Effect of novel restoration techniques on the fracture resistance of teeth treated endodontically: An in vitro study

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The aim was to evaluate the effects of fiber-reinforced composite restorations and a bulk-fill resin composite on the fracture strength of mandibular premolars treated endodontically. Standard mesio-occluso-distal (MOD) cavities were prepared in 48 mandibular premolars. Following root canal treatment, teeth were assigned to four groups: Group 1, nano-hybrid resin composite; Group 2, polyethylene woven fiber plus nano-hybrid resin composite; Group 3, short fiber-reinforced resin composite plus nano-hybrid resin composite; and Group 4, bulk-fill resin composite plus nano-hybrid resin composite. Then, the teeth were subjected to the fracture toughness test. The data were analyzed statistically using one-way ANOVA, followed by Tukey’s post-hoc test. The fiber-reinforced groups had better results than the nano-hybrid and bulk-fill composites (p<0.05), while the bulk-fill and nano-hybrid composite restorations gave similar results (p>0.05). Fiber-reinforcement improved the fracture strength of teeth with large MOD cavities treated endodontically. Bulk-fill composites can be used reliably as well as nano-hybrid composites.

Keywords: Bulk-fill composite resin, Fracture resistance, Polyethylene woven fiber, Short fiber-reinforced composite

INTRODUCTION

The quality of a coronal restoration plays an important role in the success of endodontic treatment1. Non-restorable destruction of the coronal part of the tooth is one of the main factors leading to the extraction of teeth treated endodontically2. Recently, resin composites have become the preferred materials for coronal restoration, since they can be applied in a single appointment and have sufficient aesthetic and mechanical properties. Although the fracture strength of a tooth increases after applying resin composites, the resistance of coronal restorations of teeth with severe coronal tissue loss needs to be improved3.

Ribbond (Ribbond, Seattle, WA, USA) is a leno-woven, ultra-high-molecular-weight polyethylene fiber (PWF) with an ultra-high elastic modulus4. This material has been reinforced with cold gas plasma to increase its adhesion to restorative materials5. The woven network allows wetting of the fibers and the infusion of the resin into the fibers. A polyethylene fiber network effectively changes the stress dynamics at the interface of the enamel and the composite and adhesive materials and allows effective force transfer6. PWF has been used widely in dental practice to increase the fracture strength of restorative and prosthetic materials6,7.

Polymerisation of resin composites in large increments increases the shrinkage rate of the materials, which could reduce the clinical performance via the high microleakage and poor mechanical properties of the restoration8,9. In recent years, a new resin-based composite called bulk fill has been introduced and can be applied in 4–5-mm thicknesses without using an incremental technique and cured in one step10. This accelerates the application of the material and reduces the chairside time. In addition, Ilie et al.11 and Jin et al.12 reported lower shrinkage rates for the bulk-fill materials than for conventional flowable and non-flowable resin-based composites.

Recently a novel restoration material, short fiber-reinforced composite (SFRC) (everX Posterior, GC Europe, Leuven, Belgium), was introduced for use as a reinforcement under conventional composites. It contains short fibers that can stop crack propagation though the restoration and act as a load-bearing barrier under high occlusal forces. A few recent studies of the physical and mechanical properties of SFRC showed promising results10,13,14. However, no study has compared the fracture resistance of endodontically treated teeth reinforced with SFRC and PWF. Therefore, this in vitro study evaluated the fracture strength of endodontically treated premolars restored with these reinforcement materials and bulk-fill resin composite.

The null hypotheses of the study were that: 1) the fracture resistance of fiber-reinforced composite restorations is higher than that of the bulk fill and nano-hybrid resin composites; and 2) bulk-fill resin composites have lower fracture resistance than nano-hybrid resin composites.

MATERIALS AND METHODS

Forty-eight mandibular premolars with similar dimensions (mesiodistal: 6.4±0.5 mm, buccolingual: 7.9±0.5 mm) and single root canals were studied. Following endodontic access cavity preparation, the working length of each tooth was determined using #10 K-files (Kendo, VDW, Munich, Germany) and all teeth were instrumented using ProTaper rotary files (Dentsply Maillefer, Ballaigues, Switzerland) up to size...
Table 1—The materials used in coronal restorations and their compositions

<table>
<thead>
<tr>
<th>Materials</th>
<th>Type</th>
<th>Manufacturer</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scotch Bond Universal Etchant</td>
<td>35% Phosphoric acid</td>
<td>3M ESPE, St. Paul, MN, USA</td>
<td>Water, Phosphoric acid, Synthetic amorphous silica, Polyethylene glycol, Aluminum oxide</td>
</tr>
<tr>
<td>Filtek Z550</td>
<td>Nano-hybrid resin composite</td>
<td>3M ESPE, St. Paul, MN, USA</td>
<td>Matrix: Bis-GMA, UDMA, Bis-EMA, TEGMA and PEGDMA; Fillers: Surface-modified zirconia/silica fillers 3,000 nm (3 μm or less), non-agglomerated/non-aggregated surface-modified silica particles 20 nm</td>
</tr>
<tr>
<td>Ribbond Polyethylene woven fiber</td>
<td>Ribbond Inc., Seattle, WA, USA</td>
<td></td>
<td>Ultra-high molecular weight polyethylene, Homopolymer H-(CH2-CH2)n-H</td>
</tr>
<tr>
<td>EverX Posterior Short fiber-reinforced resin composite</td>
<td>GC Europe, Leuven, Belgium</td>
<td></td>
<td>Bis-GMA, Triethyleneglycol dimethacrylate, Silicon dioxide, Barium glass, Glass fiber, Polymethylmethacrylate Trace Photo initiator</td>
</tr>
<tr>
<td>Filtek Bulk Fill Bulk-fill resin composite</td>
<td>3M ESPE, St. Paul, MN, USA</td>
<td></td>
<td>Matrix: Bis-GMA, UDMA, Bis-EMA, Procrylat resins; Fillers: Zirconia/silica, ytterbium trifluoride</td>
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During preparation, the root canals were irrigated with 2 mL of 2.5% sodium hypochlorite between each file. After completing the instrumentation, 5 mL of 5% EDTA, 5 mL of 2.5% NaOCl, and distilled water were used for the final irrigation and all teeth were obturated with gutta-percha and AH Plus sealer (Dentsply De Trey, Konstanz, Germany) using the single-cone technique.

Following the root canal treatments, standard mesio-occluso-distal (MOD) cavities (buccal wall thickness 2.5 mm, lingual wall thickness 2.5 mm, height 4.0 mm) were prepared. Then, the specimens were assigned randomly into four groups (n=12 each) according to the restoration techniques. The materials used in the coronal restorations are listed in Table 1. Selective enamel etching was used for all of the specimens in all four groups. The enamel margins of the cavities were etched with 35% phosphoric acid (Scotch Bond Etchant, 3M ESPE, St. Paul, MN, USA) for 15 s, rinsed, and dried. Then, a one-step self-etching bonding system (Single Bond Universal, 3M ESPE) was applied to the cavities, according to the manufacturer’s instructions. Initially, the missing mesial and distal walls were restored with 1-mm-thick nano-hybrid resin composite (Filtek Z550, 3M ESPE) using the Tofflemire matrix system (KerrHawe, Bioggio, Switzerland) and polymerized for 20 s using a light-emitting diode (LED) curing lamp (Elipar FreeLight S10, 3M ESPE) at a minimum intensity of 1,200 mW/cm². Then, the cavities were restored as follows:

Group 1: Nano-hybrid resin composite was placed in four increments (max 2-mm thickness) and each increment was light-cured for 10 s.

Group 2: PWF was cut so that the buccal and lingual walls would be covered with 2 mm of fiber from the cavity floor and wetted with wetting resin (Ribbond wetting resin, Ribbond). The PWF had been kept in the dark for 5 min before the restoration procedures. After applying a flowable resin composite (FRC) (Ribbond securing composite, Ribbond) to the cavity floor, the fiber piece was placed in a buccolingual direction to be in close contact with the buccal and lingual walls and was cured for 20 s. After applying a thin layer of FRC, a second layer of fiber was placed on the uncured FRC perpendicular to the first layer, covering the mesial and distal walls to 2 mm, and was cured for 20 s. The rest of the cavity was restored in four increments of max 2-mm thickness using the same nano-hybrid resin composite as in Group 1 (Fig. 1).

Group 3: SFRC was placed using the bulk-fill technique and cured for 40 s. The thickness of the material was limited to 3 mm; and the remaining occlusal part was restored using the nano-hybrid resin composite (Fig. 2).

Group 4: Bulk-fill resin composite (Filtek™ Bulk Fill Flowable, 3M ESPE) resin composite was placed in bulk to 3 mm and polymerized for 20 s. The nano-hybrid resin composite was used to fill the remaining part of the cavity, as in Group 3.

After finishing the restorations with Sof-Lex discs (3M ESPE), all of the root surfaces of all of the teeth were covered with a thin layer of stretch film and embedded in a stainless steel mould filled with auto-polymerizing acrylic resin (Meliodent, Heraeus Kulzer, Hanau, Germany).
Germany) to a level of 1 mm apical to the cemento-enamel junction. During this procedure, care was taken to keep the long axis of the tooth parallel to that of the mould. After setting the acrylic resin, the teeth were extruded from the moulds and the stretch film was removed from the resin blocks. Then, light body silicone (Xantopren, Heraeus Kulzer) was injected into the resin blocks and the teeth were placed in their previous sockets to mimic periodontal ligament. All specimens were subjected to 10,000 cycles of thermal cycling between 5°C and 55°C using a dwell time of 30 s after being stored in distilled water at 37°C for 48 h. Finally, the specimens were placed in a universal testing machine (Autograph AG-5 kNG, Shimadzu, Tokyo, Japan) for the axial compression test. The compression load was applied with a modified steel ball at a speed of 1 mm per min on the occlusal surface of the restoration and in contact with the cusps being parallel to the long axis of the tooth until fracture occurred. The load resulting in tooth fracture was recorded. The fractured specimens were then removed from acrylic resin and assessed for fracture patterns according to the description of Fokkinga et al.¹⁵)

Repairable fractures above the level of simulated bone were defined as “Favourable failures”, whereas unrepairable fractures below this line were defined as “Unfavourable failures”. Statistical analysis for fracture load was performed using analysis of variance (ANOVA) and Tukey’s test (α=0.05). Differences between the failure modes of each group were analyzed by using Chi-square test (α=0.05).

**RESULTS**

The mean fracture resistances and standard deviations of the four test groups are presented in Table 2. The greatest fracture strength was observed in teeth restored with PWF (Group 2), followed by the teeth restored with SFRC (Group 3), although the difference was not significant (p>0.05). The results obtained in the fiber-reinforced groups were significantly higher than for the nano-hybrid and bulk-fill resin composites (Groups 1 and 4) (p<0.05). Although the bulk-fill resin composite had the lowest fracture resistance in the study, the results were not significantly different from nano-hybrid resin composite (p>0.05).

When the failure modes were evaluated, it was observed that the number of specimens that exhibited favorable failures were higher than the number of

<table>
<thead>
<tr>
<th>Groups</th>
<th>Restoration type</th>
<th>n</th>
<th>Mean (Std) (N)</th>
<th>Min</th>
<th>Max</th>
<th>Unfavorable/ Favorable failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Nano-hybrid resin composite</td>
<td>12</td>
<td>823.35⁺(34.05)</td>
<td>762.16</td>
<td>865.90</td>
<td>6/6⁺</td>
</tr>
<tr>
<td>Group 2</td>
<td>PWF+Nano-hybrid resin composite</td>
<td>12</td>
<td>919.86⁺(47.67)</td>
<td>804.69</td>
<td>991.56</td>
<td>1/11⁺</td>
</tr>
<tr>
<td>Group 3</td>
<td>SFRC+Nano-hybrid resin composite</td>
<td>12</td>
<td>889.43⁺(72.87)</td>
<td>843.14</td>
<td>935.73</td>
<td>3/9⁺</td>
</tr>
<tr>
<td>Group 4</td>
<td>Bulk-fill resin composite+Nano-hybrid resin composite</td>
<td>12</td>
<td>817.10⁺(60.82)</td>
<td>778.45</td>
<td>855.74</td>
<td>7/5⁺</td>
</tr>
</tbody>
</table>

Same letters within one column indicate statistically similar values (p>0.05).
unfavorable failures in fiber-reinforced groups (Table 2). Especially the restorations reinforced with PWF exhibited the lowest incidence of unfavorable failure modes compared to the nano-hybrid ($p=0.025$) and bulk-fill resin composite ($p=0.009$) groups. No significant difference was found in failure modes among the other groups ($p>0.05$).

**DISCUSSION**

It is generally agreed that the successful treatment of teeth treated endodontically depends not only on good endodontic therapy but also on good coronal restoration after the endodontic therapy is completed. The final coronal restoration is the last step of the treatment procedure, which not only aims to restore the tooth, but also to strengthen the tooth structure. When the tooth crown is damaged by caries or fractures, and endodontic treatment is needed, the remaining tooth structure is weakened further by preparing the access cavity and endodontic treatment. The amount of the structure left after cavity preparation is the main factor determining the fracture strength of the tooth. Many studies of the fracture resistance of endodontically treated teeth with MOD cavities show that the fracture resistance is reduced after preparing large cavities. Therefore, in this study MOD cavities were prepared to determine the strengthening effects of resin composites in a worst-case scenario.

Recently, a variety of materials have been developed to enhance the mechanical properties of structurally weakened teeth. Increasing demand for good appearance has extended the range of possible aesthetic restorations for teeth with large, deep cavities. Although indirect restorations are considered reliable options for the restoration of teeth treated endodontically, on-going developments in direct resin composites with improved mechanical properties empower their use, even in stress-bearing areas. There are various material options for direct composite restorations that can strengthen teeth, while maintaining aesthetics. Bulk-fill and fiber-reinforced composites are two contemporary materials, which have low shrinkage and tooth-strengthening effects. Therefore, this study included only bulk-fill composite and two fiber-reinforced composites with different compositions. The lack of literature on newly introduced fiber-reinforced composites was another reason that we selected these materials. The literature contains many studies of PWF, but few of SFRC.

Many studies emphasize the importance of mimicking periodontal ligament. During sample preparation, a space should be left around the roots for the duplication of periodontal ligament. An elastomeric material should be used to simulate how periodontal ligaments distribute the load of the occlusal forces to the alveolar bone evenly. If rigid materials were used, this would affect the fracture modes of the failures due to the distorted loads. In this study, the roots were coated with polyvinyl siloxane to simulate periodontal ligament.

In this study, the fracture resistance of the fiber-reinforced groups was higher than that of the bulk-fill and conventional resin composites. There was a significant increase in the strength of the teeth that were restored with the fiber-reinforcement technique. Therefore, the first null hypothesis of the study was accepted. These data concur with those of Bell et al. and Ayad et al., who pointed out the strengthening effect of fibers. Sengun et al. recommended using fiber-reinforced composite restorations rather than conventional composite restorations, although the difference between the two groups was not significant. Comparing the fracture resistance of PWF and SFRC, the fracture resistance of PWF was higher, but not significantly so. Although the compositions of the materials and their application methods are different, they both strengthened endodontically treated teeth remarkably. Due to its multi-step application, PWF is more technique-sensitive and involves a complex procedure than SFRC. The PWF fibers must be impregnated with wetting resin before being inserted in the flowable resin composite and then applied in two layers perpendicular to each other. It is thought that the leno design enhances impregnation of the wetting resin and therefore improves the chemical bonding of the fiber with flowable resin composing a unique united structure. One study claimed that the lock-stitch property transferred the forces thorough the weave without stress propagation into the resin. We used two layers of woven fibers perpendicular to each other when preparing the samples. Therefore, the higher fracture resistance of the samples in this group could also be related to this double-layer insertion technique.

SFRC, the other fiber-reinforced composite studied, was introduced recently as a novel direct restorative material for posterior teeth with enhanced mechanical properties. Although there is little research on SFRC, Fräter et al. investigated the fracture strength of SFRC using different layering techniques and concluded that there was a clear tendency towards higher fracture resistance with the oblique layering technique only. In our study, SFRC was inserted using the bulk technique and a significant improvement in fracture resistance was obtained compared to the nano-hybrid and bulk-fill composites. The results might have been better if a layering technique was used; however, the bulk-filling technique was used to eliminate the positive effects of the layering technique on fracture strength. SFRC has short fibers that are responsible for the improved mechanical properties of the composite. In this study, 3 mm of SFRC were used under the final 1-mm layer of nano-hybrid composite. It is possible that this layer served as a stress bearing barrier, with its short fibers working as a “crack stopper”, as stated by Garoushi et al."

In addition to discussing the positive effects of fibers, it should also be emphasized that the bulk-fill composite did not give any strengthening effect to conventional composites significantly. Conversely, the fracture strength results were lower. Although the bulk-fill resin composite had the lowest fracture resistance in the study, the results were not significantly different
from nano-hybrid resin composite \((p>0.05)\). Therefore, the second null hypothesis was rejected.

The present study also analyzed the failure modes of each test group. Assessments showed that specimens restored with nano-hybrid and bulk-fill composites were more prone to unrepairable fractures with fracture line below the bone level. In addition, although there was no statistically significant difference between the results of SFRC, nano-hybrid and bulk-fill groups; fiber-reinforcement had a positive influence on the level of fracture due to proportion of the number of repairable restorations to unrepairable ones. Both PWF and SFRC had higher number of repairable restorations than unrepairable ones which means that they could provide protection against unfavorable fractures.

**CONCLUSIONS**

Based on the results of this in vitro study, the following conclusions were reached:

- Fiber reinforcement increased the fracture strength of teeth with large MOD cavities treated endodontically when compared to bulk-fill and nano-hybrid resin composites.
- The bulk-fill resin composite had fracture strengths similar to the nano-hybrid resin composite.
- Bulk-fill resin composite can be used reliably for the coronal restoration of teeth with large cavities treated endodontically.

These conclusions are valid only for the materials used in this study.

**REFERENCES**