

Original Article

Fracture resistance of endodontically treated premolars restored with bulk-fill composite resins: The effect of fiber reinforcement

Fereshteh Shafiei, Paria Dehghanian, Nasibeh Ghaderi, Maryam Doozandeh

Department of Operative Dentistry, Oral and Dental Disease Research Center, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran

ABSTRACT

Background: Coronal restoration of endodontically treated teeth (ETT) with mesio-occluso-distal (MOD) cavities is of a great importance in long-term success of the treatment. This study evaluated the effect of fiber reinforcement on the fracture resistance (FR) of ETT restored with flowable or paste bulk (PB)-fill composite resin compared to conventional composite (CC) resin.

Materials and Methods: In this *in vitro* experimental study, eighty maxillary premolars were divided into eight groups ($n = 10$). The first group was left intact (G_1) and the other groups received MOD cavities along with endodontic treatment. G_2 : Remained unrestored while the other experimental groups were restored with three types of composite resin with or without fiber insertion. G_3 : CC resin, G_4 : PB fill, G_5 : Flowable bulk fill (FB). G_6 : Fiber + CC, G_7 : Fiber + PB, and G_8 : Fiber + FB. FR was tested at crosshead speed of 1 mm/min and recorded in Newton. Data were analyzed using one-way analysis of variance and Tukey's tests at significance level of $P < 0.05$.

Results: G_1 and G_2 revealed the highest and the lowest FR, respectively. The mean FR of the testing groups in Newton was as follows: $G_1 = 1204.8^A$, $G_2 = 352.1^C$, $G_3 = 579.6^{BD}$, $G_4 = 596.7^{BD}$, $G_5 = 624.9^{BDE}$, $G_6 = 858.3^E$, $G_7 = 529.6^{CB}$, and $G_8 = 802.5^{DE}$. Different uppercase letters indicate the significant difference between the groups.

Conclusion: The effect of fiber insertion on FR depended on the type of composite resin; the highest reinforcing effect was obtained in the CC resin + fiber, followed by bulk-fill flowable + fiber, and flowable bulk (FB)-fill composite resin. The strength of the former was significantly higher than the conventional and PB fill with and without fiber.

Key Words: Composite resins, dental materials, dental restoration failure, tooth fracture

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Address for correspondence:

Dr. Maryam Doozandeh,
Department of Operative
Dentistry, Oral and Dental
Disease Research Center,
School of Dentistry, Shiraz
University of Medical
Sciences, Shiraz, Iran.
E-mail: mdoozandeh@sums.
ac.ir

INTRODUCTION

Coronal restorations of pulpless teeth after endodontic therapy are still a challenging issue.^[1] The strength of endodontically treated teeth (ETT) could be enormously reduced due to the weak tooth structure resulting from caries, trauma, or previous restorations and loss of pulp chamber roof. The design of restoration and type of restorative materials are very

determining in this situation; they not only restore and seal the weakened tooth but also reinforce it.^[2] Today, resin composites have become the preferred choice of many dentists and patients for the coronal restorations because of their sufficient retention and esthetic and mechanical properties with maximum

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conservation of tooth structure.^[1] The latter is a result of their bonding ability to dental substrates that leads to cusp splinting/reinforcing effect.^[3] It has been debated that intracoronal adhesive composite resin restorations provide internal reinforcement of mesio-occluso-distal (MOD) restorations in ETT without occlusal coverage.^[4] These restorations may be an alternative restorative treatment if a normal occlusion, without parafunctional habit, is present.^[5]

Polymerization shrinkage of composite resin, as an inherent property, is considered a major problem so that if the resultant force exceeds the interfacial bond strength, adhesive failure negates the adhesive reinforcement of the weakened cusps.^[6] With high bond strength, tooth structure may be involved in stress fracture.^[7] Consequently, incremental technique was suggested to overcome these problems and ensure complete curing to achieve optimum performance of the restoration.^[8] However, the effectiveness of this sensitive and time-consuming placement on reduction of shrinkage stress was not confirmed by some authors.^[9] Recently, the “bulk-fill” materials were introduced into the market. Development in photoinitiator dynamics and increased translucency could allow a deeper light penetration and curing. Therefore, bulk-fill composite resins could be applied in a thickness of 4–5 mm and cured at once with low shrinkage stress. Similar to the conventional composite (CC) resins, this new category is provided in low-viscosity (flowable) and high-viscosity (paste) types.^[10]

Bulk-fill materials simplify the restorative procedure and save clinical time, especially in wide and deep cavities. Recently, better performance of these composite resins, compared to conventional ones, in extensive MOD cavities has been reported in terms of shrinkage stress and fracture resistance (FR).^[11] However, this result was not supported in two other situations on FR of ETT, with similar FR for two types of composite resins.^[12,13]

The development of different types of fibers, such as polyethylene or glass fiber in fiber-reinforced composite, has increased the resin composite applications. Fibers have the ability to reduce polymerization shrinkage, tolerate tensile stress, and stop crack propagation in resin composite materials.^[14] Ribbond (Ribbond, Seattle, WA, USA) is a polyethylene fiber with woven network that allows an infusion of the resin into the fibers. The

fiber network, higher modulus of elasticity, and lower flexural modulus of the polyethylene fibers are believed to have a modifying impact on the interfacial stresses developed along the adhesive interface and allow efficient force transmission.^[13,15] Therefore, they could act as stress relievers in restored teeth and may prevent unfavorable subgingival fracture of composite restorations and increase the reparability of fractured teeth.^[16] Despite some reports on the beneficial effect of fiber reinforcement in composite resin restorations on FR of ETT,^[13,17] no significant strengthening effect has also been reported.^[12] To the best of our knowledge, there was no study evaluating the effectiveness of using fibers beneath bulk-fill resin composites. Therefore, the present study aimed to analyze fiber reinforcement on the fracture strength (FR) and failure mode of flowable and paste bulk (PB)-fill resin composites in endodontically treated premolars.

MATERIALS AND METHODS

The materials used in this *in vitro* experimental study are listed in Table 1. Eighty freshly extracted human maxillary premolars with approximately the same sizes (measured mesiodistally and buccolingually by a digital caliper) and complete root formation were selected. The teeth were checked to be free of caries, any restorations, fractures, or cracks through transillumination technique. After removing any soft-tissue deposits by hand scaler and being stored in chloramine-T solution at 4°C for 24 h, the teeth were stored in distilled water up to 1 month and randomly assigned to eight groups, ten teeth in each.

- Group 1: Intact teeth with no cavity preparation or root canal treatment were used as control samples
- Groups 2–8: Standard MOD cavities were prepared with diamond bur (#57 Teezkavan, Tehran, Iran). The occlusal isthmus of the cavities was 1/3 of the intercusp distance, and the proximal box was 2/3 of the buccopalatal width. The gingival floor was placed 1 mm above the cemento-enamel junction (CEJ). The cavosurface margins were prepared at 90°. The preparation dimensions were checked using a periodontal probe in all samples. Then, standard endodontic access cavities were prepared using a high-speed bur (#245, Teezkavan, Tehran, Iran) and water coolant. Thereafter, the canals were instrumented with k-file with a step-back technique up to size 70 and 5.25% sodium hypochlorite irrigation

Table 1: Materials used in this study

Materials	Manufacturer	Batch	Composition
Tetric N-Flow	Ivoclar Vivadent	U27804	Dimethacrylates (including TEGDMA), barium glass, ytterbium trifluoride, highly dispersed silica and mixed oxide, catalysts, stabilizers, and pigments
Tetric N-Ceram (nanohybrid)	Ivoclar Vivadent, Schaan, Liechtenstein	U33191	Bis-GMA, urethane dimethacrylate, TEGDMA, barium glass, ytterbium trifluoride, silicon dioxide, Mixed oxide, initiators, stabilizers, pigments
Tetric N-Ceram (Bulk Fill)	Ivoclar Vivadent	U03089	Urethane dimethacrylate, bisphenol A dimethacrylate, barium glass, ytterbium trifluoride, mixed oxide, prepolymer (82%-83 wt%)
Tetric N-Bond	Ivoclar Vivadent	T27407	Phosphoric acid acrylate, HEMA, Bis-GMA, urethane dimethacrylate, ethanol, film-forming agent, catalysts, and stabilizers
X-tra base (low viscosity Bulk Fill)	Voco, Cuxhaven, Germany	640104	Mod UDMA, EBPADMA, TEGDMA, Ba-Al-F-B-Si glass, Sr-F-Si glass

between each file. After instrumentation, the teeth were rinsed with distilled water for final irrigation and obturated with gutta-percha and AH Plus sealer (Dentsply DeTrey, Konstanz, Germany) by cold lateral condensation technique. The chamber was cleaned and excess gutta-percha was removed and sealed with a thin layer of resin-modified glass-ionomer cement (GC, Tokyo, Japan). Then, the teeth were stored in 100% humidity for 7 days before restorative procedure

- Group 2: MOD cavities were not restored and were used as positive control
- Group 3 (CC): After drying the cavities, the surfaces of the cavity wall were etched with 37% phosphoric acid gel (Denfil, Vericom, Korea) for 15 s and rinsed with water for 15 s. Following blot drying of cavity surfaces, Tetric-N-Bond adhesive (Ivoclar Vivadent, Schaan, Liechtenstein) was actively applied for 20 s, and the solvent was air-dried for 5 s and light-cured for 20 s by a QTH light-curing unit with intensity of 600 mw/cm² (VIP Junior, Bisco, USA). Conventional nanohybrid resin composite (shade A2, Tetric-N-Ceram [TN]), Ivoclar Vivadent, Schaan, Liechtenstein) was used to restore the whole cavity walls through incremental technique with maximal thickness of 2 mm. Each increment was light cured for 40 s
- Group 4 (PB fill, PB): After the process of etch and bond, as were done for teeth in Group 3, the cavities were filled with a bulk-fill composite resin (shade IVA, TN bulk fill, TB, Ivoclar Vivadent, Liechtenstein) in one increment up to 4–5 mm thickness and then were light cured for 40 s
- Group 5 (flowable bulk [FB]-fill composite resin, FB): Having done the procedure of etching and bonding, the cavities were filled with a low-viscosity bulk-fill composite resin (X-tra base, Voco GmbH, Hanau, Germany) at up to 4 mm in

thickness and cured for 40 s. The remaining parts of the cavities were restored with a nanohybrid composite resin (TN) at maximum 2 mm thickness and then light cured for 40 s

- Group 6 (fiber + CC): Polyethylene fiber (Ribbond-THM, Ribbond, Seattle, WA, USA) was cut so that the buccal and lingual walls were covered with 2 mm of the fiber from the cavity floor. Fibers were wetted with Ribbond wetting resin (Ribbond, Seattle, WA, USA) in darkness for 10 min before the restorative procedures. After etching and bonding like previous groups, a thin layer (at least 1 mm) of flowable composite resin (Tetric flow, Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the cavity floor where the fiber was seated. Next, a piece of wetted fiber was pressed through the flowable composite resin in a buccolingual direction to be in close contact in the buccal and lingual walls and cured for 20 s. The remaining cavity was incrementally restored by CC resin (TN) like what was done in Group 3
- Group 7 (fiber + PB): Similar to previous groups, the PB-fill composite resin was used to restore the cavities following insertion of fiber
- Group 8 (fiber + FB): After insertion of fiber, the cavities were restored with flowable bulk-fill composite resin.

Remaining in distilled water at 37°C for 24 h, all restorations were finished and polished with Sof-Lex disc (3M ESPE, St. Paul, MN, USA), and rubber points. The teeth were subjected to thermocycling (5000 cycles at 5°C and 55°C, with 30-s dwell time and 5-s transfer time). All the specimens were embedded vertically in self-curing acrylic resin (Acropars, Tehran, Iran) in a Teflon mold up to 1 mm apical to the CEJ while the tooth's long axis was perpendicular to the base of the mold.

FR test was performed by a universal testing machine (Instron model 4302, Darmstadt, Germany). The compressive load was delivered using a 6-mm stainless steel sphere at crosshead speed of 1 mm/min, perpendicular to the long axis of the tooth. The sphere touched the buccal and lingual cusps of the teeth until a fracture occurred. The forces needed for fracture were recorded in Newton (N). To determine the failure modes, the fractured specimens were observed under a stereomicroscope at magnification of $\times 40$. Failure modes were classified as:

1. Restorable failures when the fracture line was above the CEJ or 1 mm or less apical to the CEJ
2. Nonrestorable failures and vertical fracture when the fracture line was more than 1 mm apical to the CEJ.^[18]

After verifying normal distribution with the normality test (Kolmogorov–Smirnov test), data were analyzed using one-way analysis of variance and Tukey's honest significance difference multiple comparison tests at the significance level of $P < 0.05$.

RESULTS

The mean and standard deviation of FR in each of the eight groups are presented in Table 2 and Figure 1. Power analysis showed that the sample size of this study resulted in acceptable power values ($80\% \leq \text{power}$). Group 1 (intact teeth, 1204 ± 252) demonstrated the highest strength and

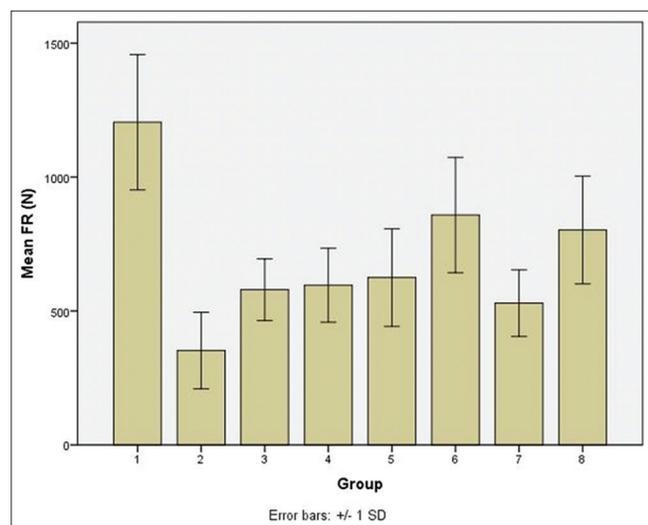


Figure 1: Mean fracture resistance and standard deviation among the groups. G1 (Control, Intact teeth), G2 (Control, unrestored teeth), G3 (conventional composite), G4 (paste bulk-fill), G5 (flowable bulk-fill), G6 (Fiber+ conventional composite) G7 (Fiber + paste bulk-fill), G8 (Fiber + flowable bulk-fill).

a significant difference with all groups ($P < 0.001$). Group 2 (unrestored teeth: 352 ± 143) had the lowest FR showing a significant difference ($P < 0.05$) with the other groups except G7. In our assessment, there was no statistically significant difference among the FR of G3, G4, and G5 ($P > 0.05$), indicating similar FR for three types of composite resin without fiber.

Fiber insertion resulted in a significantly higher FR only for CC resin ($G6 = 858 \pm 215$ vs. $G3 = 579 \pm 114$, $P = 0.01$). G6 had the highest strength with a significant difference with other experimental groups ($P < 0.03$) except for G5 (624.9 ± 182) and G8 (802 ± 201). There was no noteworthy difference between G5 and G8. Fiber in combination with PB-fill composite resin revealed no reinforcing effect and showed the lowest FR ($G7 = 529 \pm 124$) among the experimental groups that were significantly lower than that of G6 and G8 ($P = 0.003$ and $P = 0.002$, respectively.).

Table 3 presents the frequency of different failure modes in the experimental groups. Failure mode analysis revealed that the most fracture pattern was nonrestorable in groups with no fiber (G3 and G4), although in G5, the same level of

Table 2: Mean fracture resistance (n) and standard deviation values of the experimental groups

Group	n	Mean \pm SD*
Group 1 (control, intact teeth)	10	1204 \pm 252 A
Group 2 (control, unrestored teeth)	10	352 \pm 143 C
Group 3 (CC)	10	579 \pm 114 BD
Group 4 (PB)	10	596 \pm 138 BD
Group 5 (FB)	10	624 \pm 182 BDE
Group 6 (fiber+CC)	10	858 \pm 215 E
Group 7 (fiber+PB)	10	529 \pm 124 CB
Group 8 (fiber+FB)	10	802 \pm 201 DE

*Different uppercase letters indicate a significant difference between the groups ($P < 0.05$). SD: Standard deviation; CC: Conventional composite resin; PB: Paste bulk-fill, FB: Flowable bulk-fill

Table 3: The frequency (%) of different failure modes in the experimental groups

Groups	Restorable (%)	Nonrestorable (%)
Group 1 (control, intact teeth)	10 (100)	0 (0)
Group 2 (control, unrestored teeth)	1 (10)	9 (90)
Group 3 (CC)	3 (30)	7 (70)
Group 4 (PB)	2 (20)	8 (80)
Group 5 (FB)	5 (50)	5 (50)
Group 6 (fiber+CC)	7 (70)	3 (30)
Group 7 (fiber+PB)	6 (60)	4 (40)
Group 8 (fiber+FB)	7 (70)	3 (30)

CC: Conventional composite resin; PB: Paste bulk-fill; FB: Flowable bulk-fill

fracture pattern was observed. In fiber reinforcement groups, the main fracture pattern was restorable. Figures 2 and 3 represent restorable and nonrestorable fractures, respectively.

DISCUSSION

The present study evaluated the FR of ETT with MOD cavities and intracoronally (no cuspal coverage) restored with different types of composite resins reinforced by fiber. Although cusp coverage is recommended as the definite restoration in ETT, we used intracoronally restoration to mimic a clinical scenario in which ETT cannot be restored permanently like in case of endodontic or periodontal problems. In the maintenance phase, preservation of restored ETT with no catastrophic fracture is an important issue. It is evidenced that cusp fracture is one of the main reasons for loss of ETT. In this study, we used TB as the bulk-filled material, because of its



Figure 2: Restorable fracture.



Figure 3: Nonrestorable fracture.

sculpt-able consistency, and that it can be applied in one increment; also, it was considered suitable for posterior final restoration as described by the manufacturer.^[19] Furthermore, x-tra base (low-viscosity bulk fill) was used due to its higher filler content (approximately 75 wt%) and flexural strength similar to other employed composite resins.^[20]

The results of our study revealed that also high-viscosity TB composite resin had a comparable FR compared to conventional counterpart (TN composite). These findings are in agreement with the results of Atalay *et al.* and Kemaloglu *et al.* and Yasa *et al.* studies.^[12,13,21]

These authors reported that CC resin and bulk-fill composite resin showed no difference in the strength of restored teeth. Composition, filler content of resin composites, and their elastic modulus are the important factors attributed to polymerization shrinkage stress and subsequent clinical fractures.^[22] Benetti *et al.*'s study showed that Tetric-EvoCeram (TEC) bulk-fill composite resin had the same polymerization contraction stress and gap formation similar to TEC CC resin.^[6] Do *et al.* also showed that TEC bulk fill had the lowest cuspal flexure than other tested bulk-fill composite resins.^[23] According to El-Damanhoury and Platt, TEC bulk fill exhibited lower stress than the control material with good mechanical properties, enabling it as a final restoration.^[24] Rosatto *et al.* revealed that the use of bulk-filling technique resulted in significantly lower cuspal strains and shrinkage stresses with higher FR.^[11] TB used in this study demonstrated a higher depth of cure due to the improvements in their initiator (Ivocerin) and increased translucency.^[25,26] It has filler content similar to TN (around 77%–80%). This may contribute to the similar FR obtained for two types of composite resins. Akbarian *et al.* also indicated that silorane-based composite with less volumetric shrinkage compared with dimethacrylate-based composite, both had a similar FR.^[27] It seems that polymerization shrinkage stress does not directly affect FR. Such conflicting results might be due to the variety of types and dimensions of the cavities and the direction of the applied load on the examined teeth. Our study showed that the FR of ETT restored with CC resin with Ribbond fiber was significantly higher than that without fiber. Ribbond is a leno-woven ultra-high-molecular-weight polyethylene ribbon. It has a high tensile strength, modulus of elasticity and fracture toughness, and biocompatible and excellent

optical properties.^[28] This is consistent with Ayad *et al.*'s results, indicating that polyethylene fiber has a modifying effect on the developing interfacial stresses and has a strengthening effect on the remaining tooth structure.^[29]

Khan *et al.* demonstrated that both polyethylene ribbon and glass fiber significantly enhanced the FR of MOD composite resin restorations with no difference between the two groups. It was thought that the fiber network would absorb and change the stress at the restorative/adhesive interface and reduce the risk of fracture.^[30] Furthermore, fibers would replace a part of the composite resin increment and decrease in the overall volumetric polymerization shrinkage of the composite resin. Hshad *et al.* also reported the considerably beneficial effect of polyethylene ribbon fiber on the fracture strength of ETT restored with CC resin.^[31] In contrast to our results, Göktürk *et al.* found no significant difference between the fracture strength of the restored premolars using CC resin with and without fiber insertion.^[32] Such contradictory results could be attributed to the variation in the composite resin brands, types of the teeth (premolars vs. molars), cavity size, loading device, and the experimental situation.

In contrast to the effect of fiber reinforcement with CC resin in our study, this effect was not observed using PB-fill composite resin and fiber + PB-fill composite resin showed the lowest mean FR among the experimental groups. It was not statistically different from CC resin and bulk composite resin groups. This phenomenon might be explained due to the presence of a weak interaction and gap formation between the PB-fill composite resin and the fiber. The possibility of this effect might be less in case of using flowable composite resin; hence, establishment of a unique united structure and chemical bond between flowable composite resin, fiber, and restorative resin is essential in obtaining a positive effect of fiber in the FR,^[13] which is easily achieved in CC resin placed in increments of maximum 2 mm while this integrity may be not achieved with 4 mm bulk layer. The possible presence of void between the bulk layer of the composite resin and the fiber might create some flexure of the restoration and subsequent flaw formation and the reduced FR of the teeth. When bulk-fill flowable composite resin was used with fiber, a significantly higher strength was obtained although this difference was not statistically significant. Considering similar fracture strength for bulk-fill

flowable and CC resins with fiber reinforcing, the former approach could be suggested to simplify the composite resin placement in ETT with extensive MOD cavities. This provides improved adaptation and shortened restorative time. In the literature, only in a recent study by Takce *et al.*, the fiber was used beneath a bulk-fill flowable composite resin (smart dentin replacement). These authors concluded that this approach behaves similar to CC resin with fiber in terms of FR in ETT. However, bulk-fill flowable without fiber and PB fill with or without fiber were not compared in their study. In the present study, the majority of the restorable failure pattern was observed in groups with fiber reinforcement which was similar to the intact tooth.^[33] Recently, Eliguzelolu Dalkılıç *et al.* evaluated the effect of two fiber insertion techniques on the fracture strength of restored teeth using FB-fill composite resin.^[34] They found no increase in the fracture strength values; however, fiber increased the favorable fracture modes consistently with our findings.^[34] These results are attributed to the stress distributive effect of polyethylene fiber, as shown in Yanyu *et al.* and Hshad *et al.*'s studies.^[31,35] However, the specimens restored with conventional nanohybrid and bulk-fill composite resins were more prone to unrestorable fractures.

This *in vitro* study was conducted under a static load with no simulation of *in vivo* situation. Considering the intraoral conditions, further *in vivo* studies should be performed to evaluate the effect of different fibers with different bulk-fill composite resins in restoring the ETT.

CONCLUSION

Based on the limitations of this study, the following results were reached:

1. The conventional nanohybrid composite resin and flowable and PB-fill composite resins without fiber had comparable FRs
2. Fiber significantly increased the fracture strength of endodontically treated premolars restored with CC resin. Although this reinforcing effect was not statistically significant for flowable and PB-fill composite resins, the strength of FB-fill composite resin with fiber reached the level of CC resin with fiber. Therefore, it is suggested that FB-fill composite resin with fiber simplifies the composite placement with advantage of better adaptability
3. The fiber reinforcement with conventional and

FB-fill composite resin could be suggested as intermediary restoration in ETT with questionable prognosis until subsequent definitive restorations.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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