspal inclines.

Group B: The fiber was positioned horizontally across the mold cavity immediately beneath the notch apex to simulate horizontal placement at the base of a fissure.

Group C: The fiber was placed around the external wall of the mold cavity opposite the notch apex to simulate placement at the gingival surface of a pontic. The remaining mold space was filled with Artglass composite and a mylar strip was used to extrude excess resin.

Group D: This was a composite control group without any fiber reinforcement.

Test samples were additionally post-cured in a UniXs oven for 90 seconds each. In this series of tests all the samples were stored wet in distilled water at 37°C for 24 hours before testing.

Means and standard deviations of Torque to failure strength data were calculated. Data were analyzed by one way ANOVA followed by post-hoc companion Tukey tests ($P< 0.05$). The torque to failure strength data for groups A to D were ranked in ascending order, and a Weibull analysis was carried out to determine the Weibull moduli

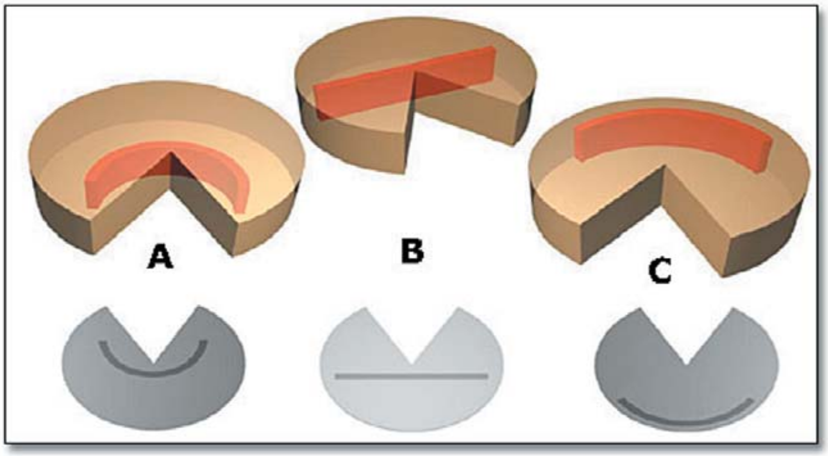


Figure 1. A diagram showing fiber position in the groups of specimens tested: In test group A fiber was wrapped around central notch. For group B specimens, fiber was placed perpendicular to the notch in a horizontal direction. Group C specimens fiber had placed around the periphery of sample on the side of the specimen opposite to the notch.

for the tested groups. A regression line, the slope of which corresponds with the Weibull modulus (m), was superimposed on the torque to failure data.

Series II

Five groups of three unit bridges (n = 5/group) coded A to E were prepared from Artglass dental composite with or without Connect fiber reinforcement and tested to failure.

Preparation of the Bridges: A three-unit bridge (23 mm in length) from lower 2nd premolar to lower 2nd molar replacing the lower 1st molar (6.5 mm length, 5.5-mm height, and 8.5-mm width) was prepared on a typodont model. Crown preparations on the two abutments incorporated a distal recess on the premolar and a mesial one on the molar (1.5-mm in width and depth). Before construction of the bridge, a vacuform pull down matrix was prepared to better standardize the exterior outer form of the bridge. Then the prepared model was duplicated using Agar-Agar impression material. This allowed bridges to be prepared on a standard preparation. By using the same pull-down, the outer form of the bridges were also duplicated in an improved-standardized fashion (Figure 2a).

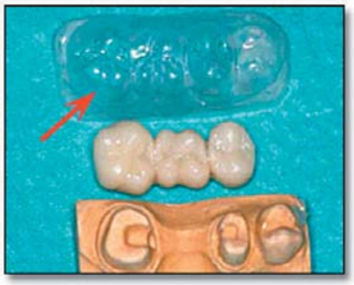


Figure 2a. A photograph showing the model and the “pulldown” (arrow) designed for this study.

Group A: 1.5mm square bar of Artglass.

Group A: Bridges completely fabricated from Artglass resin.

Artglass resin (dentine translucent shade) was adapted to the two abutment dies to form 1 mm thick copings. The recess areas were covered with a very thin layer of resin to ensure the fabricated resin bar would seat passively into place. The copings were light-cured for 20 second intervals. The distance between the distal recess in the premolar coping and the mesial recess in the molar coping was measured. Artglass resin was formed into a 1.5 mm square bar to the length required to span across the pontic area and to overlay the floor of the recessed areas in the copings. The resin bar was light-cured for 20 seconds. The cured bar was placed into the recess areas on a thin wash of Revolution 2 resin (Kerr). The bar was gently seated into place and light-cured for 20 second intervals at each end of the bar. Additional Revolution 2 resin increments were added as necessary to complete the seal between bar and copings. Each increment was light-cured for 20 seconds. A transparent addition-cured clear silicone putty (Memosil CD putty -Heraeus Kulzer) template matrix of an ideally contoured bridge was used to aid bridge construction. The mesial or distal internal surface of the matrix was partially filled with Artglass resin. This was located over the bridge substructure on the sectional cast. The resin was light-cured for 20 second intervals through the clear matrix. The matrix was removed and additional resin added as required until the bridge was complete. The bridge was removed from the dies and trimmed using fine tungsten carbide points to clearly define marginal fit and inter-proximal contact areas.

The bridge was polymerized off the dies for 180 seconds in a Unixs laboratory light-curing unit (Kulzer, Germany).

The bridge was glazed with unfilled resin being applied as a thin coating, then light-cured.

Group B: 1.0mm vertical bar of connect ribbon between the abutement teeth.

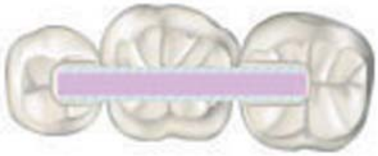
Group B: Bridges fabricated in Artglass resin with a vertically placed bar fabricated from Connect (Belle de St. Claire) between the abutment teeth.

Construction of the bridges in Group B was as for A except as follows: Connect by Belle de St. Claire was used to form the bar. The 1 mm wide reinforcement ribbon was cut to the required length to span across the pontic area and to overlay the recessed floor areas in the copings. The reinforcement ribbon was carefully impregnated with Kerr unfilled resin. When the ribbon became transparent in appearance, indicating saturation by unfilled resin, the ends of the vertically placed fiber bar in the pontic area were twisted to the horizontal position to lie flat in the coping recesses. The shaped ribbon was light-cured for 20 second intervals along its entire length. The cured ribbon bar was seated into the recess areas on a thin wash of Revolution 2 resin (Kerr) and bridge construction was completed as for Group A.

Group C: 1.0mm horizontal bar of connect ribbon between abutement teeth.

Group C: Bridges fabricated in Artglass resin with a horizontal bar placed between the abutment teeth.

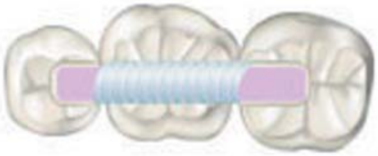
Construction of bridges in group C was the same as for group B except for the following: The cured ribbon bar was horizontally placed in to the recess areas on a thin wash of Revolution 2 resin (Kerr).



Group D: Artglass resin bar verically sandwiched between connect ribbon.

Group D: Bridges were fabricated in Artglass resin with a vertical bar sandwiched in between Connect reinforcement ribbon. This was attached along the sides of the bar and wrapped around the copings on the abutment teeth.

Artglass resin was adapted to the two abutment dies to form thin 1 mm copings. The recess areas were covered in a thin layer of resin. The distance between the distal side on the premolar coping and the mesial side on the molar coping was measured. Artglass resin was formed into a 2 mm depth by .5 mm wide bar to the length required to span across the pontic area and lie against the interproximal sides of the two-formed copings. The resin bar was light-cured for 20 seconds. The cured bar was made to fit intimately against the two inter-proximal surfaces of the copings. A minute increment of Revolution 2 resin (Kerr) was placed at each end and light-cured for 20 second intervals. Additional Revolution 2 resin increments were added as necessary to complete the seal between bar and copings. Each extra increment was light-cured for 20 seconds. Connect (Belle de St. Claire) fiber was wrapped around the copings and bar. The 1 mm wide reinforcement ribbon was cut to the required length and wrapped around the circumference of the two copings and either side of the resin vertical bar that initiated the pontic area. The reinforcement ribbon was carefully placed against the buccal side of a coping and attached with a minute amount of Revolution 2 resin (Kerr), then the next length of ribbon was impregnated by a small amount of Kerr unfilled resin. Attachment to the copings and pontic bar was undertaken in incremental stages to ensure the ribbon laid intimately against the side of the coping or pontic bar. At each attachment site, when the ribbon had become transparent in appearance, it was immediately light-cured for 20 seconds. The encircling reinforcement ribbon was finished beyond the connection area between pontic and retainer. Otherwise the bridges were constructed as for group A.



Group E: 1.5mm square bar of Artglass wrapped with connect ribbon over pontic area.

Group E: Bridges fabricated in Artglass resin with a horizontal bar placed between the abutment teeth that had 50 mm length of Connect reinforcement ribbon wrapped around the pontic bar.

Fabrication of the bridges in this group was similar to group A except for the following: A 50 mm length of Connect reinforcement ribbon

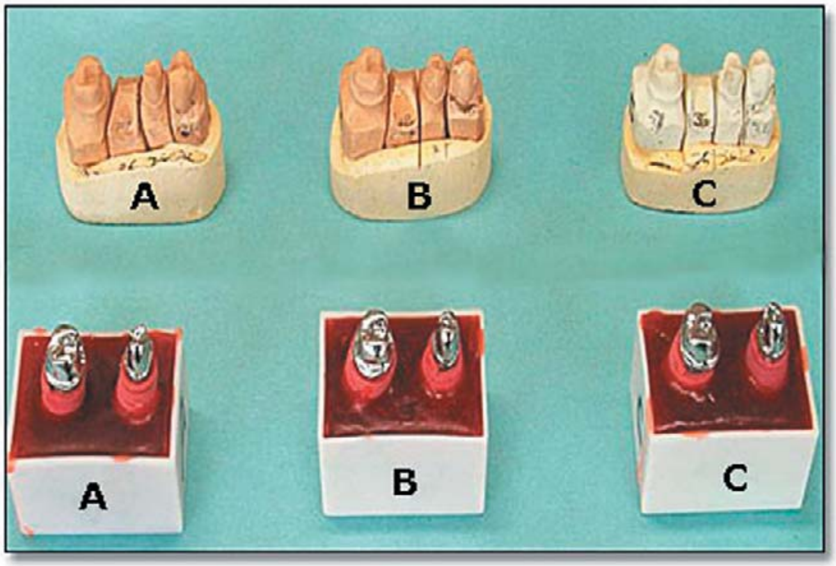


Figure 2b. Photograph showing the metallic supports designed for testing a fiber-reinforced bridge.

was wrapped around the pontic bar in such a fashion as not to impinge on the ends of the bar that would rest passively on the recess areas in the two copings. The 50 mm length of ribbon was attached to the bar with a minute amount of unfilled resin and light-cured. The ribbon was then saturated in unfilled resin; when the ribbon appeared transparent, it was wrapped tightly around the central area of the pontic bar and light cured for 20 second sessions around the entire circumference of the bar. The cured ribbon bar was placed in to the recess areas on a thin wash of Revolution 2 resin (Kerr) and bridge construction was completed as for group A.

Testing the Reinforced/Unreinforced Three Unit Bridges: The bridges of all the groups were stored in distilled water at 37°C for 24 hours. Before testing the bridges were cemented using 2-bond cement (Batch # 020022, dual curing polyglass, Heraeus Kulzer, Germany) to a metallic support (Heraenium CE, Batch # 1077/1, Heraeus Kulzer, Germany) covered with a 1 mm thick elastic layer of polyether to simulate the function of periodontium[9] and inserted in self-cure acrylic resin (Palapress Vario, Kulzer, Wehrheim, Germany). This support was designed for this test and it is shown in Figure (2b).

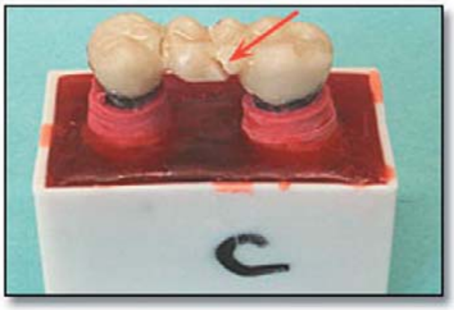
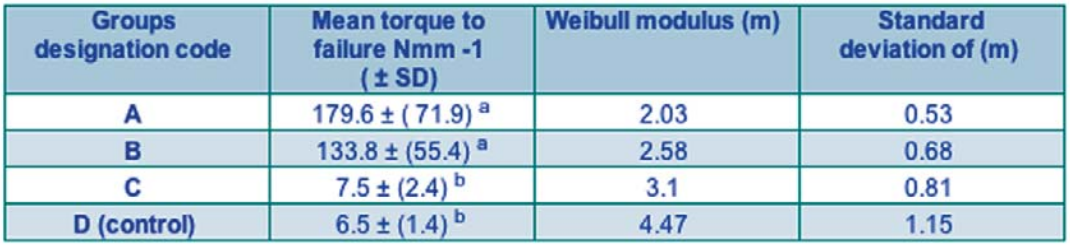


Figure 3. Photograph showing one of the bridges after testing. The bridge is broken through the pontic (arrow).

The metallic support (Figure 3) is cast in cobalt chromium alloy (Heraeus). Its chemical composition is Co 63.5 %, Cr 27.8 %, Mo 6.5 % by weight, and Si, C.

Before cementation the widths and heights of the connectors anterior and posterior to the pontic were measured in mm to 0.1 mm and 0.01 mm, respectively. Five minutes after cementation the bridges were exposed to a compressive load in the pontic area with a steel ball 10 mm in diameter (strain rate 1mm/min) using a mechanical testing machine (Zwick, 1445, Materialprufung, Germany) that automatically records the maximum compressive force in Newton before final failure. One way ANOVA followed by Tukey test comparisons were used to compare all the groups tested ($P<0.05$). SEM (a Jeol JSM 5300 LV, Akishima Tokyo, Japan) was used to examine the fiber matrix interface of all the tested reinforced bridges. Specimens (3 Specimens/group) were mounted in a cold mounting epoxy resin with Epofix (Struers, Glasgow, UK) before being ground in a mesio-

Table 1. Torque to failure data of Artglass dental composite reinforced with Connect fiber at different positions stored in distilled water at 37°C for 24 hours.



Groups designation code	Mean torque to failure Nmm -1 (± SD)	Weibull modulus (m)	Standard deviation of (m)
A	179.6 ± (71.9) ^{a}	2.03	0.53
B	133.8 ± (55.4) ^{a}	2.58	0.68
C	7.5 ± (2.4) ^{b}	3.1	0.81
D (control)	6.5 ± (1.4) ^{b}	4.47	1.15

Groups with the same superscript letter were not significantly different ($P>0.05$) according to post-hoc Tukey tests.

distal direction on silicone carbide papers in the order 320-500-800-1,200-2,400 grit with water as a lubricant. Specimens were applied to each grade of paper for 25 seconds. Final polishing was carried out using a MD-Dac polishing cloth in a conjunction with 3 m polycrystalline diamond suspension and DP-Lubricant blue for 4 minutes followed by a new MD-Dac cloth with 1 m polycrystalline diamond suspension and lubricant for 1 minute. Polished cross sections were then sputter coated with a layer of gold, dagged, and mounted in the appropriate stub holder.

Series I

The mean torque to failure strength for group A specimens (179.6 Nmm^{1}) was more than twenty times greater than the mean figure for the unreinforced composite control group (6.5 Nmm^{1}), which is a remarkable result considering the much lower degrees of reinforcement seen for fiber reinforced composite samples using standard 3 point bend flexural strength/modulus testing.[6,7] Placement of the fiber around the V notch (group A) or at right angles to the notch apex (group B) improved the torque to failure significantly ($P<0.05$). Placement of the fiber at the circumference of the disc shaped specimens opposite the notch apex (group C) did not improve the fracture resistance of the samples significantly in comparison to the unreinforced composite control group ($P>0.05$). (Table 1)

The coefficients of determination (R^2-values) of the regression lines for groups A to D were 0.92, 0.94, 0.92, and 0.97, respectively. The Weibull moduli of group A and B were 2.03 ± 0.53 and 2.58 ± 0.68, respectively. The Weibull moduli for groups C and D were 3.1 ± 0.81 and 4.47 ± 1.15, respectively.

Since the 95% confidence intervals of the Weibull moduli for groups A, C, and D did not overlap, it was concluded there was a significant difference between the reliability of the torque to fracture data.

The 95% confidence interval of the Weibull modulus for the torque to failure strength data for group A (1.6-2.4) overlapped with the intervals of group B (2.1-2.9). It can be concluded there was no significant difference between the reliability of the torque to fracture data between the two groups.

Series II

Group A failed catastrophically. The mode of failure of groups B to E was similar. Failure occurred either through the connector between the abutment and the pontic, but the bridge fragments remained attached to each other (Figure 3). When the breaking force for all the groups was compared, ANOVA test showed no significant ($P=0.08$) difference at the 5% significance level. However, when the breaking force per unit area was compared, the one way ANOVA test followed by post-hoc Tukey tests showed a significant difference ($P=0.02$) between the test groups. The mean force (N) / area (mm2) required to fracture the unreinforced composite control group bridges (A) and the fiber-reinforced group (D) was significantly lower than that of group (B). (Table 2)

On occasion SEM results revealed some air bubbles trapped between the fiber and the overlying composite in group D only as shown in Figure (4).

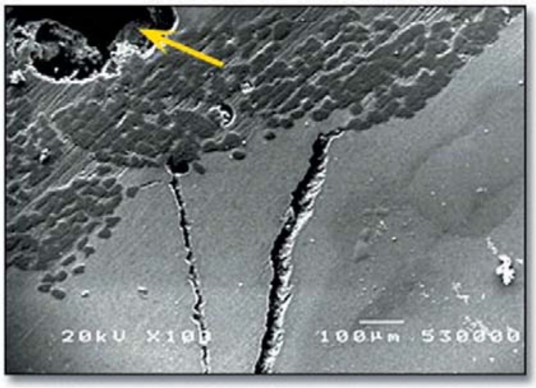


Figure 4. SEM showing air bubbles trapped between the fiber and the overlying composite (arrow).

Discussion

In series I the remarkable difference in the fracture between groups A and B from C and D was mainly attributed to crack arrest by the fiber in these groups. However, in group C the fiber was placed at the periphery of the samples, crack propagation could, therefore, continue unimpeded through the bulk of the sample due to load application without any resistance from the fibers.

The sample design selected for this test is small in comparison to the standard three-point bend test sample but it may have much greater clinical relevance.[10]

The higher scatter seen in the fiber reinforced test groups of series I (coefficients of variation ranging from 32% for group C to > 40% for groups A and B) in comparison to the un-reinforced composite control samples (21.5% / group D) must in part be related to difficulties in laying the fiber down in a standardized fashion in the relatively small test mold cavities. It is interesting to note previous publications, which used the notched disc test technique, have generally reported much lower scatters (coefficients of variation less than 10% normally) for solid[9,15] or luted[16] composite test pieces when using a smaller mold. Operator differences, differences in materials, and curing conditions may all have had a part to play in this difference but this requires further investigation.

The V shaped notch represents a fissure in the occclusionl surface with the sides of the notch representing cuspal inclines.

The V shaped notch may be taken as representing a fissure in the occlusal surface of a load bearing restoration with the sides of the notch representing cuspal inclines.

The results of this test also signify the importance of fiber position in the dental restoration. Weibull analysis was used also to evaluate the strength data obtained, but the failure of the samples was not completely brittle in nature due to fiber reinforcement. This may explain the lower values of the Weibull moduli and at the same time may reflect the value of this sort of statistical approach for materials that fail in a completely brittle manner.

In series II in this study the four different fabrication techniques employed were proposed to investigate the influence of fiber framework design on the fracture resistance of FRC bridges. The preparation of mesial and distal recesses in the occlusal surfaces of the two abutments was designed to allow room for placing the fiber framework while maintaining space for occlusal veneering composite. The improvement in the fracture resistance of the reinforced groups (B, C, E) was minimal and not statistically significant ($P > 0.05$) in comparison to the un-reinforced group (A). This may be explained by the low fiber volume fraction used to reinforce the tested three-unit dental composite bridges coupled with the more complex specimen design and fabrication variables in comparison to standard flexural strength samples. To achieve the same remarkable significant improvement (315%) achieved in three-point bend testing in comparison to unreinforced group[11], more research is required. Maximizing fiber volume fraction by increasing the proportion of fiber to composite should significantly improve strength.[2,4] However, the fiber position and the fiber framework used in this study will have influenced the final results. A possible explanation for the poor performance in group D is related to the more complex fabrication technique required for this test group which may have led to fiber – abutment misalignment and/or increased risk of air voids and so the possibility of failure. The increased complexity in fabrication for group D may have negated any additional reinforcing effect of this technique of fiber application by increasing the risk of incorporating voids. Fabrication of FRC fixed partial dentures is technique sensitive and air entrapped between layers of material locally inhibits polymerization and weakens the structure.[4,5] Placing the fiber framework in vertical (group B) or horizontal directions (group C) improved the fracture resistance of the tested bridges. According to the previous mentioned results for groups B and C, the combination of two directions of unidirectional of fiber framework may be required to optimize reinforcement of the three unit bridges and at the same time increase the fiber volume fraction. The direction, magnitude, and loading rates of forces on a FRC FPD pontic *in vivo* will be much more diverse than can be mimicked by any simple *in vitro* simulation. The rationale for the addition of woven fiber elements overlaid onto unidirectional fiber substructures for pontic reinforcement relies on the ability of the former to reinforce the polymer in two directions.[5] In group E the improved fracture resistance of these bridges may be attributed to wrapping the fiber around the horizontal bar, i.e., increasing the amount of fiber volume fraction in the final bridges. The combination of fiber both at the base of the pontic cusps and at the gingival surface pontic should maximize potential reinforcement with a relatively limited increase in fiber volume fraction. The retainer also seems to play an important role in the efficiency of reinforcement, and more research is needed to find whether reinforcing of these retainers, especially in three unit bridges, is necessary or not. A recently published 2-dimensional finite element analysis study failed to differentiate between three inlay abutment preparation configurations (interproximal slot versus 2-surface MO/DO and 3-surface MOD).[18] An interesting finding of the current investigation was all of the reinforced composite bridges remained attached and the possibility for repair exists. Repair of fractured glass-fiber-reinforced inlay retained FPDs may extend clinical service life[4] but was only recommended for slight damage.[5] The fracture resistance of all the tested bridges ranged from 535 N to 850 N suggesting the possibility of using these materials in posterior stress bearing area. The main reason for estimating the breaking force/unit area was to detect any difference in the four techniques employed. While not very significant, the results of this study showed a trend for improvement of fracture resistance for reinforced bridges. This was especially the case for group E (850N). This may be attributed to the relatively small sample size for each test group together with the difficulties of fabricating the large test samples reflecting the typical dimensions of the clinical situation. It would be interesting to repeat the experiment using a vacuum forming fabrication technique for all test groups to see how this may have influenced the results. It is difficult to compare the results of this study with others of the same type, as other workers compared the failure load without generally paying attention to the applied load surface area.[12] This is an important variable that should be kept in mind in any further *in vitro* study to standardize the evaluation. Whether the results of this study can be transferred to other FRC systems requires further investigation.

The metallic supports (abutments) used in this study have been proposed as a suitable material to replace natural teeth. However, it has been reported the high modulus of these materials may be reflected in higher fracture resistance of the restoration tested.[13] The results of this study are in agreement with those of Samadzaheh et al.[12] and Vallittu and Docent[14] who concluded a plasma–treated polyethylene reinforced polymethyl methacrylate (PMMA) restoration showed no significant increase in fracture load when compared with unreinforced restorations.

The findings of this research investigation clearly demonstrate test method, sample shape and size, fabrication variables, method of specimen support during testing, and method of load application all play a critical role in any *in vitro* assessment of the potential reinforcement of fiber reinforced dental composites. The more complex three-unit bridge design of the samples used in series II failed to discriminate between fiber-reinforced and un-reinforced composite specimens on the basis of load to failure as compared to the findings with the much smaller notched disc samples employed in series I tests. This finding leads us to reject our aforementioned research hypothesis. There are many variables to be considered in designing clinically relevant *in vitro* test methods when attempting to predict the clinical failure behaviour of even "simple" crown restorations.[17] Despite the relatively high scatter seen with the series I test samples in comparison to previously published research with this technique, its superior potential to discriminate between "fiber reinforced" composite samples and unreinforced controls (even at a low fiber volume fraction) suggests this test method has significant potential for future research in this field in comparison to the more traditional three-point bend tests on fiber composite bridges and bars. Non-destructive approaches rather than experimental load-to-failure tests are most suited to understanding fatigue yielding.[18] Fatigue testing of notched disc samples coupled with finite element modelling may allow us an improved insight into the failure behaviour patterns of FRCs.

Conclusion

The different techniques of laboratory construction of fiber framework in the pontic area significantly ($P<0.05$) affected the fracture resistance of fiber-reinforced bridges.

Many variables are involved in the construction of fiber reinforced composite bridges, which may influence their strength and potential for clinical service.

In the future more emphasis should be given to developing *in vitro* test methods that have greater potential to predict failure patterns as found in clinical service.

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