Original Article

Evaluation of Fracture Resistance in Root Canal-Treated Teeth Restored Using Different Techniques

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Abstract

Objective: This study aimed to evaluate the effects of different coronal restoration techniques on fracture resistance of root canal-treated mandibular premolars with mesio-occluso-distal (MOD) cavities. **Materials and Methods:** A total of 105 mandibular premolars were selected and randomly distributed into seven groups (n = 15). MOD cavities were prepared except the control group. Root canal treatments were performed. Each tooth was embedded in acrylic resin. Groups were classified as follows; G1: intact teeth (control), G2: unfilled MOD cavity, G3: MOD + composite resin, G4: 10-mm-long fiber post + composite resin, G5: 5-mm-long fiber post + composite resin, G6: Ribbond in the occlusal surface + composite resin, and G7: horizontal fiber post + composite resin. Specimens were loaded using a universal testing machine until fracture occurs. Fracture loads were recorded and statistical interpretations were made ($\alpha = 0.05$). **Results:** In Groups 1, 6, and 7, the greatest fracture resistance was shown and there were no significant differences among these groups ($P > 0.05$). No significant differences were detected among the Groups 3, 4, and 5 ($P > 0.05$), whereas the fracture resistances of Groups 1, 6, and 7 were significantly greater than these three groups ($P < 0.05$). Group 2 had the lowest fracture resistance of all groups ($P < 0.05$). **Conclusion:** Usage of horizontal post or occlusal Ribbond usage increased the fracture resistance of root canal-treated premolars with MOD cavities.

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Introduction

A root canal-treated tooth (RCTT) can be compromised by coronal destruction caused by caries, fractures, previous restorations, and endodontic access;[1] in addition, there is more likely to have biomechanical failure with RCTT than a tooth with vital pulp.[2] Therefore, different materials and restorative methods have been recommended to improve the structural integrity of teeth with major coronal loss. Adhesive restorations transmit and distribute stresses across the bonding interface to the tooth; thus, the occlusal forces can be spread in a wide surface area as a result of micromechanical adhesion and reinforce a weakened tooth structure.[3] Usually, fiber post placement is indicated if the coronal tooth structure is insufficient to support a core buildup.[4] Although studies examining fiber post placement in the root canal have shown contradictory results regarding fracture resistance of RCTT, placement of fiber post in the buccolingual direction across the mesio-occluso-distal (MOD) cavity preparation of an RCTT has shown an improvement in the fracture resistance.[5] However, the fiber post placement procedure does have some limitations, including a weakening of the radicular structure due to some dentin tissue

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removal during the post space preparation[6] and poor bonding strength in the apical areas of the post space.[7,8] Therefore, the application of horizontal fiber posts in MOD cavities has come into question. Fortunately, the studies being conducted in this area have indicated positive results with the use of horizontal fiber posts.[9-11]

Polyethylene fibers are reinforced ribbons with an ultra-high modulus of elasticity,[12] and they are treated with cold gas plasma to enhance their adhesion to synthetic restorative materials, including chemically cured or light-cured composite.[12,13] Therefore, they have been widely used to increase the fracture strength of restorative and prosthetic materials in dental practice.[14,15] In addition, a polyethylene fiber network can effectively modify the stress dynamics at the interface between the enamel, composite, and adhesive materials, and it provides effective force transfer.[12,14]

Several studies have attempted to identify the best techniques and materials that can be used to increase the fracture resistance of an RCTT.[16-18] The aim of this study was to evaluate the effects of different polyethylene fiber applications, two different fiber post placement lengths, and horizontal fiber post applications on the fracture resistance of mandibular premolar teeth. The null hypotheses of this study were as follows:

1. Fracture resistance does not vary among the experimental groups
2. There are no differences among the experimental groups in terms of the fracture types.

Materials and Methods

After obtaining the approval of the Local Ethical Committee of Erciyes University in Kayseri, Turkey (decision number: 2015/234), 105 single-rooted human mandibular premolar teeth with a single root canal and with nearly the same crown and root sizes (21.3 ± 0.8 mm in length) that were extracted for periodontal or orthodontic reasons were collected for this study. The teeth were free of caries, restorations, and fractures, and were stored in distilled water and a 0.2% thymol solution at 37°C until they were tested. Then, the teeth were randomly divided into seven groups (n = 15 in each group).

Using a high-speed diamond fissure bur (DiaSwiss FG, Geneva, Switzerland) under water cooling, standardized MOD cavities were prepared for all of the teeth, except the control group (intact teeth). For further weakening of the teeth, the gingival cavosurface margins of the cavities were prepared at the cementoenamel junction (CEJ) level. The buccolingual width of the cavities was 4.5 mm, and the maximum residual thickness of the remaining walls was 2 ± 0.5 mm. Following the MOD cavity preparations, endodontic access cavities were prepared with the diamond fissure bur under water cooling. The root canals were instrumented up to a size #40 Reciproc instrument (VDW, Munich, Germany). Then, irrigation was performed with 1% NaOCl (Wizard, Rehber Kimya, Istanbul, Turkey) and 17% EDTA (Werax, Spot, Izmir, Turkey) using a syringe and a 27G needle. The root canals were dried with paper points (VDW, Munich, Germany) and were obturated with a combination of the downpack and backfill techniques (Dia-Pen and Dia-Gun; DiaDent, Seoul, South Korea).

To simulate clinical conditions, each tooth was embedded in self-curing acrylic resin cylinders (Elite SC Tray; Zhermack, Rovigo, Italy) at a level of 2.0 mm below the CEJ. The periodontal ligaments were simulated using a polyether impression material at a thickness of 0.3 mm (Impregum™ F; 3M ESPE, St. Paul, MN, USA). The groups were as follows according to the coronal restoration techniques:

- Group 1: Intact teeth used as controls [Figure 1a]
- Group 2: Teeth with MOD cavities and no coronal restorations [Figure 1b]
- Group 3: Composite resin-restored MOD cavity group [Figure 1c]
- Group 4: 10-mm-long placed fiber post group. The post spaces were prepared with post drills (RelyX™ Fiber Post drill; 3M ESPE, Deutschland GmbH, Germany) to a depth of 10 mm from the CEJ. Glass fiber posts (RelyX™ Fiber Post; 3M ESPE, Deutschland GmbH, Germany) were luted with resin cement (Panavia F 2.0; Kuraray, Okayama, Japan) into the post spaces [Figure 1d]
- Group 5: 5-mm-long placed fiber post group. The post spaces were prepared with post drills (RelyX™ Fiber Post drill) to a depth of 5 mm from the CEJ. Glass fiber posts (RelyX™ Fiber Post) were luted with resin cement (Panavia F 2.0; Kuraray) into the post spaces [Figure 1e]
- Group 6: Occlusal Ribbond group. After the composite resin restoration of the cavities, a groove was prepared that was 2 mm in width and 1 mm in depth extending buccolingually on the cusp tips. The groove terminals were on the occlusal third of the buccal and lingual surfaces. After the groove was etched and bonded, a piece of Ribbond fiber (Ribbond, Seattle, WA, USA) was placed on the floor of the groove using flowable composite resin (Filtek Flow; 3M ESPE, St. Paul, MN, USA), and then light cured for 40 s. The exposed surface of the fiber was also covered with composite resin [Figure 1f]
- Group 7: Horizontal fiber post group. Round-shaped holes were prepared with a rounded diamond bur (DiaSwiss FG) under air–water cooling in the center of the buccal and lingual walls. Then, a glass

fiber post (RelyX™ Fiber Post) was horizontally luted between the buccal and lingual holes with a flowable composite resin (Filtek Flow) [Figure 1g].

In all of the groups (except Group 1 and Group 2), the composite restorations of the MOD cavities were performed as follows: first, the walls of MOD cavities were etched with 35% phosphoric acid (Scotchbond Etchant; 3M ESPE, St. Paul, MN, USA) for 15 s for the dentin and 30 s for the enamel, rinsed with a water spray, and gently air dried. Then, the cavity walls were bonded with a dentin bonding agent (Single Bond Universal; 3M ESPE, St. Paul, MN, USA) according to the manufacturer's instructions. A resin composite (Filtek Ultimate; 3M ESPE, St. Paul, MN, USA) was applied and light cured following the incremental technique procedure. The teeth were stored in 37°C distilled water for 24 h; then, the finishing and polishing procedures were performed meticulously under water cooling. To ensure the standardization of the procedures, all of the procedures were performed by one operator.

A 45° oblique compressive load was applied to the composite filling and enamel tissue junction on the buccal cusps of the restored teeth (in the control group, the load was applied to the point corresponding to the application in the other groups) with a crosshead speed of 0.5 mm/min with a universal testing machine (Instron, Canton, MA, USA) until a fracture occurred, and the maximum load before fracture was recorded [Figure 1h]. The type of fracture was determined by visual inspection with the aid of transillumination and recorded as favorable or unfavorable [Figure 2].

The Shapiro–Wilk's test showed that the fracture resistance values were not distributed normally ($P < 0.05$). Therefore, the Kruskal–Wallis test was used for multiple comparisons, and the Student–Newman–Keuls test was used for the *post hoc* comparisons of the data ($\alpha = 0.05$). To examine the fracture type differences among the groups, a Chi-square test was used ($\alpha = 0.05$). All of the statistical analyses were performed using SPSS 20.0 (IBM Corporation Software Group, Armonk, NY, USA).

Results

Groups 1, 6, and 7 were significantly more resistant to fractures than Groups 3, 4, and 5 ($P < 0.05$). However,

Table 1: Median and 25% and 75% quartile values of the groups

	n	Median (Newton)	25%	75%
Group 1 (control)[a]	15	416.07	279.61	458.7
Group 2 (unfilled MOD)[b]	15	86.88	66.32	112.3
Group 3 (full composite)[c]	15	271.68	243.59	311.34
Group 4 (10-mm-long fiber post)[c]	15	238.19	197.64	312.55
Group 5 (5-mm-long fiber post)[c]	15	286.06	216.65	321.7
Group 6 (occlusal Ribbond)[a]	15	364.7	322.24	436.8
Group 7 (horizontal fiber post)[a]	15	365.49	299.83	444.79

Significantly different groups are shown with different superscript letters. MOD=Mesio-occluso-distal

Table 2: Frequencies of favorable and unfavorable fractures

	Favorable	Unfavorable
Group 1 (control)[a]	12 (80)	3 (20)
Group 2 (unfilled MOD)[a]	11 (73.4)	4 (26.6)
Group 3 (full composite)[a]	8 (53.4)	7 (46.6)
Group 4 (10-mm-long fiber post)[a]	14 (93.4)	1 (6.6)
Group 5 (5-mm-long fiber post)[a]	9 (60)	6 (40)
Group 6 (occlusal Ribbond)[a]	13 (86.7)	2 (13.3)
Group 7 (horizontal fiber post)[a]	13 (86.7)	2 (13.3)

The values in parentheses refer to percentages, significantly different groups are shown with different superscript letters. MOD=Mesio-occluso-distal

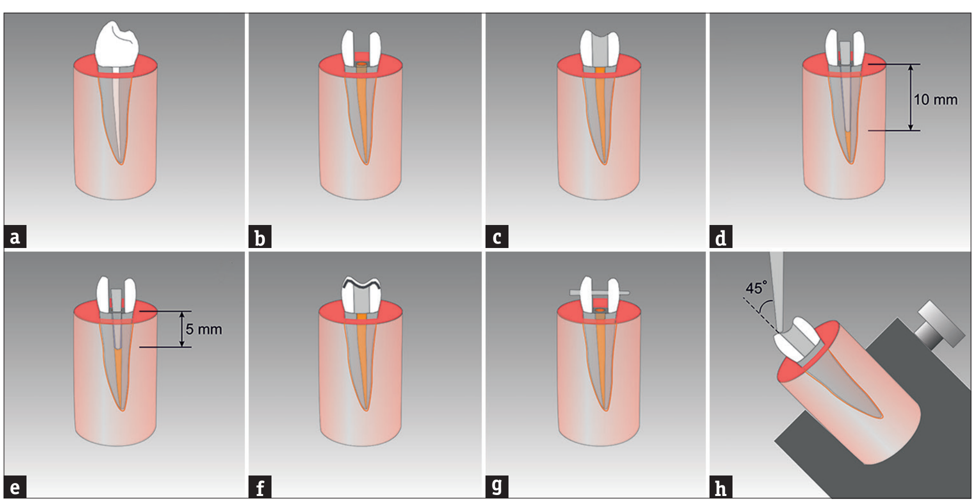

Figure 1: (a-g) The Groups 1, 2, 3, 4, 5, 6, and 7, respectively. (h) The loading of the restored tooth in the universal testing machine

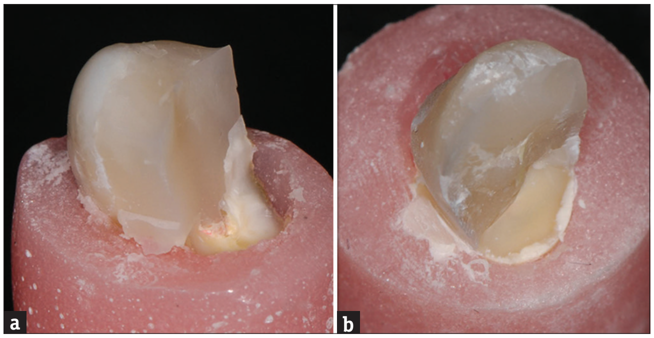

Figure 2: (a) Unfavorable and (b) favorable fracture types occurring in the teeth

there were no significant differences among Groups 1, 6, and 7 and Groups 3, 4, and 5 ($P > 0.05$). The lowest fracture resistances were observed in Group 2, and there was a statistically significant difference between the other groups ($P < 0.05$). The descriptive statistics are summarized in Table 1. Table 2 shows the frequencies of the fracture types classified as "favorable" and "unfavorable." According to the Chi-square test results, there were no significant differences among the experimental groups in terms of the fracture types ($P > 0.05$).

Discussion

This study evaluated the fracture resistance of root canal-treated mandibular premolars using different restoration strategies that can be used against different challenges in clinical practice. Premolar teeth were used because they are more frequently exposed to destructive lateral forces than molar teeth.[19] According to the findings of this study, the null hypothesis that there would be no significant differences among the different coronal restoration techniques of the RCTT with MOD cavities had to be rejected. The control group (Group 1), horizontal fiber post group (Group 6), and occlusal Ribbond group (Group 7) showed statistically significantly higher fracture resistances than the other groups.

Previous studies have shown that substance loss is the main factor affecting the survival rate of RCTT.[6,20] Magne[21] stated that, if both of the proximal marginal ridges were removed, the stress concentration became greater for those teeth with endodontic access cavity preparations. The MOD cavities were used in this study to simulate a common clinical situation and it is also shown that MOD cavity preparation reduces the structural stability by about 63%.[22] In Group 2 (unfilled MOD cavity), the worst results might be attributed to the fact that teeth in this group removed the structure and leaving without restoration weakened the tooth against loading. In addition, the results of Group 1 (intact teeth) might be explained by the fact that the preservation of the tooth structure enhanced the fracture resistance under occlusal loads.[16]

The effects of fiber-reinforced composite on the fracture resistance of RCTT have been investigated in several previous studies.[23,24] Belli *et al.*[23] stated that a ribbon of glass fiber in the occlusal third of the restoration was an efficient technique to reinforce the fracture resistance of a tooth. Particularly, they stated that a polyethylene fiber network would create a change in the stress dynamics at the restoration/adhesive resin interface by providing multiple stress paths along the fibers. By this way, imposed load can be redistributed to intact portions of the teeth and the forces can be transferred away from the bonded surfaces.[23]

In the present study, the results showed that the root canal-treated mandibular premolars restored with occlusal Ribbond exhibited a fracture resistance similar to that of the horizontal fiber post group. Larson *et al.*[25] indicated that the extension of a horizontal glass fiber post through the buccal and lingual cusps reinforces the teeth and enhances the fracture resistance of root canal-treated premolars. In previous studies, it was reported that the reinforcing effect of glass fiber posts is greater than that of polyethylene fibers.[26,27] In contrast, Oskoee *et al.*[28] found that polyethylene fibers exhibited a greater reinforcing effect than glass fibers. However, these studies evaluated the conventional glass fiber post placement and polyethylene fiber usage and, in this regard, differ from the present study. In this study, similar results between the horizontal post and occlusal Ribbond groups could be related to the potential reinforcement of the dental structure by preventing cusp deflection.[10] The current results also indicate that the horizontal fiber post and occlusal Ribbond groups showed similar median values with the intact teeth group, and that there was no statistically significant difference. Both the buccolingually placed polyethylene fiber and horizontally transfixed glass fiber post improved the fracture resistance, and they are minimally invasive methods of reinforcing the tooth structure.

There are contradictory data in the literature about the reinforcing effects of different lengths of placed fiber posts. Some studies have reported that longer fiber posts have larger bonded areas and allow a better distribution of stress, preventing fractures in the root.[29,30] However, other studies have indicated that the post length has no effect on the fracture resistance of an RCTT.[31,32] Cecchin *et al.*[29] stated that further post space preparation for a longer post was unnecessary because they obtained similar fracture resistances with crowns restored using 8- and 12-mm-long post cores in their study. In the present study, there was no significant difference between the 10- and 5-mm-long posts in terms of fracture resistance. These results are compatible with those of Cecchin *et al.*[29] and the previously mentioned studies.[31,32] Moreover, the 10- and 5-mm-long fiber post groups showed similar values with the full composite group (Group 3). Mohammadi *et al.*[33] stated that the placement of a fiber post into the root canal did not show a further benefit when compared to a composite resin restoration without a post. One study found that placing a glass fiber post did not restore the fracture strength of an RCTT with major structural loss.[34] In this study, the fracture resistances of the short and long fiber post groups were lower than those of the horizontal fiber post and occlusal Ribbond groups. During the fiber post space preparation, more root dentin was generally removed; thus, the resistance to occlusal forces is diminished, and the possibility of fracture increases.[35] In the event, results in this study could be related with all these factors.

According to the statistical evaluation of the groups, there was no significant difference among the groups in terms of the fracture types. The favorable fracture type occurred more frequently than the unfavorable fracture type in all of the groups, meaning that the fracture occurred in the cervical third of the root, which is favorable in many clinical instances. This can be explained by the morphology of the MOD cavities, leaving a limited amount of residual tooth structure at the level of the cervical margin of the specimen. Moreover, the loading angle of 45° with the long axis in a buccal direction could also have affected the results. Thus, the stress concentration in the thin dentin of the cervical area may cause a favorable fracture.[9] In this study, the control group also showed more favorable fractures than unfavorable fractures. This could be related to the direction of the force that could only affect parts of the buccal sides of the intact teeth. If the force were applied in the vertical direction, such teeth might have shown deeper fractures.

The main limitation of this study was that the complexity of the forces generated in intraoral restoration techniques in clinical conditions could not be fully mimicked in *in vitro* conditions. During occlusal movement of the teeth, the speed of the chewing activity and the magnitude and direction of the intraoral forces vary. However, the forces applied to the teeth *in vitro* were at a constant speed and direction. In addition, they were increased continuously until a fracture occurred. In this regard, further *in vivo* studies are needed.

According to the findings of this study, the presence of a horizontal glass fiber post or occlusal Ribbond application can increase the fracture resistance of root canal-treated premolars with MOD cavities against a fracture load. However, the application of fiber posts with different cementation lengths into the root canals did not show any improvement in the fracture resistance. Despite the advantages of these novel techniques, they may not guarantee more favorable fracture patterns than conventional techniques.

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Conflicts of interest

There are no conflicts of interest.

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