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ORIGINAL RESEARCH

Effect of fibre-reinforced composite on the fracture resistance of endodontically treated teeth

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Abstract

The aim of this study is to evaluate the fracture resistance of root-filled teeth restored with fibre-reinforced composite (everX posterior). Fifty mandibular molars were divided into five groups ($n = 10$). Group 1: no treatment was applied (intact teeth). Group 2–5: canals were prepared and root filled. Group 2: no coronal restoration was placed. Group 3: teeth were coronally restored with composite. Group 4: composite restorations were performed following polyethylene fibre insertion at the cavity base. Group 5: composite resin placed over everX posterior. After thermocycling (5–55°C, 5000×), fracture resistance was measured. Mean force load for each sample was recorded in Newtons (N). Results were statistically analysed with one-way analysis of variance and post hoc Tukey's tests. The mean force required to fracture samples and standard deviations are as follows: group 1: 2859.5 ± 551.27 N, group 2: 318.97 ± 108.67 N, group 3: 1489.5 ± 505.04 N, group 4: 1958.3 ± 362.94 N, group 5: 2550.7 ± 586.1 N. everX posterior (group 5) was higher than groups 2, 3 and 4 ($P < 0.05$). There were no significant differences between everX posterior and intact teeth ($P > 0.05$). Placing fibre-reinforced composite under composite increased the fracture strength of root-filled teeth to the level of intact teeth.

Introduction

Fracture of endodontically treated teeth is primarily a result of loss of tooth structure. Particularly, large cavity design with the combination of access cavity may result in additional weakening (1,2). Because teeth are subjected to chewing forces, occlusal habits and temperature changes (3,4) unless coronal restorations complementary to root canal therapy are performed well, unsupported dental tissues may lead to fractures that require periodontal surgery and even extraction (5).

Several techniques and materials have been developed for the restoration of endodontically treated teeth including complete cast coverage, composite resins and amalgam and indirect cast restorations covering cusps (2,6,7). Resin-based materials provide rigidity and increase the fracture resistance of non-vital teeth by reinforcing unsupported tissues (8). Advanced adhesive systems with improved physical properties are more aesthetic and support remaining tooth structures better than amalgam (2,9). Polymerisation shrinkage during composite placement may result in microleakage (10). In order to reduce shrinkage stresses, flowable resins with low elastic modulus have been suggested as a stress-absorbing layer under composite restorations (10,11). However, because the use of flowable resin does not increase fracture resistance, and this layer results in contraction stresses (12), Belli *et al.* (13) placed a Leno Weave Ultra High Modulus (LWUHM) polyethylene fibre ribbon in the bed of flowable resin to strengthen tooth structure. Ribbond has a very high molecular weight (14). These fibres have a very high modulus of elasticity resulting in resistance to stretch and distortion. Furthermore, their closed-stitch structure provides very high resistance to traction (15).

everX posterior (GC Corporation, Tokyo, Japan) is a new fibre-reinforced composite designed to be used as dentin replacement. The manufacturer claims that everX posterior's short-fibre structure reinforces restorations in large cavities by avoiding crack formation through the filling, which is considered to be the main cause of composite failures.

There have been previous studies about polyethylene fibre (13,16,17), but everX posterior is a new material whose capacity to reinforce the coronal structure of root-filled teeth has not yet been studied. The aim of this study is to compare the fracture resistance of teeth that have been endodontically treated and restored with conventional composite restorations, composite restorations placed over LWUHM polyethylene fibre ribbon and composite restoration placed over fibre-reinforced composite – everX posterior.

Materials and methods

The study used 50 intact, human mandibular molars of similar dimensions, which were extracted for periodontal reasons and free of caries, restorations, abrasions and fractures. Any calculus and soft-tissue remnants were removed with scalers. The teeth were kept in physiological saline at +4°C until they were used. All samples were randomly divided into five groups each including 10 teeth. The teeth in each group were prepared as follows.

Group 1

No endodontic or restorative intervention was applied to the teeth in this group (positive control group).

Groups 2–5

Access cavities were prepared with high-speed diamond burs (Medin, Nove Mesto na Morave, Czech Republic) under water cooling allowing an easy inlet to the root canals. A size 15 K-file (Sybron Endo, Scafati, Italy) was inserted through the canal until the file tip was visible at the apex. Working length was determined to be 1 mm beyond this point. Root canal preparation was conducted until apical enlargement reached size 35. Preparation continued by step-back technique, 1 mm withdrawn after each file until size 60. Coronal enlargement was further achieved with Gates–Glidden burs (Thomas, Bourges, France). After each file, canals were rinsed with 2 mL of NaOCl. At the end of preparation, canals were dried with absorbent paper points (Dentplus, Choonchong, Korea). Root canal obturation was performed with lateral condensation of gutta-percha (Dentplus) and AD seal (Meta-Biomed, Cheongwon, Korea). Excessive gutta-percha was removed with a hot instrument at the level of canal orifices (Gutta Cut®, VDW GmbH, München, Germany). Cavities of all samples were modified to Mesial-occlusal-distal (MOD) configuration until obtaining a thickness of 2 mm at the buccal occlusal wall, 2.5 mm at the buccal cemento-enamel junction (CEJ), 1.5 mm at the lingual occlusal surface and 1.5 mm at the lingual CEJ. These thicknesses were measured with a digital calliper (Aydal, Istanbul, Turkey) from cavity floor to outer surface or from occlusal end of cavity to outer surface. Roots of all samples were embedded in cylinders filled to the level of the CEJ with self-curing polymethylmethacrylate. Pulp chambers were filled with resin-modified glass-ionomer cement (GC Fuji II LC Capsule, GC Corporation). Coronal restorations were completed as follows.

Group 2

No further restoration or temporary filling was applied (Fig. 1a) (negative control group).

Group 3

After applying self-etching bonding agent (Clearfil SE, Kuraray Noritake Dental Inc., Tokyo, Japan) for 20 s, it was gently dried and light cured for 10 s. Cavities were restored with composite resin (G–ænial posterior, GC Corporation) with incremental technique by placing 2 mm of resin in each turn (Fig. 1b). To provide standardisation, the light source was applied just over the cusp tips and after every 10 samples, the power of the light source was checked with a dental radiometer (Demetron, Kerr, Orange, CA, USA) to avoid the light source device declining in intensity to less than 1000 mW/cm^2.

Group 4

Polyethylene fibre ribbons with length of 8 mm and width of 3 mm were prepared, embedded in bond (Clearfil SE, Kuraray Noritake Dental Inc., Tokyo, Japan) and kept in a dark place. After the cavities were bonded as in group 3, cavity surfaces were coated with 1 mm thickness of flowable resin (Competence Flow, WP, Bevern, Germany). Before curing, excessive bond was removed from ribbons and they were placed in the flowable resin (Fig. 1c) and light cured for 20 s. Composite restoration was completed as in group 3.

Group 5

Bonding procedures were carried out as described earlier. Walls of 2 mm thickness were constructed of composite resin (G–ænial posterior, GC Corporation) on the mesial and distal sites according to the manufacturer's

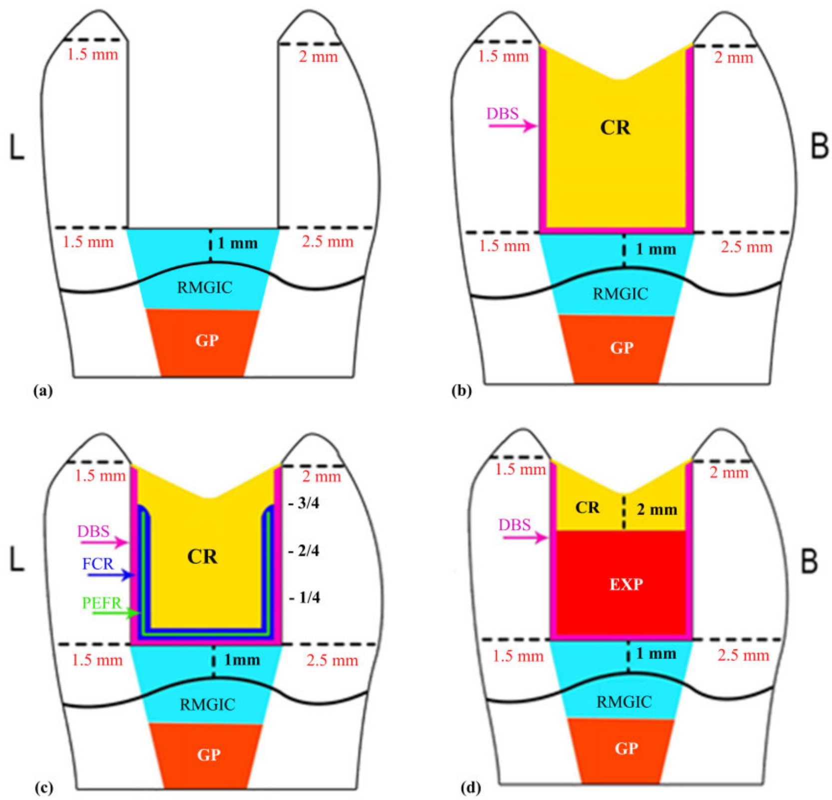

Figure 1 Schematic representation of the teeth. (a) Not coronally restored after endodontic treatment, (b) coronally restored with composite resin following dentin bonding system application, (c) coronally restored with composite resin following dentin bonding system application and polyethylene placement at the cavity base, (d) coronally restored with composite resin following dentin bonding system application and everX posterior. B, buccal; CR, composite resin; DBS, dentin bonding system; EXP, everX posterior; FCR, flowable composite resin; GP, gutta-percha; L, lingual; PEFR, polyethylene fibre ribbon; RMGIC, resin-modified glass-ionomer cement.

instructions. Remaining occlusal cavities were first filled with everX posterior using its special applicator, leaving 2 mm for placement of final composite resin and then light cured for 20 s. Finally, coronal restoration was completed with composite resin, as in the other groups (Fig. 1d).

After finishing and polishing, all specimens were thermocycled for 5000 cycles between 5 and 55°C using a dwell time of 30 s in each bath. Then, all specimens were placed in a Universal Testing Machine (AGS-X, Shimadzu, Kyoto, Japan). A round-shaped tip made of steel with a diameter of 5 mm was mounted to the testing machine in contact with three points including restoration surface, buccal and lingual walls of the teeth. Force parallel to the long axis of each tooth at a crosshead speed of 1 mm/min was applied to the samples. Force necessary to fracture each tooth was recorded in Newtons (N). Sample size was determined as 10 teeth for each group according to the power analysis ($\alpha = 0.05$, $1\text{-}\beta = 0.80$). The data were statistically analysed with one-way analysis of variance and post hoc Tukey's tests. (SPSS Inc. Chicago, IL, USA) 22 for Windows was used for statistical analysis. The level of significance was set to 5% ($P < 0.05$).

Results

Table 1 shows the mean fracture resistance (N) and the standard deviation for each group. Results show that fracture resistance of the intact teeth and everX posterior groups were significantly higher than that of the other groups ($P < 0.05$). There were no significant differences between intact teeth and the everX posterior group. Teeth restored with resin composite (group 3) and those restored with polyethylene fibre and resin composite (group 4) showed increased fracture strength compared with the non-restored group (group 2) ($P < 0.05$). However, those teeth that had polyethylene fibre ribbon placed under composite resin restorations (group 4) were not significantly strengthened compared with teeth that had composite restoration alone (group 3) ($P > 0.05$).

Table 1 Mean fracture resistances and standard deviations of five experimental groups

Group	Restoration type	Fracture resistance (*n*)	SD
Group 1	Intact teeth	2859.5[b]	551.27
Group 2	Not coronally restored	318.97[a]	108.67
Group 3	Composite restoration	1489.5[c]	505.04
Group 4	Ribbond and composite restoration	1958.3[c]	362.94
Group 5	everX posterior and composite restoration	2550.7[b]	586.1

Mean values identified with the same superscript letters are not statistically different ($P < 0.05$). SD, standard deviation.

Discussion

Cuspal and vertical fractures are undesired sequels of root canal treatment. In their study investigating the extraction reasons of root-filled teeth, Toure *et al*. (18) found that the percentages of the teeth extracted because of vertical root fracture and non-restorable cuspal and crown fractures were 13.4% and 15.1%, respectively, whereas Vire (19) found an incidence of 13% for vertical fractures. Chen *et al*. (20) found this percentage to be 28.1%. These differences may originate from the type of tooth used for the studies. Mandibular molars are more prone to vertical fractures (21) and most likely to be extracted (18). For this reason, mandibular molars were included in the present study.

Remaining dental tissue is an important factor affecting the resistance of root-filled teeth. Particularly, if the marginal integrity is disturbed and/or large cavities exist, fracture resistance is significantly reduced (22). Tang *et al*. (23) found that MOD cavities are more prone to cuspal fractures than MO/DO cavities. Reeh *et al*. (2) corroborated their findings. Steel and Johnson (5) found no significant difference between the fracture resistance of unaltered teeth and of teeth with standard access cavities. In the present study, MOD cavities were prepared in order to decrease fracture resistance as much as possible and to better evaluate the reinforcement abilities of the materials. For the restoration of MOD cavities, techniques and materials mentioned earlier including direct and indirect restorations covering cusps such as overlay restorations may also be beneficial in terms of fracture resistance. However, the present study aimed to determine restoration techniques avoiding fractures with minimal tissue loss and appointment time (for indirect restorations).

Final restoration of root-filled teeth is very important, as it prevents microleakage and reinforces the teeth against fractures. Selecting appropriate material for coronal restoration to compensate for the loss of dental hard tissues is crucial to successful treatment (17). Conventional methods for restoring endodontically treated teeth include post and core restorations, cast coverage, cast inlays, indirect cast restorations covering cusps and amalgam restorations with or without cuspal coverage (2,7,24). However, with advances in adhesive technology, conventional materials are being replaced by resin-based materials (9).

Because of their adhesive properties, composite restorations that are bonded directly to dentin reinforce the stiffness of dental hard tissues, especially in large cavities (17). They also decrease flexion by binding cusps (25). However, there is no consensus about final coronal restoration of endodontically treated, posterior teeth (17,26). Despite studies suggesting that composite restorations support tooth structures better than amalgam (2,9), Steele and Johnson (5) concluded that there is no significant difference between them. Furthermore, polymerisation shrinkage is a consequence of composite resins (27) and flowable composite resins have been widely used as an elastic intermediate layer to reduce shrinkage stresses (28). However, Cadenaro *et al*. (29) found that flowable composites do not significantly reduce polymerisation stresses and flowable composites risk debonding at the adhesive interface.

Because of these vulnerabilities of composite resins, further modifications would seem to be necessary to improve the quality of resin-based materials used for final restoration of endodontically treated teeth. One of these modifications was studied by Belli *et al*. (13,16) who evaluated the use of LWUHM polyethylene fibre ribbon embedded in a thin layer of flowable composite beneath composite restorations. The study concluded that this technique increases the resistance of endodontically treated teeth with large cavities. The researchers used a polyethylene fibre with high modulus of elasticity and low flexural modulus to distribute stresses along the restoration tooth interface, hypothesising that the fibre network (17) would increase fracture resistance of endodontically treated teeth. Because this material is manufactured using cold gas plasma, its adhesion to synthetic materials, such as composite resins, is high (17). It can be applied as a piece of ribbon and cured with bond and flowable composite. In this way, its structure of braided fibres is protected even after cutting. However, in the present study, polyethylene fibre insertion under composite restorations did not result in a significant increase in fracture resistance compared with applying composite restoration alone. This situation may be due to the use of thermocycling procedure in the present study different from Belli *et al*. (13,16). Eakle (30) stated that strengthening capability of bonded resins decreases after a period of thermocycling. Thermal and mechanical cycling processes lead to better simulation of aging as intraoral conditions result (31).

everX posterior is a light-cured and radio-opaque fibre-reinforced composite. This material is made of randomly oriented short E-glass and inorganic particulate fillers in combination with a semi-interpenetrating polymer network matrix that consists in a compound of bis-GMA, TEGDMA and PMMA (32). The manufacturer claims that if covered with a layer of universal restorative composite, this material's short-fibre structure results in a degree of toughness that is equivalent to dentin. Furthermore, it shrinks minimally and by this way prevents fracture occurrence. Thus, the present study compared selected techniques with this contemporary material as an alternative restorative technique. The present study found that placing everX posterior under composite restorations provided strength very similar to that of intact teeth and superior to that of the composite alone and ribbon and composite groups.

Researchers have recommended incremental technique to reduce polymerisation shrinkage stresses and cuspal deflection (33,34). The incremental layering technique yields better shrinkage results compared with the bulk technique because the degree of cure increases and the amount of cavity bonded decreases at each level in the incremental technique (10). Contrary to Belli *et al.* (13,16) and in accordance with Sengun *et al.* (17), in this study, the incremental layering technique was applied to avoid increased polymerisation shrinkage and achieve a better comparison.

In vitro testing of fracture resistance is non-physiological (5) because intraoral forces caused by occlusal forces differ in magnitude, speed and direction from those simulated by testing machines (35). Further *in vivo* investigations may be beneficial to better identify the advantages and disadvantages of final restorations associated with root-filled teeth.

Composite resins are compatible materials for coronal restoration of endodontically treated teeth. Placing a piece of polyethylene fibre ribbon increases fracture resistance but not significantly different from that in teeth restored with composite resin alone. everX posterior is a contemporary fibre-reinforced composite that reinforces teeth better than other materials. Also, it has ease of use compared with LWUHM polyethylene fibre ribbon because as mentioned earlier, polyethylene fibres can be applied following several stages that constitute an undesired time-consuming situation for clinicians. Particularly, during clinical *in vivo* applications, placing polyethylene fibre at the cavity base may be more challenging compared with everX posterior. Furthermore, it is obvious that using polyethylene fibre ribbon necessitates a proper clinical evaluation before deciding on its use. Although molar teeth were included in the present study, other types of teeth with smaller dimensions may not be suitable for fibre placement and using everX posterior for these teeth may be easier. However, mechanical behaviours of both materials must be further evaluated before deciding on their daily use. More *in vivo* and *in vitro* investigations are needed to identify the mechanical properties of these contemporary materials.

Conclusion

Within the limitations of the present study, using everX posterior under composite restorations resulted in fracture resistance similar to that of intact teeth. Furthermore, it reinforced root-filled teeth more than composite alone and ribbon and composite restorations.

Conflict of interest

The authors deny any conflict of interest or financial support for the present study.

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