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Original Article

Effect of fiber orientation and placement on fracture resistance of large class II mesio-occluso-distal cavities in maxillary premolars: An *in vitro* study

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Abstract

Background and Aim: To analyze the outcome of fiber placement and orientation over fracture resistance in wide Class II (Mesio-occluso-distal [MOD]) cavities prepared on maxillary premolars.

Materials and Methods: After selection of 120 extracted human maxillary premolars, Class II (MOD) cavities were prepared maintaining uniform dimensions and samples were divided into six groups randomly (n = 20 each): Group I, G-aenial posterior; Group II, G-aenial posterior + Horizontal Ribbond placement on gingival and pulpal floor; Group III, G-aenial posterior + Horizontal Ribbond placement only on pulpal floor; Group IV, G-aenial posterior + vertical Ribbond placement on gingival and pulpal floor; Group V, G-aenial posterior + Ribbond chips; Group VI, Ever-X posterior. After restorations and completion of thermocycling process, universal testing machine measured the fracture resistance of all samples. Fracture modes were inspected under stereomicroscope. Analyzation of data was performed using one-way ANOVA and Tukey test at significance levels of $P < 0.05$.

Results: Fiber placement significantly increased fracture resistance. The highest fracture resistance was shown by Group 2 (1288.8 N) followed by Group 3 (976 N), group 4 (942.3 N), Group 5 (876.3 N), and Group 6 (833 N). Group 1 (No Fiber group) showed the least fracture resistance of 588.41 N. Repairable fractures were seen highest with Group 2 (80%) followed by Group 6 (70%) and least in Group 1 (30%).

Conclusions: Horizontal orientation of polyethylene fiber on both pulpal and gingival floor of MOD cavities gives the highest fracture resistance in maxillary premolars and repairable mode of fracture.

Keywords: Fiber position and orientation; fiber-reinforced composites; fracture resistance; polyethylene fibers

INTRODUCTION

Restoring an extensively carious teeth is one of the demanding circumstances in the field of operative dentistry. Situations where both marginal ridges are involved in caries, pose a challenge for the dentist to preserve the remaining tooth structure and restore with a material with high strength and acceptable clinical performance. Teeth become more prone to fracture due to the preparation of wide Class II mesio-occluso-distal (MOD) cavities, due to loss of marginal ridges and decrease strength.[1]

Modern adhesive systems and composite resins have played a significant role in reinforcing the dental structure. The evolution of newer dental composites with improved properties due to extensive research and advancements at the molecular level have led to a better clinical performance with reduced polymerization shrinkage and improved resistance to withstand the forces of mastication.[2] Nevertheless, the composite resin being a rigid material; lacks toughness instead of strength or stiffness. Toughness

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is interpreted as the ability of a material to absorb energy to the quick proliferation of cracks.[3] Polymerization shrinkage of composites leads to stress development on the surrounded tooth structure leading to microcrack formation and the predisposing tooth to fracture.[4]

Leno weaved ultra-high-molecular-weight polyethylene continuous fiber ribbon systems are developed to enhance the toughness of composite resins, increasing their durability and damage tolerance.[5,6] No additional preparation is required and these continuous fibers can be adapted in close approximation to the sound tooth substance. Multiple directional yarns and mesh-like nodal intersections in these continuous fibers lead to multiple load paths that redistribute the masticatory forces over a larger bed of composite restoration.[5,7] These polyethylene fibers alter interfacial stresses due to higher elastic modulous and lower flexural modulus.[5,8] A fail-safe mechanism was reported by Sengun *et al*.[9] for fiber-reinforced restorations, whereby catastrophic failures are avoided as fractures occur upwards of cementoenamel junction (CEJ), ensuring the restorability of the remaining tooth structure. Placement of the fiber against the cavity walls strategically can lead to proper stress distribution and energy absorption, leading to avoidance of failure in large class II cavities.

Clinically, placement of fibers might be cumbersome, technique sensitive, and time-consuming procedure. This led to the development of preincorporated fiber-reinforced composite Ever X. Ever X posterior composite consists of short E-glass fibers and filler in form of barium glass, whereby the length of preincorporated glass fiber is 1–2 mm. These short-fiber helps in stopping the crack progression same as the function of dentine. Ever X is used as a dentine replacement composite and has to be covered proximally and occlusally with conventional composite as enamel coverage to avoid the roughness of fibers on the external surface and better finishing and polishing.[10,11]

Reports from several studies indicated that placing fibers such that its longitudinal axis is subjected perpendicular to compressive forces, it increases the strength of restoration, but, if the longitudinal axis of fiber is parallel to compressive forces, no enhancement will occur in restoration.[12,13] In nearly all studies, fibers were inserted centrally in composite restoration, and the position of fiber definitely affects the mechanical properties of restoration. The present study was designed considering the importance of fiber location and orientation in the reinforcement of composite resin restorations.

The null hypothesis tested was that there is no effect of different fiber placement and orientation on fracture resistance of teeth restored with fiber-reinforced composite.

MATERIALS AND METHODS

120 human maxillary premolars which were extracted due to orthodontic reasons were used in the study. Completely erupted teeth with closed apices, sound enamel, and dentin without any carious lesion, cracks, restorations, or developmental disturbances were included in the study. Cleaning of plaque, calculus, tissue remnants, and other deposits was done using periodontal scalers (Satelec; Gustave Eiffel BP, Merignac Cedex, France), and teeth were stored in 0.5% chloramine T (Narsipur Chemicals Pvt. Ltd. Navi Mumbai, India) solution for disinfection for 1 month.

Class II (MOD) cavities were cut in all the specimens using an airotor handpiece with a straight fissure diamond bur (SF - 12C; Mani Dia Burs). All cavities were cut uniformly keeping the buccal and lingual wall thickness 2.5 ± 0.2 mm from the height of contour, and the gingival cavosurface margin was kept 1.5 mm above CEJ. UNC-15 periodontal probe was used to measure the uniformity. No bevel was given except for axiopulpal line angles. Single bur was used to prepare four teeth.

Subsequently, random allocation of teeth was done into six groups ($n = 20$ in each group).

- Group I ($n = 20$): G-aenial posterior (GC dental products Corp, Aichi, Japan)
- Group II ($n = 20$): G-aenial posterior + horizontal polyethylene fiber (Ribbond, Seattle, WA, USA) placement on the gingival and pulpal floor
- Group III ($n = 20$): G-aenial posterior + horizontal polyethylene fiber placement only on the pulpal floor
- Group IV ($n = 20$): G-aenial posterior + vertical polyethylene fiber placement on gingival and pulpal floor
- Group V ($n = 20$): G-aenial posterior + polyethylene fiber chips
- Group VI ($n = 20$): Ever-X posterior (GC Corporation, Tokyo, Japan).

A Tofflemire retainer (API, Schweinfurt, Germany) and matrix band (Hahnenkratt, Benzstrasse, Germany) were positioned around each prepared tooth and a low-fusing compound (DPI, Mumbai, India) was used to support the matrix band.

Cavities were restored as follows [Figure 1]:

Group I

Teeth were self-etched with Clearfil SE Bond primer (Clearfil SE bond, Kuraray, Tokyo, Japan) and left for 20 s followed by mild air drying. Clearfil SE Bond bond was applied, dried gently and light-cured for 10s using Elipar S10 LED curing unit (3M ESPE, St. Paul, MN, USA). G-aenial posterior was dispensed directly by the incremental layering technique in 2 mm increments. Light curing was done for 40 s for each

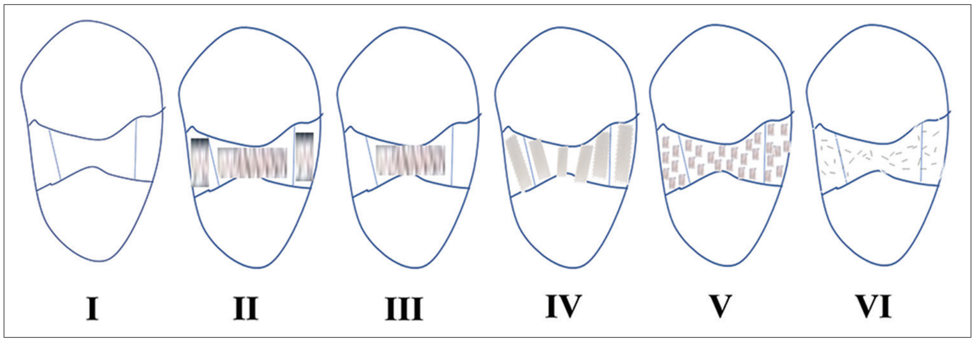

Figure 1: Schematic representation of test groups (Group I to VI)

increment. Removing band, curing was again done from all sides for 40 s.

Group 2

Self-etch primer and bond application were done similar to the aforementioned group. Three Ribbond fiber pieces are cut almost 1 mm less than the bucco-lingual dimension, impregnated with Ribbond wetting resin and placed directly on gingival and pulpal floor against tooth substrate secured with ribbond securing composite (Ribbond, Seattle, WA, USA) and light-cured for 40 s. G-aenial posterior was then placed into the rest of the cut cavity in 2-mm increments similar to Group 1.

Group 3

Restoration was done similar to Group 2 except that the Ribbond fiber was placed horizontally only on the pulpal floor.

Group 4

Restoration was done similar to Group 2 except that the Ribbond fiber was placed vertically on both gingival and pulpal floor and secured with ribbond securing composite.

Group 5

Restoration was done similar to Group 2 except that the Ribbond fiber was cut into small chips rather than an insert, and these chips were dispersed on both gingival and pulpal floor.

Group 6

Application of the self-etch primer and bond was done similarly to Group 1. Ever-x posterior was placed directly into the cut cavity in 2-mm increments by the incremental layering technique. Occlusal 2 mm of cavity was restored with G-aenial posterior covering the Ever-x posterior. Each increment was light-cured for 40 s. Removing band, curing was again done from all sides for 40 s.

Finishing of restorations was accomplished with graded series of aluminum oxide discs (Sof-Lex TM; 3M ESPE). Thereafter, all teeth were thermocycled according to the International Organization for Standardization standard 11405 for 500 cycles at 5°C–55°C with a 30-s dwell time. After storing specimens in an incubator at 37°C for 24 h, they were mounted in a cold cure acrylic resin block such that it is 1.5 mm apical to CEJ. To simulate periodontal ligament, light body elastomeric impression material was applied over the root surfaces.

A compressive force was applied at a strain rate of 0.5 mm/min using Instron universal testing machine (TINIUS OLSEN/H50KL, India Pvt. Ltd., U.P) by a 2 mm diameter round bar, placing it centrally over the occlusal surface of teeth and parallel to the long axis of teeth. Forces required to fracture each tooth were calculated in Newtons (N). After recording forces, each specimen was visually examined for the type of fracture mode, and according to Sáry *et al*.,[14] distinction was made between repairable (fracture above CEJ) or nonrepairable fractures (Fracture below CEJ) under stereomicroscope.

RESULTS

Highest mean fracture resistance was detected with group 2 followed by Group 3, 4, 5, and 6. The lowest mean fracture resistance observed with Group 1 (Non-fiber group). One-way ANOVA [Table 1] showed a statistically significant difference ($P < 0.001$) between all the groups. Intergroup multiple comparisons were made by Tukey's honestly significant difference test [Table 2] which revealed statistically significant differences existed between some of the groups. The mean difference in fracture resistances is statistically and significantly higher in between group 1 and group 2, it is further followed by the mean difference in fracture resistance between group 2 and group 6 which is also found to be statistically significant. This table also shows that the mean difference in fracture resistance between Group 1 and the rest of all other groups are highly statistically significant at 1% level of significance, and this situation is also similar for Group 2 as well, that is the mean difference in fracture resistance between Group 2 and rest of all the groups are also highly significant at 1% level of significance. Whereas Groups 4, 5, and 6 are statistically and significantly different in their respective

Table 1: One-way ANOVA test

Group	*n* (sample size)	Range	Minimum	Maximum	Mean	SE	SD	*P*
1	20	245	446.6	691.6	588.4	15.5	69.6	<0.001
2	20	670.6	890	1560.6	1288.8	41.8	186.9	
3	20	498	700.4	1198.4	976	31.8	142.3	
4	20	429.6	720.3	1150	942.3	33.8	151.5	
5	20	499.6	600.7	1100.4	876.3	37	165.8	
6	20	531.6	568.3	1100	833	44.9	201.1	

SE: Standard error, SD: Standard deviation

Table 2: Tukey honest significant differences test results

Group (I)	Group (J)	Mean difference (I-J)	SE	*P*	95% CI	
					Lower bound	Upper bound
1	2	−700.4*	50.1	0.000	−845.8	−555
1	3	−387.5*	50.1	0.000	−532.9	−242.1
1	4	−353.9*	50.1	0.000	−499.3	−208.4
1	5	−287.9*	50.1	0.000	−433.3	−142.4
1	6	−244.5*	50.1	0.000	−389.9	−99.1
2	3	312.8*	50.1	0.000	167.4	458.2
2	4	346.5*	50.1	0.000	201.1	491.9
2	5	412.5*	50.1	0.000	267.1	557.9
2	6	455.8*	50.1	0.000	310.4	601.2
3	4	33.6	50.1	0.985	−111.7	179
3	5	99.6	50.1	0.356	−45.7	245
3	6	143	50.1	0.057	−2.3	288.4
4	5	66	50.1	0.776	−79.4	211.4
4	6	109.3	50.1	0.256	−36.0	254.7
5	6	43.3	50.1	0.954	−102	188.7

SE: Standard error, CI: Confidence interval

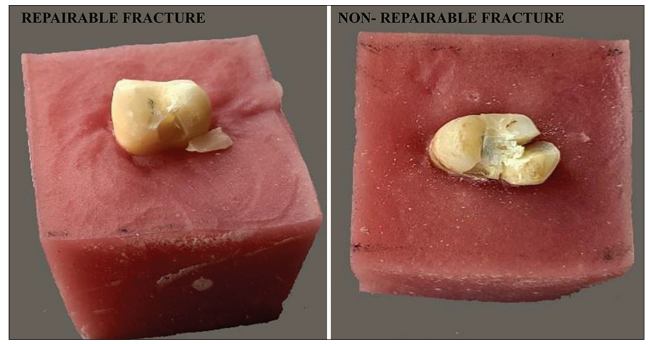

Figure 2: Specimens showing repairable and non-repairable fracture modes

mean differences of fracture resistance from Groups 1 and 2 only and for the rest of the groups there mean differences in fracture resistance are insignificant.

In terms of fracture mode, the incorporation of the fibers in different orientations and positions has influenced the ratio of repairable and nonrepairable fractures [Figure 2]. Group II (horizontal fibers both on the gingival and pulpal floor) was characterized by the highest percentage (80%) of repairable fractures followed by Group VI (Ever-x Posterior) 70% while Group I (Composite alone) yielded the lowest ratio of 30%.

DISCUSSION

Composite restorations are the material of choice for restoration in the present generation due to the many advantages; they offer over metallic restorations. In spite of ample of improvement in the composite materials, one of the major drawbacks remains is polymerization shrinkage (1.6%–7.1%) which creates contraction stresses leading to decreased fracture resistance and restoration failure.[10] Fortunately, reinforcing dental materials with fiber has resulted in increased strength and toughness of composite resins also. An increase in flexural strength of direct composite resins has been seen with fiber reinforcement.[15,16] The objective of this study was to analyze the effect on fracture resistance of teeth restored with fiber-reinforced composite with different fiber locations and orientation in maxillary premolars.

The anatomical shape of maxillary premolars with steep cuspal inclines leads to cuspal separation during mastication and makes them more prone to fracture. Moreover, the preparation of MOD cavities in this teeth presents the worst scenario in terms of fracture resistance.[10,17]

Good flexural strength, better impregnation with resin, good adhesion properties, no mechanical retention required are some of the desirable properties of fibers.[18] Fibers lead to decrease stress transmission to the remaining tooth structure by dissipating and distributing stress within the composite resin. Each fibers present in Ribbond are in a locked stitch interwoven framework with nodal intersections. Thus individual fibers act as crack stoppers by changing the stress direction that eventually dissipates the strain.[5,19] When the Ribbond fibers are adapted closely to the internal contours of the remaining tooth substrate, crack shielding mechanism is reinforced. The Leno weaved structure of Ribbond helps in distributing stressess over a wider region and hence providing multiple load paths. Polymerization shrinkage and occulsal load stresses are distributed over a larger surface and are better controlled. Like Dentino-enamel complex, which helps dentin and enamel to work in strain harmony together, the Ribbond fibers placed immediately against the cavity walls, act similarly to dentino-enamel complex, enabling tooth substrate and restorative composite to function in strain harmony.[5] Belli *et al*.[13] reported increase in fractural strength and decrease cuspal movement by insertion of Ribbond fibers over dentin walls of endodontically treated molars with Class II (MOD) cavities.

Ever-X posterior-a new fiber-reinforced composite contains short E-glass fibers impregnated within the nanohybrid composite. This premixed material is more convenient to use as it eliminates the need to place fibers separately in the cavity. It consists of total inorganic and filler content of 76 wt%/57 vol%. The short E-glass fibers prevent and arrest crack propagation that often starts from the surface of the restoration.

Hence, in the present study, everX posterior was compared with Geanial posterior composite with polyethylene fibers inserted at different locations and varying orientations.

To simulate the thermal changes taking place in the oral cavity *in vitro*, thermocycling of the samples was done. To simulate periodontal ligament, light body elastomeric impression material, polyvinyl siloxane, a layer was applied over root surfaces before mounting of specimens in acrylic block.[10]

Sadr *et al*.[20] suggested that fibers should be impregnated with resin before placement because it helps in merging of the fiber with the polymer matrix. Improper wetting leads to void and oxygen entrapment, which can interfere with the polymerization of the resin, resulting in higher residual monomer and reduced strength. Hence, Ribbond fibers were impregnated into ribbond wetting resin before placement.

Results of our study showed statistically significant and highest fracture resistance was exhibited by ribbond fiber placed horizontally both on the pulpal and gingival floor (Group 2, 1288.8 N) followed by other ribbond fiber groups (Group 3, 976 N; Group 4, 942.3 N; Group 5, 876.3 N). Ever x Posterior (Group 6, 833 N) showed lesser fracture resistance compared to the ribbond fiber groups. The least fracture resistance was observed in the nonfiber group (Group 1, 588.4 N). Furthermore, from the results we conclude that the horizontal orientation of fibers (Group 2 and Group 3) exhibited greater fracture resistance compared to the vertical orientation of fiber (Group 4). This can be attributed to when fibers are placed perpendicular to the long axis of applied forces, reinforcement occurs, while if forces are parallel to fiber placement, no or little reinforcement leads to failure.[1]

The results showing higher fracture resistance for Group 2 (fiber placed horizontally both on the pulpal and gingival floor), maybe due to the following reasons:

1. Coverage of larger surface area (pulpal + gingival) by fiber placed horizontal, so increase capacity to bear the forces and dissipation of forces equally over the large surface area
2. As they are not cut (Chopped) as in other groups (Group 5 and 6), so leno– weave continuous structure of ribbond fiber is maintained, which might have increased fracture resistance
3. Increase quantity of fibers and adequate adaptation to the gingival floor, reduce shrinkage stress occurring during polymerization of composite resin
4. Fibers increase the strength of restoration if the longitudinal axis of fibers is perpendicular to the compressive forces but, if the longitudinal axis of fibers is parallel, it leads to matrix failure and no enhancement in strength.

No studies have been done till date comparing the vertical, horizontal, and random (Fiber chips) orientation of fibers along with the premixed fiber-reinforced composite (Ever-X), and hence, the results of the study cannot be validated with those of any other studies. Although studies by Luthria *et al*.,[21] Rahman *et al*.,[22] Patnana *et al*.,[23] Dyer *et al*.,[24] and Sáry *et al*.[14] concluded that the insertion of the polyethylene ribbond fiber into the composite restoration in any position and orientation has increased the fracture resistance of the tooth and are in line with the results of our study.

In the present study, failure modes were divided as repairable and non-repairable based on the location of the fracture line in relation to CEJ (above or below CEJ). In the groups where the fiber was incorporated, failure was mostly repairable one (above the CEJ) whereas composite alone (Group 1) showed the highest percentage of catastrophic failure (non-repairable below CEJ fractures). Furthermore, Ever-x showed dominantly the repairable fractures exhibiting its property to prevent and arrest crack propagation. These results of our study are in line with the study conducted by Sáry *et al*.[14] and Fráter *et al*.[25] where both the incorporation of polyethylene fibers and Short fiber-reinforced composite have shown the favorable (Repairable) modes of fracture.

CONCLUSIONS

Within the limitations of the study, it can be advocated that inserting polyethylene fiber inserts in Class II composite restorations significantly increases fracture resistance. Furthermore, the horizontal orientation of fiber on both pulpal and gingival floor of wide class II MOD cavities gives the highest fracture resistance in maxillary premolars.

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Conflicts of interest

There are no conflicts of interest.

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