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Fracture resistance of mechanically compromised premolars restored with polyethylene fiber and adhesive materials

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ABSTRACT

No previous study has tested the strength of teeth restored with a fiber post inside the root canal combined with a ribbon fiber in the crown surrounding the post. The aim of this study was to compare a new adhesive technique to other conventional techniques in the fracture resistance of endodontically treated premolars. Fifty superior premolars were divided into 5 groups ($n=10$), prepared as follows: intact teeth used in G1 as control; in the other experimental groups (G2, G3, G4 and G5), mesio-occlusal-distal cavities were prepared, extending toward the palatal cups (MODP), and root canal treatments were performed. Groups were restored by varying the restorative technique: G2 – only with composite resin (CR); G3 fiber post+CR; G4 – polyethylene fiber (Ribbond)+CR; and G5, fiber post+Ribbond+CR. The teeth were thermocycled 1000 times. After 24 h, the specimens were loaded in a universal testing machine until fracture, and the failure mode was checked. ANOVA and Tukey–Krammer tests were used for statistical analysis ($\alpha=0.05$). Results: The fracture strength (N) of control (G1 – 410.7 ± 106.9) was not significantly different ($P>0.05$) from Ribbond+CR (G4 – 300.7 ± 80.2) and fiber post+Ribbond+CR (G5 – 377.5 ± 107.7). Specimens restored only with CR (G2 – 177.7 ± 52.1) and fiber post+CR (G3 – 264.6 ± 88.5) were statistically similar ($P>0.05$), but both had their mean values differed from the control ($P<0.05$). Longitudinal and oblique crown fractures were predominant in all groups. Ribbon–fiber reinforced resin restorations provided superior fracture resistance of premolars with MODP and endodontic access cavities when compared to conventional direct techniques.

1. Introduction

Restoration of nonvital teeth is a challenging procedure, mainly in premolars with class II mesio-occlusal-distal (MOD) cavities with cusp reduction, due to excessive loss of tooth structure [1–3].

After tooth preparation, the remaining dental structure can restore the fracture resistance when restored with adhesive materials, rather than post-core techniques [4–8]. This occurs because the elastic properties of composites approximate to those of the tooth structure, such that a lesser amount of forces will form at the tooth/restoration interface and the stress created from occlusal loads will be distributed along the tooth [9,10]. For these reasons, direct composite resin restorations may be considered as a valid potential restorative technique, especially for the restoration of premolars with extensive loss of tooth structure [9–12]. However, studies have demonstrated that root-filled tooth with a large amount of coronal structure cannot present sufficient support for the restoration [13,14]. In these situations, composite resin restorations should be combined with a prefabricated glass fiber post inside root canal [13,15]. Fiber posts may act as a distributor of stress applied to the crown [13–16] and the whole tooth restoration will be a single unit and can improve fracture strength [10]. Nonetheless, there is little consensus with regard to the fiber post providing real teeth reinforcement [12,16,17].

Ribbon fiber (Ribbond) is another reinforcement adhesive material made of long longitudinal and crystallized polyethylene fibers, which provides adequate mechanical characteristic [18,19]. It has a spectrum of 215 fibers, with a very high molecular weight and coefficient of elasticity [18]. Ribbon fibers absorb water because of the "gas-plasma" treatment to which they are exposed. This treatment reduces the fibers' superficial tension, so as to ensure a good chemical bond to composite materials [20]. Ribbon fiber is biocompatible, esthetic and translucent [21]. Its fibers are also characterized by an impact strength five times higher than that of iron [23]. The open architecture of the Ribbond allows the fiber to adapt closely to the tooth contours [18,24,25].

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Due to the Ribbond wide intended properties, this fiber is indicated in various clinical dentistry situations such as the restoration of fractured teeth, the fixation of partial prostheses, orthodontic purposes, the stabilization of traumatized teeth and the direct-bonded endodontic posts and cores [6,11,21,22].

To date, only a small number of studies have compared the fracture resistance of endodontically treated premolars restored directly with composite resin and fiber posts [15,16] or with composite resin and ribbon fiber [6,11,19,20]. Moreover, no previous study has tested the strength of teeth restoration using a glass fiber post inside the root canal combined with a ribbon fiber in the crown surrounding the post.

The aim of this *in vitro* study was to compare a new adhesive technique with other conventional techniques in the fracture resistance of endodontically treated premolars. The null hypothesis is that there is no difference between the fracture resistance of premolars with access cavities and MODP preparations restored with adhesive direct techniques and intact premolars.

2. Experimental

The study protocol was reviewed and approved by the local Ethics Committee. Fifty sound superior premolars stored in steam of 0.1% thymol solution at 4 °C were washed in running water for 24 h to eliminate thymol residues. The teeth without root canal calcification and resorptions were radiographically selected and examined at 20 × magnification using a stereomicroscope (Leica Microsystems, Wetzlar, Germany) to discard those with caries, fissures or cracks. The selected premolars had a mesio-distal dimension of 6.0–7.5 mm and a vestibulo-palatal dimension of 6.0–8.0 mm. The fifty premolars were randomly divided into four experimental groups (G2, G3, G4 and G5) and one control (G1) ($n=10$).

All teeth except those of the control group (G1) were submitted to endodontic treatment. The biomechanical preparation was carried out using a Protaper system (Dentsply-Maillefer, Petrópolis, RJ, Brazil) in the following sequence: S1, S2, F1, F2 and F3. The canals were irrigated with 1% sodium solution and were dried with absorbent paper points (Dentsply-Maillefer, Petrópolis, RJ, Brazil). The teeth were filled with gutta-percha (Tanari, Manacapuru, AM, Brazil) and the AH Plus sealer (Dentsply-Maillefer, Petrópolis, RJ, Brazil) using lateral condensation technique.

The external root surface was covered with a thin layer of a polyether impression material (Impregum Soft; 3 M ESPE, St. Paul, MN, USA) to simulate the periodontal ligament [8]. The teeth were inserted into a metallic rectangular matrix (16.5 mm in width × 31.0 mm in length), and were embedded in auto-polymerized acrylic resin (Jet Clássico, São Paulo, SP, Brazil) up to 2.0 mm below the cemento-enamel junction (CEJ), so as to simulate the alveolar bone [16,24].

Class II cavities were prepared using a #1090 cylindrical diamond bur (KG Sorensen, Barueri, São Paulo, SP, Brazil), using a high-speed handpiece (Dabi Atlante, Ribeirão Preto, SP, Brazil) with air–water spray. Proximal boxes were kept 1.0 mm above the CEJ. After performing the MOD cavities, teeth preparations extended toward the palatal cups. The cusp was reduced using the same bur, in such a way that the remaining structure was 3.5-mm high and 3.0-mm thick (Fig. 1).

The measurements were checked using a digital caliper (Mitutoyo, South America Ltda, SP, Brazil. A calcium hydroxide dressing (Dentsply-Maillefer, Petrópolis, RJ, Brazil) was placed in the entrance of the root canals of all experimental teeth [18].

Groups were restored by varying the restorative technique: G2 – only with composite resin; G3 – fiber post + composite resin; G4 – Ribbon fiber + composite resin; and G5 – fiber post + ribbon fiber + composite resin. The restorative procedure of all groups is described as below:

G1 – Intact teeth used as control.

G2 – Teeth restored only with composite resin. Cavity preparations were etched with 37% phosphoric acid (3 M ESPE, St. Paul, MN, USA) for 30 s, washed for 15 s with water and dried with absorbent paper. The adhesive system (Single Bond; 3 M ESPE, St. Paul, MN, USA) was applied in two layers, using a microbrush (KG Sorensen, São Paulo, SP, Brazil) and light-cured for 20 s using a halogen lamp (Ultralux electronic; Dabi Atlante, Ribeirão Preto, SP, Brazil) at 600 mW/cm^2. The composite resin (Filtek Z250; 3 M ESPE, St. Paul, MN, USA) was inserted in increments (starting in the proximal boxes) and light was activated for 20 s (Ultralux electronic; Dabi Atlante, Ribeirão Preto, SP, Brazil). The last layer was light activated for 40 s. One operator performed all the preparations and restorations.

G3 – Teeth restored with intraradicular glass fiber posts and composite resin. The postspace was prepared using a #3 Largo bur (Dentsply-Maillefer, Petropólis, RJ, Brazil) to remove 2/3 of the filling material from root canal. Acid etching was performed for 15 s in dentin canal walls and cavity was washed for 15 s. The canal was gently dried with absorbent paper points. Later, a layer of the adhesive system (Scotchbond Multi-Purpose Plus; 3 M ESPE Dental Products, St. Paul, MN, USA) was applied to canal walls according to the manufacturer, using a microbrush. The adhesive system was light-cured for 20 s. After this, the fiber post (Angelus, Londrina, PR, Brazil) was selected, cleaned with alcohol and a layer of silano (Angelus, Londrina, PR, Brazil) was applied over its surface. The excess of silano was removed with compressed air for 5 s. The fiber post was cemented with resinous cement (RelyX ARC, 3 M-ESPE, St. Paul, Minnesotta, USA), manipulated according to the manufacturer's recommendations. The cement was inserted into the root canal using a #40 lentulo bur and applied over the post surface. Then the post was inserted into the canal in a single movement and kept under digital pressure for 60 s. The cement excess was removed and the material was light-activated with a halogen lamp (Dabi Atlante, Ribeirão Preto, SP, Brazil) for 30 s on each tooth face

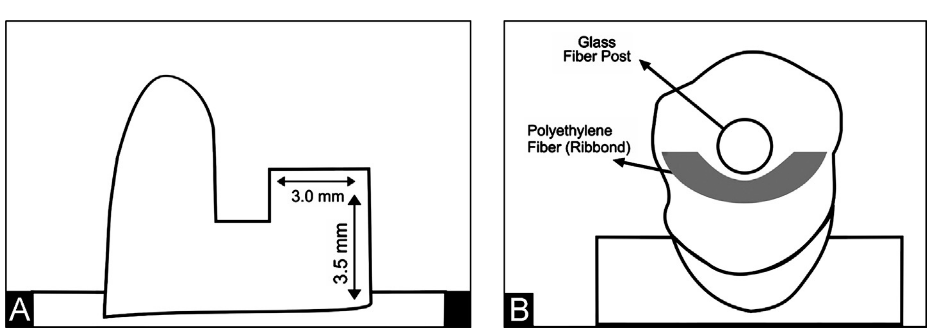

Fig. 1. (A) MODP cavity with the remaining palatal cusp measurements and (B) Ribbon fiber fixed in the cavity surrounding the fiber post.

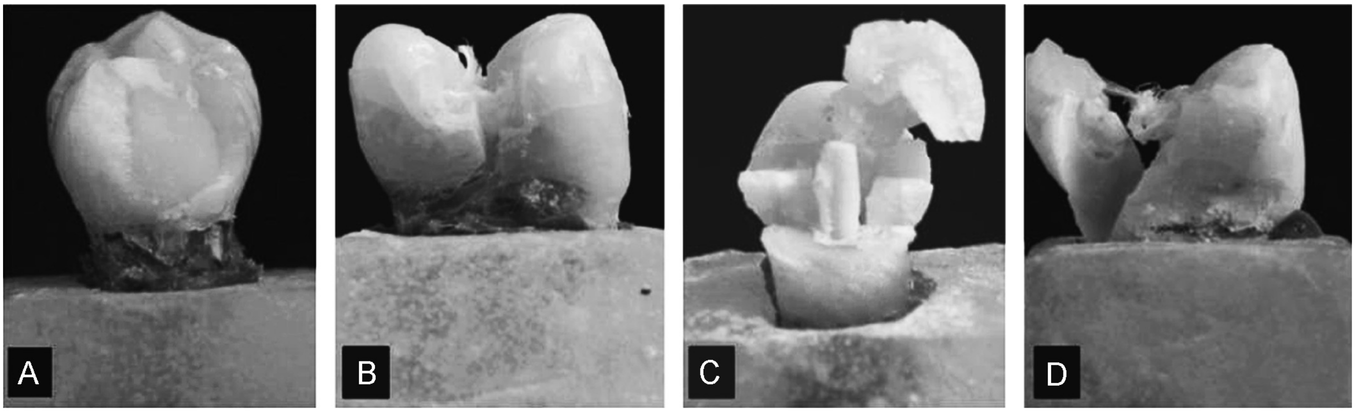

Fig. 2. Some representative failure modes after the fracture test: (A) oblique fracture in the cervical portion of the crown (G1); (B) longitudinal fracture in the cervical portion of the crown (G5); (C) longitudinal fracture in the cervical portion of the crown (G3) and (D) oblique fracture in the cervical portion of root (G4).

(buccal, palatal and proximal). After cementation, the remaining post length was cut off and the final restoration was carried out with composite resin, in the same way as described for G2.

G4 – Teeth restored with Ribbond and composite resin. Cavity preparations were etched with 37% phosphoric acid (3 M ESPE, St. Paul, MN, USA) for 30 s, washed for 15 s with water and dried with absorbent paper. An 8 mm long piece of polyethylene ribbon fiber (Ribbond; Ribbond Inc., Seatle, WA, USA) was cut and covered with the adhesive system (Single bond; 3 M ESPE, St. Paul, MN, USA). The same adhesive system was applied to the cavity walls. The ribbon fiber was inserted into a cavity, and the set was light-cured for 20 s. Restoration was carried out with composite resin, in the same way as described for G2.

G5 – Teeth restored with intraradicular glass fiber posts, Ribbond and composite resin. The post space was prepared and fiber glass post was cemented in root canal as described in G3. The cavity received acid etching and an adhesive system. The piece of ribbon fiber was fixed in the cavity surrounding the post, using the adhesive system (Fig. 2). Composite restoration was carried out in the same way as described for G2. All composite restorations were undertaken by the same operator, to ensure standardization.

The teeth were thermocycled 1000 times between 5 °C and 55 °C (Ética Equipamentos Científicos, São Paulo, SP, Brazil). After 24 h, the specimens were subjected to the fracture strength test, using a universal testing machine (Instron 4444; Instron Corp., Canton, MA, USA) with a cell load activated at a crosshead speed of 1 mm/min. The specimens were positioned at 45° in relation to the root long axis during the fracture resistance test, and a stainless steel device was developed to hold the specimen in this position. The load was applied to the palatal cusp of the tooth with a rectangular round-tipped metal point. The moment of fracture was determined by a sudden decrease in force measurement in the testing machine.

After testing, the teeth were removed from the acrylic resin blocks using extraction forceps (Quinelato, São Paulo, SP, Brazil), and the specimens were observed at a magnification of 10× to classify the fracture in relation to the direction (longitudinal, transverse or oblique) and localization – crown (occlusal, medium and cervical) or root (cervical, medium and apical).

Fracture resistance values were compared statistically. The Kolmogorov–Smirnov test showed that the results were consistent with a normal distribution curve. Parametric statistical analyses were performed (One-way ANOVA and post hoc Tukey–Kramer test), considering the restoration techniques as variable. The significance level was set as 5% (GraphPad InStat; GraphPad Software Inc., San Diego, CA, USA).

Table 1
Mean and standard deviation of teeth fracture resistance (N) restored with different direct techniques.

Groups	Mean and SD
G1 – Intact teeth (control)	(410.7 ± 106.9) **a**
G2 – Composite resin	(177.7 ± 52.1) **c**
G3 – Fiber post + composite resin	(264.6 ± 88.5) **bc**
G4 – Ribbond + composite resin	(300.7 ± 80.2) **ab**
G5 – Fiber post + Ribbond + composite resin	(377.5 ± 107.7) **ab**

Different letters indicate significant difference (Tukey–Krammer test, $P < 0.05$).

3. Results

The mean forces and standard deviations required (N) to fracture the teeth in each group are displayed in Table 1.

One-way ANOVA showed that there was a significant statistical difference between the fracture resistance of groups ($P < 0.05$); therefore, the null hypothesis was rejected, which means that there were differences in the fracture resistance of premolars restored with different direct techniques and intact premolars.

The Tukey–Krammer test showed that control group (G1) had a higher fracture strength, statistically similar ($P > 0.05$) to Ribbond + composite resin (G4) and fiber post + Ribbond + composite resin (G5).

Inferior mean values of fracture resistance ($P < 0.05$) were obtained in specimens restored only with composite resin (G2) and with fiber post + composite resin (G3), which were statistically similar ($P > 0.05$); however, only G3 was statistically similar to G4 and G5.

The failure modes (%) for each groups are shown in Table 2.

No transverse fracture was verified either in the crown or root of all tested groups. The groups with intact teeth (G1 – control) and restored with fiber posts (G3 – fiber post + composite resin and G5 – fiber post + Ribbond + composite resin) presented no root fracture. Non-restorable fractures (medium root third) were found only in samples restored with composite resin (G2) and Ribbond + composite resin (G4).

Oblique fractures in the cervical portion of the crowns (CEJ) were predominant in all specimens (40% or 30%) except for those restored only with composite resin (G2) that had 30% of longitudinal fracture in the cervical third of the roots. Fig. 2 showed some representative failure modes obtained after the fracture resistance test.

Table 2
Failure modes (%) according to localization – crown (occlusal, medium or cervical) or root (cervical, medium and apical) and direction – longitudinal and oblique.

	Crown fracture						Root fracture					
	Longitudinal			Oblique			Longitudinal			Oblique		
	O	M	C	O	M	C	C	M	A	C	M	*A*
G1 – Intact teeth (control)	10	–	30	10	10	40	–	–	–	–	–	–
G2 – Composite resin (CR)	–	–	20	–	10	10	30	–	–	20	10	–
G3 – Fiber post (FP)+CR	–	–	30	30	–	40	–	–	–	–	–	–
G4 – Ribbond+CR	–	10	20	10	–	30	10	10	–	10	–	–
G5 – FP+Ribbond+CR	–	10	20	20	10	40	–	–	–	–	–	–

Crown fracture: O=occlusal, M=medium and C=cervical (CEJ).
Root fracture: C=cervical, M=medium and A=apical.

4. Discussion

Bondable reinforcement fibers, including glass fiber post and polyethylene fibers (Ribbond), have been used to increase the durability of endodontically treated teeth, since these materials are better able to distribute forces along the teeth [12,16–19]. The current study attempted to compare the fracture resistance of weakened premolars restored with different direct restorative techniques, using a glass fiber post, ribbon fiber and composite resin.

Maxillary premolars were used in the resistance test because they are highly susceptible to fracture [2,7,11]. A simulation of the periodontal ligament was undertaken using an elastomeric material, in order to reproduce the elastic deformation and the accommodation of the tooth in the alveolus during occlusal forces [8,20,28]. The teeth were loaded in the palatal cusp at 45° to the horizontal plan, using a stainless steel tip, as recommended by the literature [11,26]. However, this in vitro model is limited, and may not reflect the clinical situation, as fracture resistance was determined by applying a heavy load to a single point [12]. The teeth were submitted to thermocycling so as to obtain more accurate results and predict the long-term prognosis of the restoration [29].

Direct composite restorations are considered predictable to restore endodontically treated premolars [11,12,24]. Contraction stress on adhesive interfaces during polymerization was reduced by using the composite-layering technique [9,20]. The present study is the first report of fracture strength in premolars restored with fiber post inside a root canal and a ribbon fiber placed in the crown circumferentially to this post. The results showed that the fracture strength of endodontically treated premolars restored with polyethylene ribbon fiber (G4 and G5) was similar to that of the intact teeth (G1), regardless of the use of intracanal glass fiber posts. Segun et al. [11] reported that inserting a ribbon fiber on the occlusal surface of endodontically treated premolars with MOD cavity increased fracture strength. Akman et al. [18] ascertained that anterior teeth that received a Ribbond inside root canal showed the highest resistance to fracture. Ayna et al., [26], in a 3-year clinical study, and Badakar et al. [21], in a laboratorial design, verified that ribbond placed inside the root canal combined with composite resin is efficient in the treatment of anterior teeth.

It is believed that polyethylene fibers create a monoblock with dentin [18]; therefore, if an excessive load was applied to the tooth, the fiber would absorb stress, reducing the possibility of root fractures [18,22,27]. Polyethylene ribbon fibers have a dense concentration of fixed nodal inter-sections that maintain the integrity of the fabric [19], called leno-wave threats [18]. This enables a "stress-modifying effect" to be produced along the restoration/dentin interface [25], consisting of transferring stress more effectively along tooth structure due to the well-defined load paths from one area to another [19]. All these physical properties and the additional anchorage from the palatal cusp of tooth provided by ribbon fiber [22] could explain the decrease in fracture susceptibility in groups restored with Ribbond.

Despite the advance in adhesive materials and technology, the total etching adhesive system (Single Bond) and microhybrid composite resin (Filtek Z250) used in this study were not able to restore the fracture strength of premolars with MODP cavities without using another reinforcement material, probably due to the excessive stress along the dentin/resin, causing debonding of the material [26]. This outcome partially corroborates the findings of Akman et al. [19], which affirm that the composite resin-restored group has a greater molar cusp movement when compared to other groups.

In corroborating the results of the present study, further investigations [4,5] have shown that root-filled maxillary premolars without fiber posts showed similar fracture resistance to those with a post. This may be attributed to the fact that more tooth structure is removed during post placement, and that an additional adhesive interface could participate in the propagation of microcracks, thus leading to reduced fracture resistance [5,9].

Although the posts did not reinforce the endodontically treated teeth, they resulted in a more favorable fracture mode above CEJ, making them more amenable to treatment. Similar results were found by Sengun et al. [11] and Makade et al. [12]. Root fractures (unfavourable) were observed in experimental groups without the intracanal fiber post. For this reason, our findings suggests that the use of polyethylene fibers in combination with glass fiber posts should be considered to be a good option for premolars with endodontic treatment and MODP cavities.

The predominant failure patterns in all experimental groups were classified as "favorable or restorable" fractures, within or above the CEJ, and were likely to be repaired, in accordance with Melo et al. [13], and may be attributed to the good stress distribution of the restoration system. Fractures occurring in the root cervical portion can only be restored after the lengthening of the surgical crown or orthodontic extrusion [29].

Overall, the fracture strength values from other studies were not comparable with the results of the present study, owing to excessive variations in research design. The development of adhesive-based integrated restorations that minimize stress concentrations in the remaining tooth structure is recommended [7]. Further in vivo studies are necessary to identify a feasible adhesive restorative technique to recover the fracture resistance of weakened premolars.

5. Conclusion

Based on the methodology and results of this study, it may be concluded that ribbon–fiber reinforced resin restorations provided superior fracture resistance of premolars with MODP and endodontic access cavities when compared to conventional direct restorative techniques.

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