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Influence of Different Restoration Techniques on Fracture Resistance of Root-filled Teeth: *In Vitro* Investigation

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Clinical Relevance

Endodontically treated teeth with large mesio-occluso-distal cavities may be restored with different techniques to enhance structural integrity.

SUMMARY

Objective: The purpose of this study was to determine the fracture strength of endodontically treated mandibular premolar teeth restored with composites and different reinforcement techniques.

Methods and Materials: Forty-eight freshly extracted human mandibular premolar teeth were randomly divided into four groups: group IN, group CR, group FRC, and group PRF. Group IN consisted of teeth with intact crowns and served as the control group. In the other three groups, endodontic treatment was performed and standard mesio-occluso-distal (MOD) cavities were prepared. Then cavities were restored with hybrid resin composite only, flowable composite and hybrid resin composite, and Ribbond, flowable composite and hybrid resin composite in groups CR, FRC and PRF, respectively. All of the teeth were subjected to fracture by means of a universal testing machine, and compressive force was applied with a modified stainless-steel ball at a crosshead speed at 0.5 mm/min.

Results: The highest values were observed in group IN, while the lowest values were determined in group CR. There was not any statistically significant difference between group CR and group FCR ($p>0.05$). When groups CR, FCR, and PRF were compared, group PRF showed significantly better fracture strength than did groups CR and FCR ($p<0.05$). It was determined that there was not any significant

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difference between group IN and group PRF ($p>0.05$).

Conclusions: Polyethylene ribbon fiber considerably increases the fracture strength of mandibular premolar teeth with MOD cavities restored with composite.

INTRODUCTION

Endodontically treated teeth (ETT) are more prone to fractures compared to teeth with healthy pulps because of dentin dehydration and hard tissue loss.[1,2] There is a significant decrease in strength and fracture resistance of ETT, especially with the preparation of wide mesio-occluso-distal (MOD) cavities, so root canal treatment should not be considered complete until the teeth are restored permanently.[1-3] Previous studies[4,5] proposed that restorations improve structural integrity and increase the prognosis of ETT when subjected to considerable masticatory occlusal loads. Although there is no agreement on the desired type of restoration for ETT, it should reproduce anatomical form, esthetics, and function in addition to stopping bacterial microleakage, ensuring periodontal health, and protecting the remaining tooth structure against occlusal loads and antagonistic teeth.[6-8] To avoid failure of the root canal treatment, an easy, high-strength, fast, direct, and cost-effective restorative method may be appropriate.

Adhesive technology is progressing every day, making it possible to create conservative and highly esthetic restorations with direct bonding to the teeth. Flowable composites are preferred by clinicians because of the better adaptation they offer; they act as an extendable and flexible intermediate layer with a low modulus of elasticity. They involve less filler (60%-70% by weight and 46%-70% by volume) and a larger percentage of resin matrix than hybrid resins. Flowable resin composite applied before the placement of restorative material may form an elastic liner.[9,10]

Recent improvements in resin-bonded composite properties have encouraged clinicians performing adhesive restorations of ETT. Ribbond (Ribbond, Seattle, WA, USA) is a polyethylene fiber that has an ultrahigh elastic modulus. These fibers increase the flexural properties of composite resin, have similar elastic modulus to dentin, provide better levels of fatigue resistance, and permit effective force transmission.[11] In addition, Ribbond's easy manipulation and adaptation to the contours of the teeth make it a material of choice. In addition, it was reported that Ribbond behaves in such a manner that it distributes stresses and absorbs energy. It reduces the stress concentrations via distributing forces over a larger area, which in turn stops crack formation and propagation. In addition, it absorbs the energy from repeated occlusal effects.

The purpose of this study was to determine the fracture strength of endodontically treated mandibular premolars restored with composites and different reinforcement techniques.

The null hypothesis of the study was that the fracture resistance of MOD composite restorations in root-filled teeth is not affected by different reinforcement techniques, such as use of flowable composites or Ribbond.

METHODS AND MATERIALS

This study was approved by the Istanbul University Faculty of Dentistry Ethical Committee. Forty-eight single-rooted human mandibular premolar teeth with similar dimensions (mesiodistal: 5.08±0.5 mm; buccolingual: 7.15±0.7 mm) extracted for orthodontic reasons were used. The completely formed teeth were extracted from donors aged 18-30 years. The teeth were cleaned of debris and soft tissue remnants immediately after extraction and kept in saline solution for 24 hours. The samples were divided randomly into four groups (n=12 each).

Group IN consisted of intact teeth without any cavity preparations or endodontic treatment. In the other three groups, all of the teeth had endodontic treatment first. Endodontic access cavities were prepared with diamond burs at high speed, and the pulp tissues were extirpated. The working length of each tooth was determined using #15 K-files (Kendo, VDW, Munich, Germany), and all the teeth were instrumented until an apical size of #35 with K-files. The step-back technique was used to give a taper with H-files #40, #45, and #50 (Kendo). During the preparation, the root canals were irrigated with 2 mL of 5.25% NaOCL before each file was introduced into the canal. After the instrumentation and irrigation, root canals were dried with absorbent paper points (META BIOMED Co, Ltd, Chungbuk, Korea) and obturated with gutta-percha (GP; META BIOMED Co, Ltd) and AH Plus sealer (Dentsply De Trey, Konstanz, Germany) using a cold lateral condensation technique. Excessive coronal root canal filling materials were removed with heated instruments and then GP was removed 1 mm apically from the canal orifices and covered with light-cured,

Table 1: *Types of Materials Used in Coronal Restorations and their Compositions*			
Type of Materials	**Lot No.**	**Manufacturers**	**Compositions**
Clearfil SE Bond	000165	Kurary Co, Ltd, Japan	Primer: MDP, HEMA, hydrophilic dimethacrylate, *N,N*-diethanol-*p*-toluidine, water Bond: MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate, CQ, *N,N*-diethanol-*p*-toluidine, silanated colloidal silica
Clearfil Liner 2V Bond	000002	Kurary Co, Ltd, Japan	Bond liquid A: Bis-GMA, HEMA, MDP, hydrophobic dimethacrylate, CQ, accelerators
Clearfil Majesty Flowable Composite	3K0009	Kurary Co, Ltd, Japan	Silanated barium glass filler, silanated colloidal silica, TEGDMA, hydrophobic aromatic dimethacrylate, DL-CQ. The total amount of inorganic filler is approximately 62 vol%, particle size of inorganic filler ranges from 0.02 μm to 19 μm
Clearfil AP_X Composite	630062	Kurary Co, Ltd, Japan	Bis-GMA, TEGDMA, silanated barium glass filler, silanated silica filler, silanated colloidal silica, DL-CQ. The total amount of inorganic filler is approximately 71 vol%, particle size of inorganic filler ranges from 0.02 μm to 17 μm
Ribbond	9592	Ribbond Inc, Seattle, WA, USA	Ultra–high molecular weight polyethylene, Homopolymer H-(CH_2-CH_2)n-H

Abbreviations: Bis-GMA: bisphenol A glycidyl dimethacrylate, TEGDMA: Triethylene glycol dimethacrylate, HEMA: Hydroxyethyl methacrylate

resin-modified glass ionomer cement (GIC; Fusion I seal, PREVEST Denpro, Kasmir, India) 1.5 mm coronal to the cemento-enamel junction (CEJ). After all of these steps were completed, standard MOD cavities were prepared. The thicknesses of the remaining buccal and lingual walls were standardized to 2.5 ± 0.2 mm, and the height from base of the fissure to the GP was standardized to 3 mm. The height of the axial walls from the proximal sides was approximately 1.5 mm. Following MOD preparation, the teeth were divided randomly into three experimental groups.

The materials used in these experimental groups and their compositions are described in Table 1.

Group Composite Resin (CR) (n=12 Samples)

The cavities were washed and dried with air water sprays. After priming for 20 seconds (SE Primer; Kuraray, Tokyo, Japan) the cavity surfaces were gently dried. SE Bond (Kuraray) was applied to the cavity surfaces and cured for 10 seconds. The cavities were then restored with resin composite (Clearfil AP-X, Kuraray) using an incremental technique and each layer was cured for 20 seconds (Figure 1).

Group Flowable Composite Resin (FCR) (n=12 Samples)

After completion of priming and bonding procedures with Clearfil SE Bond, as for group CR, the pulpal floors of the cavities were coated with a layer of low-

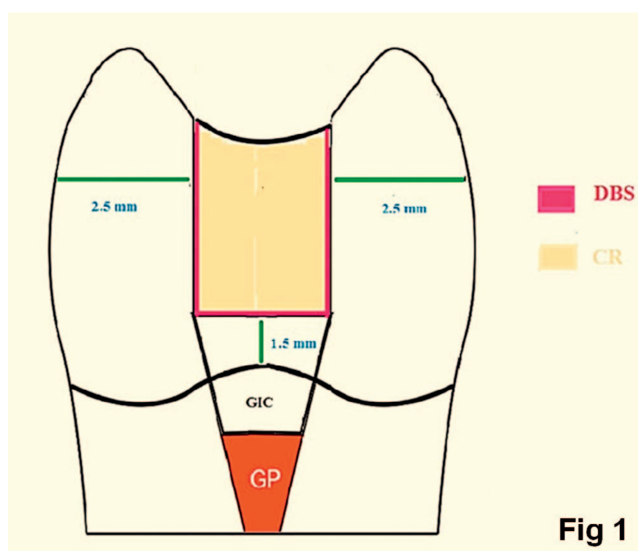

Figure 1. *The restoration of teeth in group CR with DBS (dentin bonding system) and CR.*

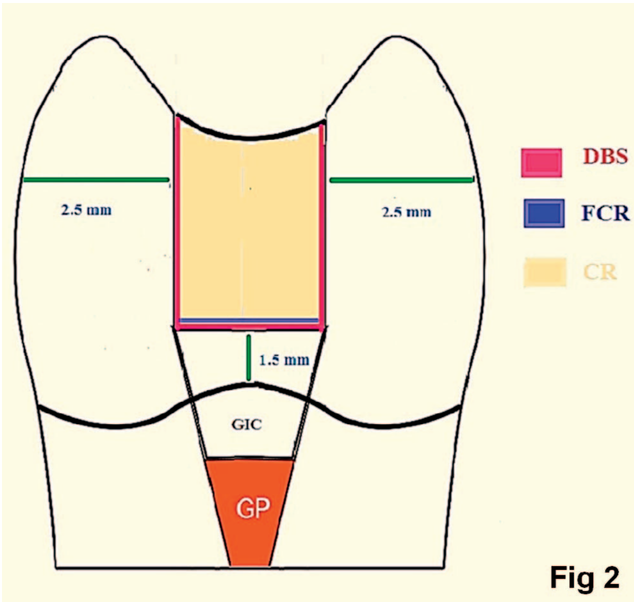

Figure 2. *The restoration of teeth in group FRC with DBS, FCR, and CR.*

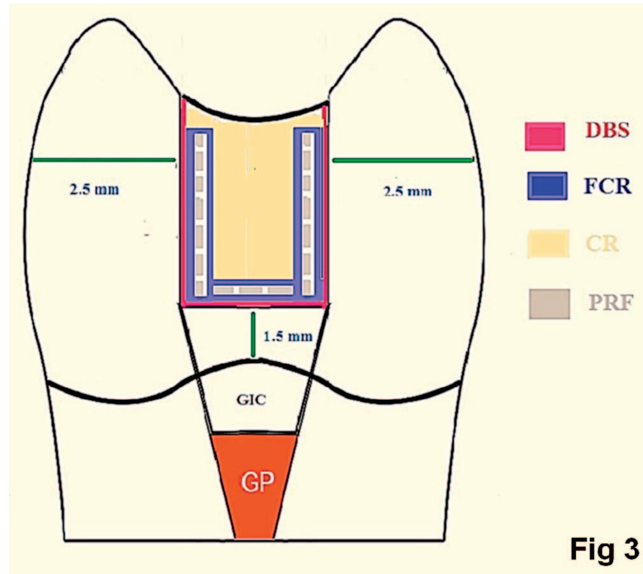

Figure 3. *The restoration of teeth in group PRF with DBS, FCR, and PRF.*

viscosity resin composite (Clearfil Majesty Flowable Universal Composite, Kuraray) and cured for 20 seconds. Then the cavities were restored with Clearfil AP-X resin composite using an incremental technique and each layer cured for 20 seconds (Figure 2).

Group Polyethylene Ribbon Fiber (PRF) (n=12 Samples)

After priming and bonding procedures with Clearfil SE Bond, as for group CR, the cavity surfaces (buccal walls, lingual walls, and pulpal floors) were covered with a layer of universal flowable, low-viscosity resin. Prior to curing, three pieces of polyethylene fiber (3-mm length, 2 mm wide) (Ribbond THM; Ribbond Inc, Seattle, WA, USA) were cut and wetted with Clearfil Liner Bond 2V Bond Liquid A (Kuraray). The Ribbond THM was kept in a dark container before the restoration process. Each polyethylene fiber was embedded inside the flowable composite on buccal, lingual walls and pulpal floors as one layer and was then cured for 20 seconds. Once cured, the cavities were restored with composite (Figure 3).

After the restoration was complete, finishing and polishing procedures with finishing burs, polishing tips, and discs (TOR VM Ltd, Moscow, Russia) were performed on all of the samples.

All of the samples (control and experimental groups) were mounted into self-curing polymethyl methacrylate resin at a level 1-1.5 mm below the CEJ with a cylinder metal mold (30-mm length, 20-mm width). During these procedures, care was taken to keep the long axis of the tooth parallel to that of the mold. Following the mounting, the samples were subjected to fracture using a universal testing machine (No. 3345J7324, Instron, Norwood, MA, US). A compressive force was applied with a modified stainless-steel ball (6 mm in diameter) parallel to the long axis and centered over the teeth until the ball contacted the internal surface of buccal functional cusps and the small part of the restoration. Compressive loading of teeth was performed at a crosshead speed at 0.5 mm/min. The mean loads required to fracture the samples were recorded in Newtons (N).

According to the failure modes, fractures were divided into two groups: 1) favorable fractures at the CEJ level and above and 2) unfavorable fractures below the level of the CEJ.

Statistical Analysis

Statistical calculations were performed with the NCSS 2007 program for Windows. In addition to standard descriptive statistical calculations (mean, standard deviation), a Kruskal-Wallis test was used in the comparison of groups, post hoc Dunn. The statistical significance level was established at $\alpha = 0.05$.

RESULTS

The fracture strength and statistical comparisons for each group are shown in Table 2. According to the

Table 2: *Mean Fracture Resistance in N, Standard Deviation (SD), Standard Error (SE), and Statistical Comparison of the Groups*[a]					
Groups	**n**	**Mean ± SD**	**SE**	**Minimum**	**Maximum**
IN	12	2156.79 ± 628.04 A	181.30	1475.99	3284.23
CR	12	1315.83 ± 352.38 B	101.72	749.63	1777.05
FCR	12	1445.35 ± 506.18 B	146.12	906.16	2272.00
PRF	12	1951.64 ± 330.94 A	95.53	1316.02	2345.91

[a] *Groups with different letters show a statistically significant difference* ($p<0.005$).

results, the highest values were seen in group IN, and the lowest values were seen in group CR. The fracture strength of the restored teeth exhibited no statistically significant difference between group CR and group FCR ($p>0.05$). Group PRF showed the highest fracture strength compared with group CR and group FCR ($p<0.05$). No statistically significant difference was observed between group IN and group PRF ($p>0.05$).

The failure modes for each group and statistical comparisons are displayed in Table 3. Regarding the failure mode, the highest percentage of favorable fractures was observed in group PRF, numerically, followed by group IN. When failure modes were compared, group PRF showed significantly more favorable fractures than did group CR ($p<0.05$).

DISCUSSION

Endodontically treated teeth are at greater risk of fracture, mostly as a result of treatment techniques that result in hard tissue loss and large cavity preparations.[1,12-14] An extensive MOD cavity preparation in a root-filled tooth may lead to cuspal fracture of the tooth if it is not restored appropriately.[15,16] Fennis and others[17] used data from over 46,000 patients in 28 dental practices and reported that of the 20.5 cusp fracture incidents per 1000 person-year, 21% involved premolar teeth.

In the oral cavity, posterior teeth are exposed to more masticatory occlusal loads and have a greater risk of fracture than is associated with anterior teeth.[18] In our study, we used premolar teeth to evaluate the strengthening and reinforcing effect of different restoration techniques. Cavity size may be another factor that altered the strengthening of the teeth. In the present study, the floor of the MOD cavity was measured to be approximately 2.15 mm in width, as was the case in a previous study.[12] We applied axial forces on the functional cusps, parallel to the long axis of the teeth, to mimic the forces of centric occlusion. Several studies[19,24] have used a universal testing machine to produce a compressive load to the specimen by means of several metallic load devices, such as steel spheres, steel cylinders, and wedge-shaped devices with a straight and cast-metal antagonist tooth. Burke and others[25] determined that the best method with which to evaluate the resistance of premolars to fracture involves using a ball of a defined diameter. In addition, in our study, we subjected the teeth to vertical compressive loading with a 6-mm-diameter, stainless-steel sphere. All of the teeth were stored in saline solution for a day before the tests. We avoided longer times of storage in solution to eliminate the postmortal changes of the tooth structure. Moreover, we used only intact teeth as a control group to compare the biomechanical properties of healthy teeth to ETT restored with different techniques.

Recently, a variety of materials have been developed to improve the mechanical properties of structurally weakened teeth. Direct composite restorations offer a good option that can strengthen teeth while maintaining esthetics.[1,26,27] Current studies[26-28] have revealed that adhesive restorations improve resistance and have superior properties for transmitting and distributing functional stress. In our study, the samples from groups CR and FRC showed the lowest fracture resistance. Although the fracture strength of the specimens can be increased by using flowable composite under the restorations, no significant difference was observed between these groups. In accordance with our results, it was reported that MOD composite restorations of maxillary premolar teeth with or without cavity liners underneath showed similar resistance to fracture.[29]

Table 3: *The Fracture Modes, Percentages, and Statistical Comparisons of the Groups*[a]				
Groups	**Favorable Fracture**		**Unfavorable Fracture**	
	No.	**%**	**No.**	**%**
IN	8 AB	77.78	4	22.22
CR	5 A	61.11	7	38.89
FCR	6 AB	66.67	6	33.33
PRF	11 B	94.44	1	5.56

[a] *Groups with different letters show a statistically significant difference* ($p<0.005$).

Ribbond is a leno-woven, ultra–high-molecular-weight polyethylene fiber with an ultrahigh elastic modulus. Its intrinsic fabric architecture, which has fibers oriented in various directions forming an interwoven structure, permits for forces to be dispersed over a broader area, diminishing stress altitudes.[11,30] Ribbond needs to be impregnated with wetting resin before being placed in the flowable resin composite. The leno design enhances impregnation of the wetting resin and thereby enhances the chemical bonding of the fiber with flowable resin, creating a unique united structure. In a previous study, Belli and others[31] claimed that the lock-stitch property delivered the forces through the weave without stress propagation into the resin. As a result of the interwoven nature of the fabric, it was expected that polyethylene fiber had a stress-altering effect.[30] Cobankara and others[14] reported that inserting Ribbond below the composite did not reduce the fracture strength of endodontic molar teeth with MOD cavity preparations. On the other hand, Sengun and others[32] described that inserting a ribbon fiber on the occlusal surface of endodontically treated premolar teeth with MOD cavity preparations improved fracture strength. Belli and others[33] evaluated the influence of using low-viscosity flowable composite with or without Ribbond fiber on the fracture resistance of endodontically treated mandibular molar teeth with MOD cavity preparations, and they concluded that inserting Ribbond significantly improved fracture resistance. Similarly, in our study, inserting Ribbond to pulpal, buccal, and lingual walls of the cavity improved the fracture resistance of endodontically treated premolar teeth with MOD adhesive restorations.

In our study, fiber insertion procedures on cavity walls (pulpal, buccal, and lingual walls) showed a positive influence on distributing stress along the teeth with significantly similar fracture resistance to that observed for group IN. In accordance with our results, Costa and others[34] also reported that the fracture strength of endodontically treated premolars restored with polyethylene ribbon fiber was similar to that of intact teeth. Belli and others[33] determined that the use of polyethylene ribbon fiber below composite restorations in root-filled molar teeth with MOD preparations produces a significant increase of fracture resistance compared to that associated with intact teeth. The discrepancy between these studies may involve the lack of standardized preparation and/or standardized test design. In the present study, we used premolar teeth with smaller cavity sizes than molar teeth. Inserting more than one strip of ribbon fiber in premolar teeth with smaller cavities results in a bridging effect between the cusps of the teeth and improvement of strength.

In the current study, the failure modes of each test group were also analyzed. Our results indicated that teeth restored with only composite and flowable composite were more prone to unfavorable fractures with the fracture line lower than 1 mm below the CEJ. However, group PRF revealed favorable fractures that can be restored more simply, and the teeth may be preserved in clinical service without any extra treatment. Sengun and others[32] examined the influence of a new fiber-reinforced composite restoration method on the fracture resistance of endodontically treated premolars, and they determined that most of the failure modes of the reinforced teeth were restricted to the level of the enamel, whereas the other groups revealed fractures generally at the level of the CEJ or below it. The possible explanation for this can be the leno-wave pattern of polyethylene fibers, which has crack-stopping or crack-deflecting mechanisms.

The results of this study are only introductory and comparative. The study has some limitations and does not completely simulate the clinical situation. Although fracture resistance was considered, the biomechanical properties of the periodontium were not included. The forces applied in this study were at a constant direction and speed, while forces produced intraorally differ in magnitude, speed of application, and direction. Additional research is necessary to determine the influence of mechanical, thermal, and chemical stress on the durability of the restorations.

CONCLUSIONS

Within the limitations of the study, the null hypothesis is rejected, and it is concluded that

- Intact teeth and polyethylene ribbon fiber groups revealed significantly similar fracture resistance.
- Use of flowable composite resin below composite restorations did not significantly increase the fracture strength of root-filled premolar teeth with MOD cavity preparations.
- Use of reinforced polyethylene ribbon fiber beneath composite restorations in root-filled premolar teeth with MOD preparations considerably increased the fracture strength.
- Most of the failure modes of group PRF were restricted to the level of the enamel, whereas the

other three groups revealed fractures mostly at the level of lower than 1 mm below the CEJ.

- Polyethylene ribbon fiber–reinforced composite resin restorations appeared to represent a more reliable restorative technique than did composite restoration for wide cavities.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Istanbul University Faculty of Dentistry Ethical Committee. The approval code for this study is 2016/23.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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