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ORIGINAL ARTICLE

The Effect of Incorporation, Orientation and Silane Treatment of Glass Fibers on the Fracture Resistance of Interim Fixed Partial Dentures

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Abstract Fracture of interim fixed partial dentures (FPD) is of important concern to the dental surgeon, especially with long-span fixed partial dentures or areas of heavy occlusal stress. Polymers used in interim FPDs, reinforced with glass fibers have shown to have a positive effect on the fracture resistance of interim FPDs. Since little research has been done on the influence of silane treated glass fibers on the fracture resistance of interim FPDs, this study was conducted to evaluate the effect of silane treatment of glass fibers on the fracture resistance of interim FPDs and its correlation with the position of fiber reinforcement and length of the span of the interim FPD. Interim FPDs were fabricated from an autopolymerizing polymethyl methacrylate (PMMA) resin. Seven FPDs were made in each group. The FPDs in the control group were unreinforced, and in the other groups the FPDs were reinforced either with non silane treated glass fiber or with silane treated glass fiber. The fibers were placed in two different locations in the FPDs. Three length of span of FPDs were tested. The load was applied to the FPD by a steel ball placed in the center of the pontic space. One Way Anova, Two Way Anova, Studentized range test (Scheffe's). Results showed that the load required for fracturing the unreinforced FPDs varied from 272 to 998 N. Mean fracture load of reinforced FPDs varied from 536 to 1642 N. One-way analysis of variance showed that the position of fibers and the silane treatment fibers significantly affected the fracture load. The results of this study suggested that the silane treatment of glass fibers had a marked improvement in the fracture resistance of FPDs as compared to untreated glass fibers. Selective placement of the glass fibers at the undersurface of the pontic and the occlusal surface of the interim fixed partial denture showed more increase in the fracture resistance as compared to the randomly distributed glass fibers. The glass fiber reinforcement is effective in increasing the fracture resistance with the effectiveness most evident in interim FPDs with long spans. With increase in the length of span of interim fixed partial denture the fracture resistance was shown to decrease significantly in all the groups.

Keywords Interim fixed partial denture · Fracture resistance · Silane treatment

Introduction

During the fabrication of cast fixed restorations, tooth protection with interim restorations after preparation is mandatory. Normally, short-term interim restorations are fabricated. Occasionally, however, interim treatment has to function for extended intervals and provide long-term tooth protection and stability while adjunctive treatment is accomplished. In such cases the fracture incidence of the interim fixed partial dentures are increased [1–4]. Rigidity and strength of interim fixed partial denture are dependent on the polymer of the fixed partial denture and the type of possible reinforcement [1].

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The fracture resistance of interim fixed partial dentures can be increased by reinforcing them with fibers [2]. Various types of fiber reinforcements have been investigated for use with dental polymers. Glass fibers have been shown to improve the fracture resistance of interim fixed partial dentures [3, 4].

The reinforcing capacity of the fibers depends on the orientation of the fibers, adhesion of fibers to the resin, and impregnation of fibers with the resin [5]. The high tensile strength of glass fibers reinforcement can be most effectively used on the side of tensile stress i.e. the undersurface of the pontic. A longer distance between occlusally placed glass fibers and those placed on the undersurface of the pontic has been shown to increase the fracture resistance of the interim fixed partial dentures [1]. Silane treatment of glass fibers can improve the adhesion between fibers and acrylic denture base resin [6]. But there is little literature regarding the effect of silane treated glass fiber reinforcements on the fracture resistance of polymethyl methacrylate based interim fixed partial dentures.

Therefore, this study was conducted to evaluate the influence of the silane treatment and position of glass fiber reinforcement on the fracture resistance of interim fixed partial dentures and its correlation with the length of span of the interim fixed partial denture.

Materials and Methods

Interim fixed partial dentures were made according to a technique described by Nohrstrom et al. [1]. A metal jig with dimensions (Figs. 1, 2, 3, 4) was made to simulate the prepared premolar and molar abutments of 3 unit, 4 unit and 5 unit Interim Fixed partial denture. The jig was designed such that the distance between the abutments could be adjusted to 11.0, 18.0 and 28.5 mm respectively, measured from the distal axial surface of the premolar

Fig. 1 Mounting Jig with stabilizing screw and loading device

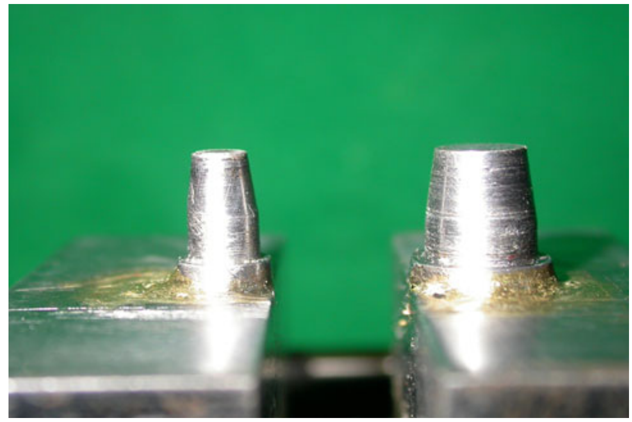

Fig. 2 Lateral view of the abutments

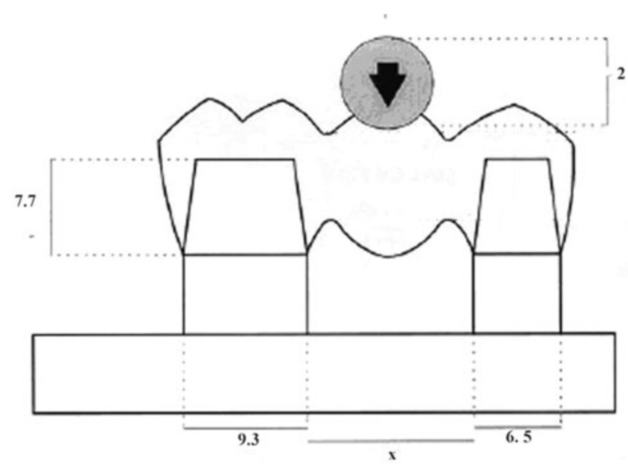

Fig. 3 Lateral view of jig and fixed partial denture (dimensions in mm) where 'x' indicates the pontic span. *Arrow* indicates direction of occlusal load through steel ball

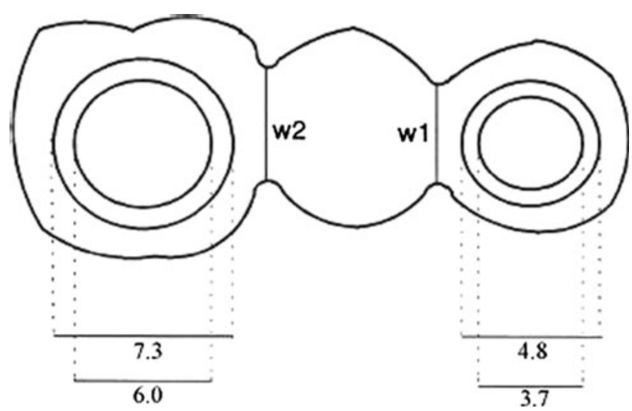

Fig. 4 Occlusal view of abutments and fixed partial denture (dimensions in mm)

abutment to the mesial axial surface of the molar abutment (Fig. 5). Each of the three lengths of pontic spans of interim fixed partial dentures were divided into five groups depending on the location of glass fiber reinforcement and

Fig. 5 Span of interim fixed partial denture being measured using a digital caliper

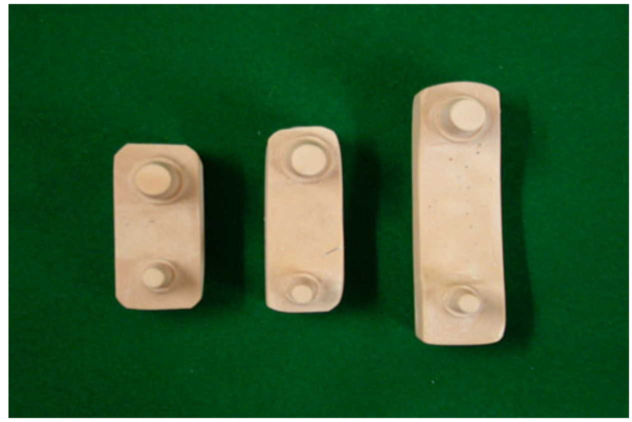

Fig. 6 Different length of spans of interim fixed partial denture

non silane or silane treatment of glass fibers. Seven samples were made for each of the groups.

The samples were divided as follows:

1. Group I: Control group (No glass fiber reinforcements).
2. Group II: Randomly distributed untreated glass fibers.
3. Group III: Selectively distributed (Occlusal surface of fixed partial denture and undersurface of pontic) untreated glass fibers.
4. Group IV: Randomly distributed silane treated glass fibers.
5. Group V: Selectively distributed (Occlusal surface of fixed partial denture and undersurface of pontic) silane treated glass fibers.

A total of 21 unreinforced and 84 glass fibers reinforced interim fixed partial denture samples were prepared, with 7 interim fixed partial dentures samples in each group.

An impression of the abutments was made with a polyvinylsiloxane impression material (Express STD, 3 M Dental Products, St. Paul, Minn.), and Type IV die stone (Kalrock, Kalabhai Karson Private Limited, India) was poured into the impression. After the gypsum model (Fig. 6) was set, it was removed from the impression and the abutments were coated with die lubricant (Die Lub WaxSep, Dentecon, USA). Wax pattern of the interim fixed partial denture was made using wax (No. 474-0200, Crowax, Renfert, Germany) (Fig. 7). The undersurface of the wax pattern at pontic area (ridge lap) was blocked out with the help of die stone. The wax pattern represented a 3 unit fixed partial denture replacing mandibular 1st molar, with 2nd mandibular premolar and 2nd mandibular molar as abutments. The outer surface of the wax pattern was then duplicated with the polyvinylsiloxane putty impression material on the gypsum cast.

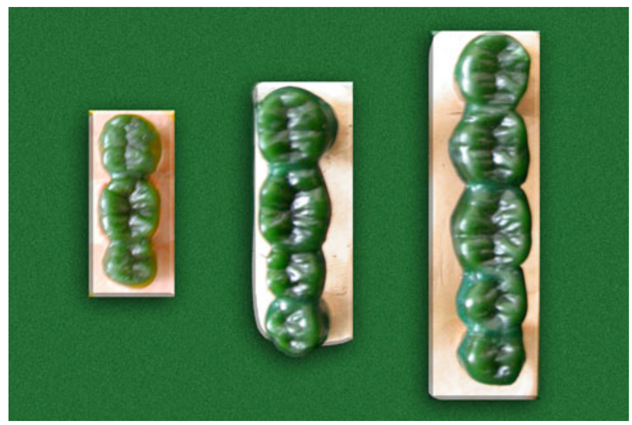

Fig. 7 Wax pattern of interim fixed partial dentures

The interim fixed partial dentures were made using tooth colored polymethyl methacrylate powder (Batch No. VS7, DPI Self Cure Tooth Moulding Powder, Dental Products of India) and methyl methacrylate liquid (Batch No. Px52, DPI-RR cold cure, Dental Products of India).

Randomly Distributed Glass Fibers Samples

Unidirectional Stick fibers (Batch No. 2051026-R-0074, Stick Fibers, Stick tech Limited, Finland) were cut to a predetermined length according to the length span of interim fixed partial denture. Two lengths of stick glass fibers were cut. The first length was cut equal to the total length of span of the interim fixed partial denture, measured from the mesial surface of the premolar abutment till the distal surface of the molar abutment. The second length was cut equal to the length of the pontic span. The fibers were soaked in self cure methyl methacrylate monomer in a glass petri dish for a period of 10 min for better bonding with acrylic resin; after the fibers were removed from the monomer, excess liquid was allowed to dry. The fibers were cut into smaller pieces of fibers using a pair of sharp bladed scissors.

The powder and liquid ratio was maintained as 1.5 g to 1.0 ml. The resin was hand mixed for 15 s in a glass dampen dish using a stainless steel cement mixing spatula. Immediately after mixing the powder and the liquid of the resin, the already cut small lengths of fibers were incorporated into the resin mix. The fibers were completely wetted in the resin mix. After the resin impregnated with glass fibers reached the dough stage, it was placed in the polyvinylsiloxane mold of the interim fixed partial denture and the mold was placed on the gypsum model. It was held securely in place and the resin was allowed to set at room temperature. After the resin had set, the putty impression was removed and then the resin interim fixed partial denture was carefully removed from the gypsum model, taking care not to damage the interim fixed partial denture. The process was repeated for the other six samples also.

For the randomly distributed silane treated fibers, the fibers after been cut into predetermined length as described earlier, were soaked in a silane coupling agent (Order No. 2721, RelyX, 3M ESPE, USA) for a period of 5 min in a glass petri dish (Fig. 8) and were allowed to air dry completely before treatment with monomer [7]. The silane treated fibers were then treated with the monomer for a period of 10 min in a glass Petri dish. For the incorporation of fibers in the interim fixed partial denture, same procedure as described earlier was used (Fig. 9).

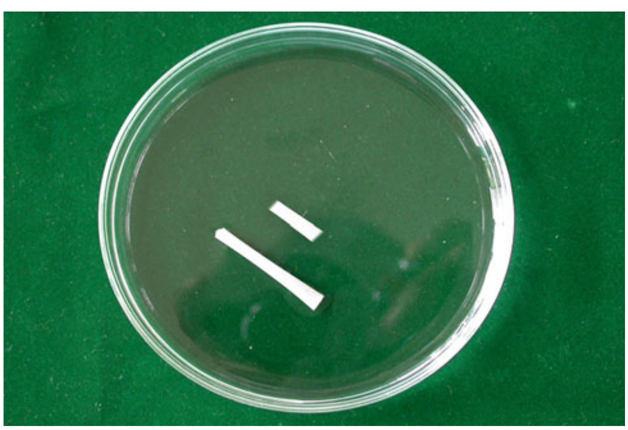

Fig. 8 Silane treatment of glass fibers

Selectively Distributed Glass Fibers Samples

Unidirectional Stick fibers were cut to a predetermined length according to the length of the pontic span. Two lengths of stick fibers were cut. The first length was cut equal to the total length of span of the interim fixed partial denture, measured from the mesial surface of the premolar abutment till the distal surface of the molar abutment. The second length was cut equal to the length of the pontic span. The cut fibers were treated with self cure methyl methacrylate monomer in a glass petri dish for a period of 10 min. Immediately after mixing the powder and the liquid of the resin, the already cut lengths of fibers were selectively incorporated in the resin mix. The first length of fibers were placed near the occlusal surface and the second length of fibers were placed near the tissue surface of the pontic region of the interim fixed partial denture.

The polymerized interim fixed partial denture samples were visually examined carefully for any voids and surface imperfections. The marginal fit of the sample on the metal die was then examined. The dimensional similarities of the interim fixed partial dentures samples was ensured thereby ensuring the standardization of the connector height and the embrasure space (Fig. 10). Any sample not meeting the above criteria was discarded and new sample was made. The prepared samples were then tested using the unconfined compression testing machine (AIMIL, India). The loading was carried out in the unconfined compression testing machine in air at 36 ± 1°C with a cross head speed of 2 mm/min (Fig. 11). The values were noted at the point of first fracture of the sample. The force causing the first fracture in the interim fixed partial denture was considered to be the fracture resistance of the sample. Similarly, tests were conducted for all samples and values recorded and statistically analyzed.

Fig. 9 Glass fibers being incorporated

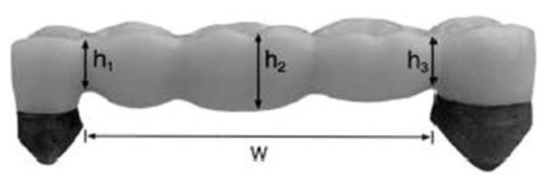

Fig. 10 Dimensions of the FPD samples made. Pontic width span (w) was 11 mm for 3-unit, 18 mm for 4-unit, and 28.5 mm for 5-unit FPDs. Pontic height was $h_1 = 4.3$ mm, $h_2 = 7.7$ mm and $h_3 = 4.3$ mm for all FPDs. Pontic width, buccally/lingually was 7.5 mm at h_1 and h_2 and 10.5 mm at h_3

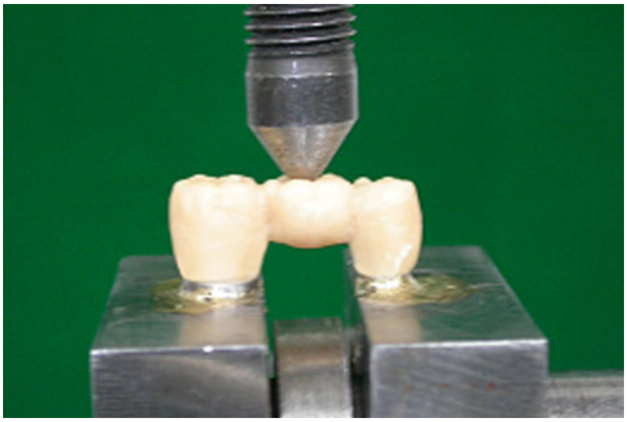

Fig. 11 Completed interim fixed partial denture being load tested

Results

The mean fracture resistance for unreinforced samples ranged from 273.0 N to 998.0 N, where as for glass fiber reinforced samples the mean fracture resistance ranged from 536.6 N to 1642.6 N. The mean fracture resistance also showed a decreased value when the length of pontic spans was increased from 11 mm to 28.5 mm. This trend was exhibited in the mean fracture resistance of all the five groups. The highest mean fracture resistance was exhibited by silane treated selectively distributed glass fiber reinforced group at all the three length of pontic spans.

Silane treated glass fibers (group IV and group V) also had a statistically significant effect ($P < 0.01$) in increasing the fracture resistance interim fixed partial dentures as compared to non silane treated glass fibers (group II and group III). This was true for all the three length of pontic spans.

The positioning of glass fiber reinforcement selectively at occlusal surface of interim fixed partial denture and the undersurface of pontic (group III and group V) had a statistically significant effect ($P < 0.01$) in increasing the mean fracture resistance of the interim fixed partial dentures as compared to randomly distributed glass fiber reinforcements (group III and group V). This was true for all the three length of pontic spans (Table 1).

Discussion

In prosthodontics, fibers have been used to improve the fracture resistance of polymer materials. The usefulness of glass fibers as strengtheners of dental resins has been established [1, 3, 8].

Glass fibers are most often used for reinforcing polymers because of there good esthetic qualities and good bonding of glass fibers to polymers via silane coupling agents [9]. The most common type of glass used in fiber production is so called E-glass (Electrical glass); this type of glass is also that is most often used in dental fiber composites [10]. E-glass fiber, which has high alumina and low alkali and borosilicate, is claimed to be superior in flexural strength [7]. E-glass fibers have also shown relatively good long term stability against water [11] and resistance to chemical attacks [12].

To solve the problem of impregnating the fibers with polymers of high viscosity, preimpregnated glass fiber reinforcement (Stick fiber) was developed. The Stick reinforcements were preimpregnated with a polymer that could be wetted with the monomers used in dentistry. In addition, the preimpregnation of the fiber bundles or weaves with polymer made the glass fiber reinforcement easy to use, namely, the reinforcement did not fray and was easy to place in the desired region of the construction [9]. The use the Stick reinforcements to reinforce provisional fixed partial denture restorations in this study were promising with regard to the handling of the reinforcements.

The accepted engineering beam theory [13] states that when a beam is loaded mid-span between two supporting points, the applied load induces tension at the bottom and compression at the top. Similarly in loading the fixed partial denture from the occlusal surface, the occlusal side of the fixed partial denture undergoes compressive stress and the undersurface of the pontic undergoes tensile stress. Thus, the high tensile strength of the glass fiber reinforcement could most effectively be used on the side of the tensile stress. It has been also been reported that the fiber reinforcement plays a role in resisting the applied load, provided that the reinforcement is not at the neutral axis (a line approximately in the middle of the connectors). This can be expressed mathematically by the moment resistance (M), which is defined with the equation:

$$M = (F_1X_1) + (F_2X_2) + (F_3X_3)$$

where F_1, F_2, and F_3 is the resultant compressive and tensile forces; and X_1, X_2, and X_3 is the distance from the neutral axis. From this equation, it can be seen that the reinforcement plays a important role in testing the applied load, provided that this reinforcement is not at the neutral axis ($X_3 = 0$), and as the reinforcement distance X_3 increases, the moment resistance also increases. In this study also the interim fixed partial dentures samples with glass fiber reinforcement at the undersurface of the pontic and the occlusal surface of the fixed partial denture demonstrated higher fracture resistance values than the randomly distributed glass fibers reinforcements, which were in accordance with the explanation above.

Silane or organofunctional trialkoxysilane coupling agents form a large group of organic compounds that essentially contain a silicon atom or atoms. Silanes can

Table 1 Comparison between mean fracture resistance of three lengths of pontic spans for all of the five groups

Lengths of pontic span	Fracture force (Newtons)				
	Mean ± SD				
	Group I	Group II	Group III	Group IV	Group V
A. 11 mm pontic span	998.0 ± 50.3	1180 ± 36.2	1283.3 ± 48.9	1444.3 ± 33.8	1642.6 ± 31.1
B. 18 mm pontic span	473.6 ± 23.1	700 ± 14.7	1008.0 ± 27.8	1089.6 ± 32.3	1180.7 ± 22.5
C. 28.5 mm pontic span	273.0 ± 29.4	536.6 ± 110.9	774.7 ± 20.8	1005.6 ± 43.1	1138.6 ± 18.2
One-way ANOVA					
F	751.3	170.2	378.5	281.7	910.8
P	$P < 0.001$, HS	$P < 0.001$, HS	$P < 0.001$, HS	$P < 0.001$, HS	$P < 0.001$, HS
Lengths of pontic span compared					
A–B					
Mean difference	525.1	480.6	275.3	354.7	461.9
P-value	$P < 0.01$, S	$P < 0.01$, S	$P < 0.01$, S	$P < 0.01$, S	$P < 0.01$, S
A–C					
Mean difference	725.7	644.0	508.6	438.7	504.0
P-value	$P < 0.01$, S	$P < 0.01$, S	$P < 0.01$, S	$P < 0.01$, S	$P < 0.01$, S
B–C					
Mean difference	200.6	163.4	233.3	84.0	42.1
P-value	$P < 0.01$, S	$P < 0.01$, S	$P < 0.01$, S	$P < 0.01$, S	$P < 0.05$, S
Studentized range test, K = ($P < 0.05$)	49.4	92.7	47.3	50.1	33.5
($P < 0.01$)	64.3	120.6	61.5	65.2	43.6

function as mediators and promote adhesion between dissimilar, inorganic and organic matrices through dual reactivity. Silanes used in dentistry are usually in 90–95% ethanol or isopropanol solutions, but more dilute alcohol solutions, about 20% or even 40–50% are also used. The silane coupling agent used in the study (RelyX ceramic primer, 3M ESPE) contained ethanol in between 70 and 80%. Scanning electron microscope studies show that silanization of glass fibers enhances the adhesion between the fibers and organic acrylic resin in a denture material [6].

In this study, the interim fixed partial dentures reinforced with silane treated glass fibers exhibited significantly increased fracture resistance as compared to interim fixed partial dentures reinforced with non silane treated glass fibers. The increase in fracture strength of interim fixed partial dentures after reinforcement with silane treated glass fibers as compared with reinforcement with silane untreated glass fibers indicate the better adhesion of silane treated fibers to polymer matrix which is in accordance with previous studies.

This study demonstrated that the effectiveness of glass-fiber reinforcements is most evident in case of interim fixed partial dentures with long spans. This could be explained by the fact that by increasing the span of the fixed partial denture, the stress in the pontics and connectors was increased in accordance with the equation of the stress of a construction in 3-point bending [1]:

$$\sigma = \frac{3F1}{2bh^2}$$

where F is the force; l is the span length; b is the width of the pontic; and h is the height of the pontic. Because the mechanism of the action of fiber reinforcement is to transfer stress from the weak polymer matrix to the fibers with high tensile strength, the reinforcing effect in the fixed partial dentures with long spans was clearer than in the fixed partial dentures with short span.

From the clinical perspective, the loads required to fracture the silane treated glass fibers reinforced provisional fixed partial denture restorations were higher (774–1642 N) than that of maximal occlusal biting force in molar region (600–1200 N) [11]. This suggested that provisional fixed partial dentures with silane treated glass reinforcement might have clinical success also as long-lasting, high strength provisional restorations. But before being put to clinical use, the other properties such marginal accuracy, surface hardness and the effect of water sorption of the silane treated glass fiber reinforced samples require further investigation. Factors, such as the height, width, and the design of the connector also affect the fracture resistance and need to be considered in future studies.

Conclusion

Within the limitations of the study, it was concluded that

1. Silane treatment of glass fiber reinforcement showed statistically significant improvement in the fracture resistance of the interim fixed partial dentures.
2. Selective placement of the glass fibers at the under-surface of the pontic and the occlusal surface of the interim fixed partial denture showed statistically significant improvement in the fracture resistance values of the interim fixed partial denture as compared to randomly distributed glass fiber reinforced interim fixed partial dentures.
3. Length of pontic span was also shown to have a statistically significant effect on the fracture resistance of interim fixed partial dentures. With increase in the length of span of interim fixed partial denture the fracture resistance was shown to decrease significantly in both unreinforced and glass fiber reinforced interim fixed partial dentures.

Conflict of interest None.

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