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Effect of a new restoration technique on fracture resistance of endodontically treated teeth

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Abstract – The aim of the study was to investigate the effect of a new fiber-reinforced composite restoration technique on fracture resistance in endodontically treated premolars. Eighty sound extracted human mandibular premolars were assigned to four groups ($n = 20$). Group 1 did not receive any treatment. In groups 2, 3 and 4, the teeth received root canal treatment and a mesio-occluso-distal cavity preparation. Group 2 was kept unrestored. Group 3 was restored with a dentin bonding system and composite resin. In group 4, a piece of polyethylene ribbon fiber was inserted into the groove in a buccal to lingual direction during the restoration of teeth with dentin bonding system and composite resin. After finishing and polishing, the specimens were stored in 100% humidity at 37°C for 24 h and placed at an angle of 45° to the long axis of the tooth and subjected to compressive loading in a universal testing machine at a crosshead speed of 0.5 mm min^{-1}. The load necessary to fracture the samples was recorded in Newton (N) and submitted to Kruskal–Wallis ANOVA and Mann–Whitney *U*-test. The fracture strength of the teeth reinforced with a combination of polyethylene fiber and composite resin were not significantly different than those that were restored with only composite resin ($P > 0.05$). However, most of the failure modes of the reinforced teeth were limited to the level of the enamel, while the other three groups showed fractures generally at the level of the dentin, cemento-enamel junction or more below ($P < 0.05$). Therefore, polyethylene ribbon fiber-reinforced composite resin restorations seemed a more reliable restorative technique than traditional composite restorations for extensive cavities.

Endodontic practice and its success have been inextricably tied to the quality of the final restoration (1). Although not the primary cause for failure, tooth fracture may be most detrimental because it often results in extraction. Therefore, the fracture of restored teeth is a significant problem, which warrants further study. This condition is more important in endodontically treated teeth because when compared with teeth with healthy pulps, root filled teeth are considered more susceptible to fracture.

Previously, it was believed that biological changes occurred in teeth after endodontic treatment, rendering them more brittle and susceptible to failure (2). While Rosen (3) described the dentin of endodontically treated teeth as 'desiccated and inelastic', Johnson et al (4) additionally speculated that the elasticity of dentin decreased with time following endodontic treatment. In a matched-pair study of vital and endodontically treated human teeth, Papa et al. (5), however, reported no significant differences in moisture content. The biomechanical properties, punch shear strength, toughness, hardness, and load to fracture of endodontically treated teeth were also evaluated in another matched-pair study by Sedgley and Messer, which concluded that teeth do not become more brittle following endodontic treatment (6). Endodontically treated teeth often lose substantial tooth structure from previous caries, pre-existing restorations, and/or endodontic procedures. Reduction in tooth bulk and loss of sound dentin resulting from tooth preparation causes weakening of teeth (7). Reeh et al. (8) reported that endodontic procedures reduced the relative cuspal stiffness of premolar teeth by only 5%, in contrast to an occlusal cavity preparation (20%) and a mesio-occluso-distal (MOD) cavity preparation (63%). For these reasons, preservation of tooth structure is important for its protection against fracture under occlusal loads and for its survival (7).

There is no consensus regarding the preferred type of final restoration for endodontically treated posterior teeth. Some authors claim that only complete cast coverage will provide the needed protection and will ensure the clinical success of the restoration (9, 10). Others recommend the use of a complex amalgam restoration (11, 12), indirect cast restoration covering the cusps (13), or composite materials (14, 15).

With recent advancements in adhesive technology and new and stronger composite materials, it is possible to create conservative, highly esthetic restorations that are bonded directly to teeth. They are more practical, less expensive, and in some situations, less invasive than other techniques. In recent years, the development of fiber-reinforced composite technology has also created newness in metal-free, adhesive, restorative dentistry. Ribbond is a reinforced ribbon made of ultrahigh molecular weight polyethylene fiber that has an ultrahigh modulus. It is treated with cold gas plasma to enhance its adhesion to synthetic restorative materials, including chemically cured or light-cured composite resins. The special fiber network of this material allows efficient transfer of forces acting on it. It is virtually pliable and thus adapts easily to the tooth morphology. Its translucency makes it an excellent esthetic material. Therefore, the fiber-reinforced composite has increased extensive use of composite resin materials. These novel materials and techniques enable the practitioner to approach old problems from a different perspective and, thereby, achieve unique and innovative solutions (16). Although there are many studies with fiber-reinforced composite in the literature (17, 18), there is limited study about the effect of fiber-reinforced composite as stress breaker within an extensive composite restoration (19).

The aim of the present study was to investigate the effect on fracture resistance of a new fiber-reinforced composite restoration technique in endodontically treated premolars and to examine the failure types of such restorations after loading.

Material and methods

Eighty freshly extracted human mature mandibular premolar teeth with similar anatomic dimensions and without caries or fractures were used. The teeth were randomly assigned into four groups of 20 teeth each and subjected to the following procedures:

Group 1 – The teeth were left intact without any cavity preparation or root canal treatment and used as negative control.

Group 2 – Standard conservative MOD preparations with superimposed endodontic access cavity preparations were completed.

For class II MOD cavities without proximal steps and flat floor, a width of one third of the intercuspal distance was chosen for occlusal portions of preparations, and one third of the total facio-lingual dimension was used to determine the width of proximal boxes. The facial and lingual walls of the occlusal segment were prepared parallel to each other (Fig. 1). The teeth were then endodontically instrumented with K-files to an apical size 45 using step-back technique. Irrigation with 1 ml of 5.25% NaOCl preceded each file introduced into the canal.

Following biomechanical preparation, canals were obturated with gutta-percha (Diadent Group International Inc., Chongju City, Korea) and AH Plus (Dentsply; De-Trey, Konstanz, Germany) sealer using cold lateral condensation technique.

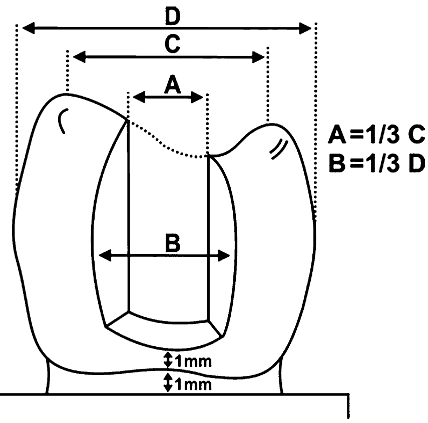

Fig. 1. Dimensions of cavity preparations determined by measurements and criteria shown.

This group was kept unrestored after MOD cavity preparation and endodontic treatment and used as positive control.

Group 3 – After preparation of teeth as in group 2, the cavities were cleaned and dried. After priming for 20 s (Clearfil SE Primer; Kuraray, Tokyo, Japan) cavity surfaces were gently dried. SE Bond (Kuraray) was applied to the cavity surfaces and cured for 10 s. The cavities were then restored with a resin composite (Clearfil AP-X; Kuraray) using an incremental technique.

Group 4 – After priming and bonding procedures, the cavities were restored as in group 3. To embed the Ribbond bucco-lingually on the occlusal surface of restored teeth, buccal and lingual grooves (2 mm in width and total 4 mm depth) were prepared using a small diamond bur under water and air cooling. These grooves were joined by an occlusal groove including composite restoration of the same depth and width of formers (Fig. 2a,b). After priming and bonding of the bucco-lingual groove, a length of best fit of polyethylene ribbon fiber (Ribbond-THM; Ribbond Inc., Seattle, WA, USA) to the groove was cut and coated with adhesive resin. The fiber was then embedded inside the composite resin from buccal to lingual direction. After curing for 20 s, the cavities were finally restored with composite resin as described above (Fig. 3).

One operator made all of the preparations and restorations. The teeth were handled in moist gauze to prevent dehydration. In addition, a thin coat of wax was first applied on the external root surface of all teeth. A stainless steel cylinder (2.5 cm diameter and 4.0 cm height) was filled with autopolymerizing acrylic resin, and the teeth were vertically mounted to a level of 1.0 mm apical to the cemento-enamel junction (CEJ), with the long axis of the tooth parallel to that of the cylinder. The wax on the root surfaces was then purified using boiling water and the space between the root surface and acrylic resin was filled with silicone paste (Dow Corning 3140 RTV coating; Cow Corning Corp., Midland, MI, USA) 1 mm apical to the CEJ to simulate a periodontal ligament (20). All specimens were stored in 100% humidity for 24 h before fracture testing.

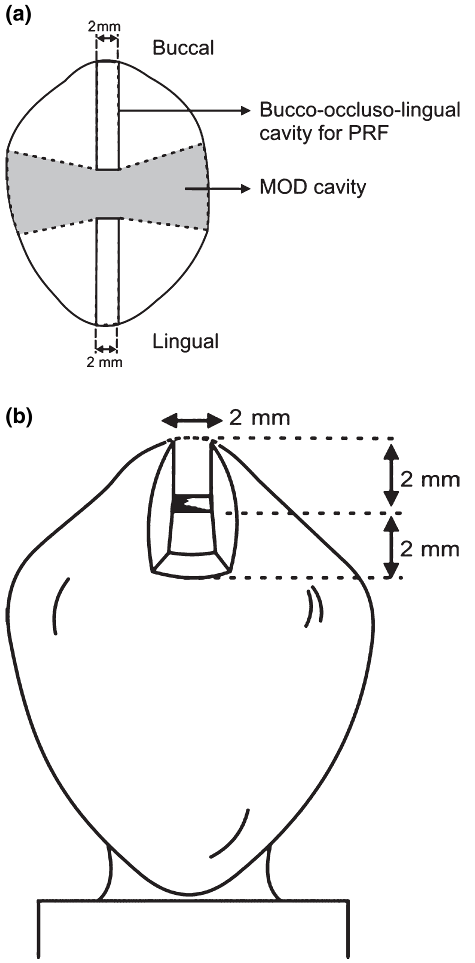

Fig. 2. Schematic drawing of preparation design for specimens in group 4. a) Appearance of mesio-occluso-distal (MOD) and polyethylene ribbon fiber (PRF) cavity from the occlusal surface. b) Appearance of PRF cavity from the buccal or lingual surface.

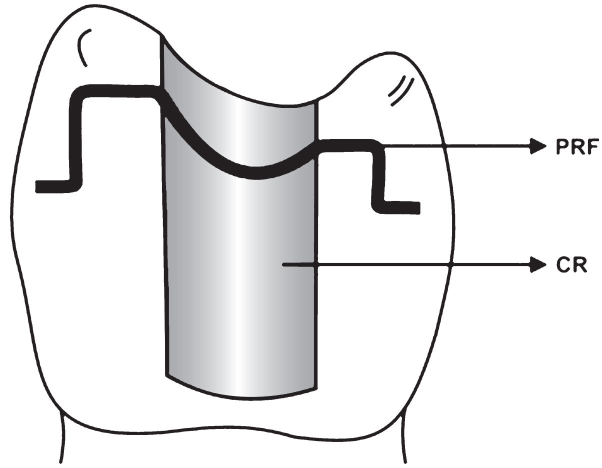

Fig. 3. Appearance of composite resin (CR) restoration with mesio-occluso-distal (MOD) cavity and polyethylene ribbon fiber (PRF) from approximal.

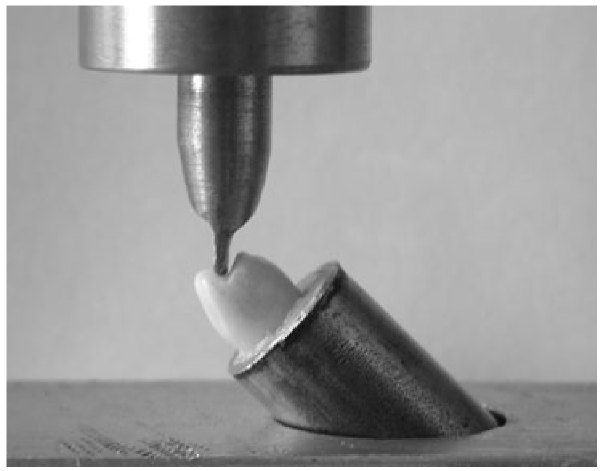

Fig. 4. View of instrument used to apply force to the occlusal surface of all specimens at an angle of 45° to the long axis of the tooth.

The specimens were placed in a jig that allowed loading at the central fossa with lingual orientation in the axio-occlusal line at an angle of 45° to the long axis of the tooth. Continuous compressive force at a cross-head speed of 0.5 mm min^{-1} was applied by a universal testing machine (Testometric Micro 500, Testometric Co. Ltd., Rochdale, UK) (Fig. 4). The force necessary to fracture each tooth was recorded in Newton (N).

The fractured specimens were then examined under 8× magnification to determine the fracture modes or levels. The fracture pattern for each specimen was classified according to the location (enamel, dentin, CEJ, or more below than CEJ) of the fracture of the facial cusps (Fig. 5).

Statistical analysis

Both fracture strength and modes were nonparametric. Therefore, Kruskal–Wallis ANOVA and Mann–Whitney *U*-tests were used to compare the fracture strength and fracture patterns among the groups. All statistical analysis was performed at the 95% level of confidence.

Results

The mean forces (N) required to fracture the teeth in each group are displayed in Table 1. Statistical analysis revealed a significant difference among groups in resistance to fracture ($P < 0.05$). The fracture strength of the intact teeth group (group 1) was higher than that of the other experimental groups ($P < 0.05$). Restoration with composite resin (group 3) or fiber-reinforced composite resin (group 4) made the teeth more resistant to fracture than prepared but unrestored teeth (group 2) ($P < 0.05$). No significant differences were found between the composite resin group (group 3) and the fiber-reinforced composite resin restoration group (group 4) with respect to fracture resistance ($P > 0.05$).

The failure modes for each group are displayed in Table 2. The intact teeth group (group 1) showed fracture levels similar to that of the composite resin group (group 3) and fiber-reinforced composite resin restoration group (group 4) ($P > 0.05$). The unrestored

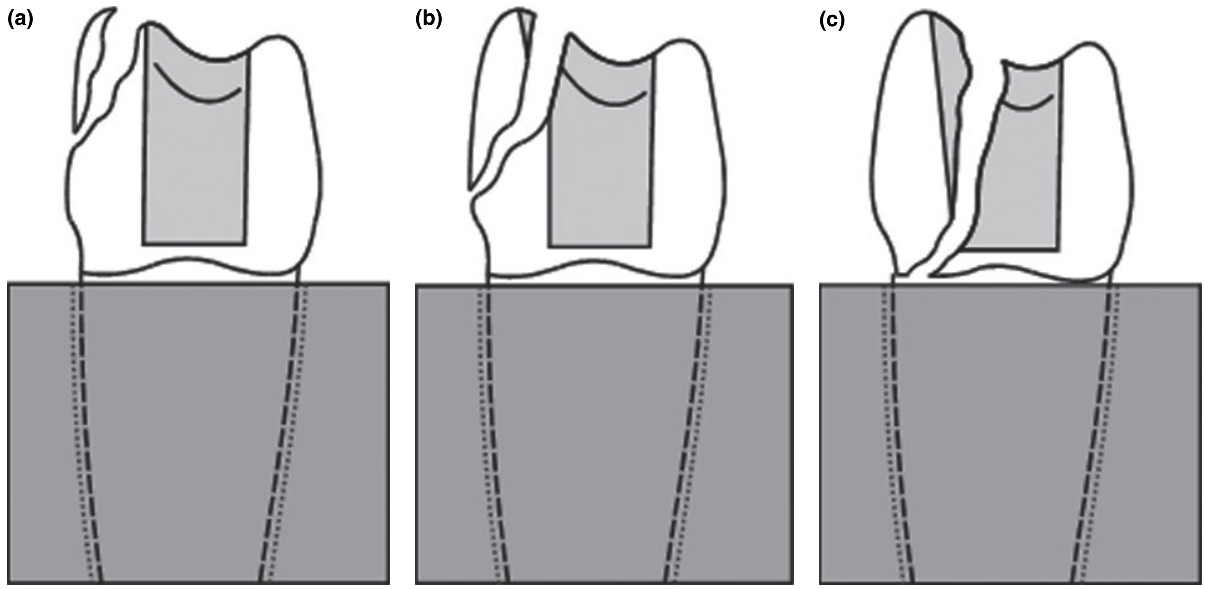

Fig. 5. Schematic representation of fracture modes of specimens. (a) Enamel level, (b) Dentin level, (c) cemento-enamel junction (CEJ) or lower.

Table 1. Mean fracture resistance (N) and standard deviation (SD) for each of the four experimental conditions ($n = 20$)

Groups	Mean ± SD
1 (intact teeth, negative control)	1053.46 ± 184.59 a
2 (prepared teeth, positive control)	177.49 ± 65.70 b
3 (only CR)	552.23 ± 128.87 c
4 (PRF and CR combination)	581.81 ± 126.68 c

CR, composite resin; PRF, polyethylene ribbon fiber. Groups with different letters show a statistically significant difference ($P < 0.05$).

Table 2. The percentage values of fracture patterns of each group and statistical comparisons

	Fracture levels (%)			
Groups	Enamel	Dentin	Under CEJ	*P*
1 (intact teeth, negative control)	27.8	38.9	33.3	a,b
2 (prepared teeth, positive control)	0.0	21.1	78.9	c
3 (only CR)	16.7	27.8	55.6	b,c
4 (PRF and CR combination)	55.0	30.0	15.0	a

CR, composite resin; PRF: polyethylene ribbon fiber; CEJ, cemento-enamel junction. Groups with the same letter did not show any statistically significant difference ($P > 0.05$).

group (group 2) and composite resin group (group 3) revealed similar fracture levels ($P > 0.05$). The fracture pattern of the fiber-reinforced composite resin restoration group (group 4) was statistically different from that of the unrestored group (group 2) and composite resin group (group 3) ($P < 0.05$).

Discussion

The final result of endodontic treatment is dependent on the appropriate and timely coronal restoration of the endodontically treated tooth. Dentin provides the solid base required for tooth restoration. Its structural strength depends on the quality and integrity of its anatomic form, so the fundamental problem is the increased quantity of sound dentin remaining to retain and support the restoration (21). Therefore, selecting the optimum restorative modality to compensate for the loss of coronal tooth structure is considered the key to restorative success.

In the present study, the strength of the teeth was reduced significantly after cavity preparation, as shown in a previous study (22). Therefore, reinforcement of the cavity with a restorative material is necessary to support the remaining tooth structure.

Some studies have suggested that bonded composite restorations will strengthen a tooth when compared with amalgam (13, 15), whereas others have not found a difference (22, 23). The restoration of teeth with indirect composite-resin restorations has also been claimed to have a strengthening effect on prepared teeth (24). However, this restoration type is not practical and economic. Also, several attempts have been made to improve the fracture resistance of endodontically treated teeth with different post systems (25, 26). These studies generally claimed that the mode of failure of deflection of the fiber-reinforced posts is protective to the remaining tooth structure. Although the post systems may provide a resistance to root structure, cuspal structure is under danger of fracture. Endodontic posts do not reinforce the crown, as enlargement of the root canal space after completion of endodontic treatment can weaken the tooth structure (27). On the other hand, Uyehara et al. (28) suggested that cusps reinforced with a combination of a dentin adhesive plus pins were as strong as intact teeth. However, pins both create stress and suffer corrosion in dental tissue. Although crown restoration has been advocated as a means of strengthening a tooth after endodontic treatment, tooth fractures are common even after crown placement (29, 30). In a study on the incidence of tooth mortality in a Swedish population, Eckerbom et al. (30) found that endodontically treated teeth with crowns were lost at the same rate as vital teeth. Gher et al. (29), in a clinical survey of 100 fractured teeth, indicated that even though the endodontically treated teeth with complete crowns seemed to have a better prognosis than teeth without crown treatment, crown coverage did not prevent root fracture. In addition, Mannocci et al. (31) indicated that the clinical success rates of endodontically treated teeth premolars restored with fiber posts and direct composite restorations after 3 years of service were equivalent to a similar treatment of full coverage with metal-ceramic crowns.

In the present study, fiber-reinforced composite restoration option was introduced for conservative restoration of endodontically treated teeth. This technique was chosen because it allowed preservation of the maximum amount of sound tooth structure and did not damage the tooth structure as pin retaining or tooth cutting for crown restoration.

Although there was no difference between fiber-reinforced composite restoration and conventional composite restoration in relation to fracture strength, in the fiber-reinforced composite restoration group, most of the observed failures were enamel level fractures whereas in the conventional composite restoration group, most of the failure types were serious failure types, such as dentin and CEJ or lower fracture levels. Fractures at the enamel level may be more easily restored than other fractures and teeth concerned may be maintained in clinical service without any addition treatment. So, this type of fracture may be considered as favorable. One possible explanation for more favorable fracture levels of teeth restored with fiber-reinforced composite vs conventional composite restoration group can be partial coverage of cusps with this restoration technique.

In this study, premolar teeth were chosen because direct composite restoration of premolars can be considered to be more predictable than that of molars. This concept was anticipated because of the lower polymerization contraction stress caused by the smaller amount of composite needed for the restoration. Also, the interproximal margins of premolars are more accessible for inspection and finishing procedures (31). In addition, premolars represent a more severe situation than molars because of crowns and less dentinal surface for bonding (32). In this way, an extreme clinical situation was simulated.

The resistance to fracture of a restored tooth may be considered to be associated with many factors, including restorative system utilized (33) and cavity dimension (34). In this study, a clinically acceptable MOD cavity preparation was used and each preparation was proportional to the tooth dimension.

It has been believed that the use of a rigid material (acrylic resin) to embed extracted teeth may lead to distorted load values and possibly affect the mode of failure of the specimens (35). Therefore, the roots were coated with a polyvinyl siloxane to simulate the periodontal ligament and surrounding anatomic structures and the roots were then embedded in acrylic resin.

The simulated shear force was applied at the central fossa with lingual orientation in the axio-occlusal line at an angle of 45° to the long axis of the tooth during this study. However, the situation may be different with extensive occlusal loading applied directly onto the restorations and, therefore, has to be evaluated in future experiments. In addition, the influence of thermal changes has to be determined.

It is important to note that no single technique is ideally suited to restore endodontically treated teeth. The restorative technique selected should be designed in such a way that functional forces do not put undue strain on the cusps, roots, or interproximal margins of the tooth. Thus, with careful attention to diagnosis and treatment planning, the fiber-reinforced composite restoration model without crown coverage suggested in this study might be considered as an economic, practical and tooth-saving alternative to the more expensive and less conservative crown coverage.

Conclusions

Within the limits of the present study, it can be concluded that:

1 MOD cavity preparation reduced fracture resistance of endodontically treated teeth.

2 Inserting a polyethylene ribbon fiber bucco-lingually on the occlusal surface in endodontically treated premolars with MOD cavity increased fracture strength.

3 As fiber-reinforced composite restorations prevented unfavorable fractures of teeth under occlusal loading, it seems to be a more reliable restorative technique than traditional composite restorations for endodontically treated teeth with MOD cavity.

4 With careful attention to diagnosis and treatment planning, the fiber-reinforced composite restoration model might be considered as an economic, practical and tooth-saving alternative.

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