Fracture Resistance of Endodontically Treated Premolars Restored with Flowable Short Fibre-Reinforced Resin Composite–An *In Vitro* Study

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ABSTRACT

Objective: This *in vitro* study aimed to evaluate the fracture resistance of endodontically treated premolar teeth restored with flowable short fibre-reinforced resin composite (FSFRRC) at varying depths within the root canals.

Methods: Fifty freshly extracted human single-rooted premolars were divided into 5 Groups (n=10), Group I (IN) intact teeth, Group II (P) restored coronally with resin composite only, Group III, IV and V (FSFRRC2, FSFRRC4, FSFRRC6) based on post space preparation to the respective depths of 2, 4 and 6 mm. Root canal treatment was performed for all the samples of Group II, III, IV, V and the teeth were decoronated 2 mm above cementoenamel junction. Following decoronation, post space preparation was done to the depths of 2, 4, and 6 mm (Group III, IV, V). Teeth were restored with FSFRRC (Groups III-V) intra-radicularly and coronally sealed using resin composite. All the teeth were subjected to fracture strength test using Universal testing machine, and mode of failure was analysed. Kruskal-Wallis test followed by Dunn Post-hoc test was conducted for statistical analysis. Statistical significance was set at P<0.05.

Results: All FSFRRC groups showed higher fracture resistance than teeth restored only with resin composite. FSFRRC4 and FSFRRC6 showed significantly (P<0.05) higher fracture resistance than intact teeth and other experimental groups.

Conclusion: Intra-radicular placement of FSFRRC increased the fractured resistance significantly and may serve as a promising alternative to conventional post systems to rehabilitate endodontically treated teeth.

Keywords: Endodontically-treated teeth, E-glass microfibers, flowable short fibre reinforced resin composite, fracture strength, intra-radicular reinforcement

HIGHLIGHTS

- A new approach for reinforcing endodontically treated teeth (ETT) with flowable short fibre-reinforced resin composite (FSFRRC).
- FSFRRC increased the fractured resistance of ETT while compared to intact teeth.
- No catastrophic failures were noted with FSFRRC at depths of 4 and 6 mm intra-radicularly.
- FSFRRC reinforces the endodontically treated teeth when placed intra-radicularly.

INTRODUCTION

Following root canal treatment procedures, adequate coronal restorations are essential to prevent bacterial leakage through the root canal obturation. However, a defective coronal seal allows ingress of microorganisms, increasing the incidence of apical periodontitis, as evidenced by several *in vivo* studies (1). Further, the post space preparation and the choice of post may influence further microleakage (2, 3). These procedures may be a potential cause for the failure of root canal-treated teeth (2). It has been suggested that an appropriate bacteria-tight coronal plug would improve the outcome of the root canal treated teeth (2). Ray and Trope substantiated the relationship between the reduction in apical periodontitis when a suitable coronal plug was used (4). Apart from preventing bacterial ingress, a definitive coronal plug should also reinforce the remaining tooth structure, which plays a significant role in determining the longevity of the endodontically treated teeth (5-7). There are numerous fibre types with different architecture and composition to support and reinforce the remaining tooth structure of an endodontically treated teeth (ETT) (8). An alternative conservative approach to restore these teeth is with the use of adhesive restoration as an extended coro-

nal plug in place of custom-made posts and cores. Short fibre resin composites have proven to reinforce the tooth by dissipating the stresses and increasing the fracture resistance of the remaining tooth structure (9, 10). Adhesive concepts utilising fibre reinforcement has categorised resin composite (11, 12). Fibre-reinforced composite (FRC) attributes to increased fracture resistance and flexural modulus of the restored tooth and acts as stress reliever by resisting crack propagation (11). The mechanical properties of FRC posts are influenced by the type and architecture of the fibres, the ratio of fibre to resin matrix and the quality of impregnation of fibre and resin (13). Although clinical prospective and retrospective studies on fibre posts have yielded encouraging results. Few studies have reported with a less favourable results (14). This could be due to the magnitude of the shrinkage and the accompanying stress through polymerisation leading to poor marginal adaptation and post-operative pain (7, 8). Adhesion failure at the post-cement-root dentine interface transforms the post into a wedge, an important predisposing factor for root-dentine fracture (15, 16). Hence an ideal material satisfying the required properties and capable of creating a homogenous stress distribution that can decrease the incidence of root fracture is required.

From a biomimetic perspective, lost tooth tissue must be replaced by a biomaterial with similar physical properties to the tooth (17, 18). Recently a new formulation of flowable short fibre-reinforced resin composite (FSFRRC) (everX Flow, GC Corp, Tokyo, Japan) with thixotropic viscosity and a high ratio of microfillers was launched as a restorative material (19). This resin composite is intended to be used in high stress-bearing regions, especially in grossly decayed vital and nonvital posterior teeth, as a dentine replacement material (20). These FSFRRCs, composed of randomly oriented glass microfibre fillers, with barium glass and silanated E-glass fibres, have been reported to possess fibre architecture like that of the collagen network in dentine (20). Although categorised as 'flow', this material is thixotropic enough to prevent slumping due to the presence of short fibres, thereby enabling better adaptation and handling (20).

Although many studies have reported using FSFRRC as a restorative material in stress-bearing areas, to the best of our knowledge, there are no studies to date in the literature evaluating its effect when used as an extended coronal plug into the root canals of ETT. Hence, this *in vitro* study aimed to evaluate the fracture resistance of endodontically treated premolar teeth restored with FSFRRC at various depths in the root canals. The null hypothesis was that there would be no difference in the fracture resistance of ETT restored with and without FSFRRC.

MATERIALS AND METHODS

Sample selection
Fifty freshly extracted human single-rooted, intact, non-carious, unrestored premolars were used with approximately similar root lengths. The collection of teeth was approved by the IRB(SRMU/M&HS/SRMDC/2020/PG/008). The teeth were extracted as part of consented treatment plan from patients who required tooth removal for varied other reasons. The teeth were examined under 25× magnification (Labomed Prima

DNT, Fremont, CA, USA), and those teeth with root caries, fractures, microfractures, cracks and root resorption were rejected. The remaining samples were cleaned and stored in 0.1% thymol solution at 37°C until use.

Sample preparation
The roots of all the teeth were covered with aluminium foil of 0.2 mm thickness, coated with petroleum jelly, which was then replaced by polyvinylsiloxane material (Virtual Extra Light Body; Ivoclar Vivadent AG, Schaan, Liechtenstein) to simulate the periodontal ligament. They were then mounted vertically in autopolymerising acrylic resin blocks until approximately 1.5 mm apical to the cementoenamel junction (CEJ). Of the 50 teeth, 40 teeth were root canal treated. Standard access cavities were prepared, and after working length determination, the canals were cleaned and shaped sequentially using stainless steel K-files #10 to 25 (Mani, Tochigi, Japan) followed by rotary nickel-titanium alloy instruments (ProTaper Gold, Dentsply Sirona, Ballaigues, Switzerland). All the canals were prepared upto ProTaper Gold F3 (ISO 30) size according to manufacturer's instructions using a single length system. The canals were copiously irrigated with 2 ml of 5.25% sodium hypochlorite between instrumentation. All teeth were obturated using calibrated gutta-percha points ProTaper Gold Gutta-Percha Points F3 (Dentsply Sirona, Ballaigues, Switzerland) and resin sealer [AH Plus; (Dentsply De Trey GmbH, Konstanz, Germany)] using the single cone obturation technique. The gutta-percha (GP) was sheared off till the level of CEJ using a heated finger plugger (Dentsply Maillefer, Ballaigues, Switzerland), and the coronal portion was temporarily sealed with Cavit G (3M ESPE, St Paul, MN, USA). The sample teeth were stored in distilled water at 37 C for 24 hours, followed by 100% relative humidity up to 14 days for allowing the sealers to set. After that, the teeth were decoronated 3 mm coronal to the most occlusal point of the CEJ. The teeth were examined again under dental operating microscope (Labomed Prima DNT, Fremont, CA, USA) under 25× magnification to exclude any cracks or fractures arising from this procedure.

Allocation to experimental groups
Each group had 10 teeth each. Group I served as negative control in which no procedure was done (IN). The 40 teeth which underwent root canal treatment were randomly divided into 4 groups. Following removal of the temporary seal, they were subjected to various treatment protocols. Group II served as positive control and received only coronal restoration with resin composite (P). Groups FSFRRC2, FSFRRC4, FSFRRC6 served as experimental groups and were subjected to post space preparation to varying respective depths of 2, 4 and 6 mm into the root canal. Following the preparation, root canals were restored with short fibre-reinforced flowable composite (FSFRRC) to the desired depth and up to 2 mm coronal to CEJ (FSFRRC2, FSFRRC4, FSFRRC6). Subsequently, remaining coronal portion (1 mm) of the teeth was restored with resin composite and light-cured for 20 seconds.

Treatment procedures
GP was removed from the root canals with heated instruments and gates glidden drills and peeso reamers (Dentsply Maillefer, Ballaigues, Switzerland) until size #3 based on varying depths in

the experimental groups (2, 4 and 6 mm from the level of CEJ). The prepared canals were irrigated with distilled water with every subsequent use of the drills. The excess moisture was removed using paper points. The presence of any residual GP on the walls of post space was evaluated by radiographic imaging.

Restorative Procedures with FSFRRC

After post space preparation, dentine was etched with 37% phosphoric acid gel for 10-15 seconds and was then rinsed with distilled water for 5 seconds and dried using paper points. Application of dual-cure bonding agent (ExciTE F DSC, Ivoclar Vivadent, Schaan, Liechtenstein) on the dentine and agitated for 10 seconds followed by pre-curing for 10 seconds (Bluephase NM; 800 mW/cm^2 Ivoclar Vivadent AG, Schaan, Liechtenstein). FSFRRC (everX Flow, Bulk Shade, GC Corp, Tokyo, Japan; Lot no.1901211) was then injected into the prepared post space using syringe tips provided by manufacturer to the desired depth and was light-cured according to manufacturer instructions. For FSFRRC2, the material was injected into post space and 2 mm coronal to CEJ and light-cured. For FSFRRC4 and 6, an initial increment to a depth of 4 mm was placed into the post space and light-cured. The remaining length of the post space in FSFRRC6 and 2 mm coronal to CEJ for both the groups were again filled with FSFRRC and light-cured. Subsequently, the remaining coronal portion (1 mm) of all groups were restored with posterior resin composite (Filtek P60; 3M ESPE, St Paul, MN, USA) and light-cured. Schematic representation of the restorative procedure is depicted in Figure 1. During the experiment, all samples were stored at 37°C in 100% relative humidity in a thermostatically controlled incubator (BBD 6220, Thermo Fisher Scientific, Waltham, MA, US) until it was subjected to mechanical testing.

Fracture resistance test

A metal jig was designed and fabricated to evaluate fracture resistance of the samples. The compressive force at a crosshead speed of 1 mm/min was applied to the sample at 45˚ to long axis of the tooth using Universal Testing Machine (Instron, Norwood, MA, USA), as depicted in Figure 2. The force necessary to fracture each tooth was recorded in Newtons. All specimens were observed for fracture, and the mode of failure was analysed under a microscope (Labomed Prima DNT, Fremont, CA, USA) with 25× magnification. The roots were then removed and inspected for the type of fracture; cohesive or adhesive and mixed type.

Statistical analysis

The data was tabulated and analysed using GraphPad Instat version 3.01(GraphPad Software, CA, USA). A Kruskal-Wallis test was conducted, with statistical significance set at P<0.05. A Dunn Post-hoc test to determine the difference between groups. Post hoc power achieved was 0.99.

RESULTS

Table 1 represents the mean load value (in Newtons). Statistical analysis revealed that teeth restored with FSFRRC4 (690.1 N) and FSFRRC6 (626.3 N) had higher fracture resistance than the other experimental and the control groups. FSFRRC4 presented significantly the highest fracture resistance among all
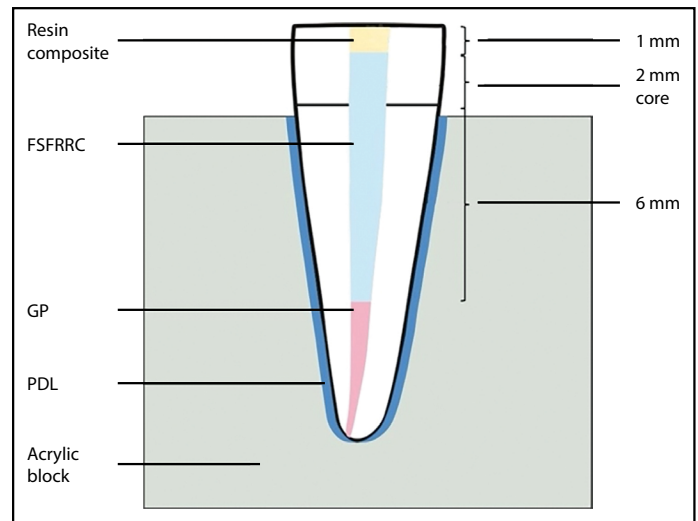

Figure 1. Schematic drawing of an endodontically treated tooth restored with FSFRRC and resin composite

FSFRRC: Flowable short fibre reinforced resin composite, GP: Gutta-percha, PDL: Periodontal ligament
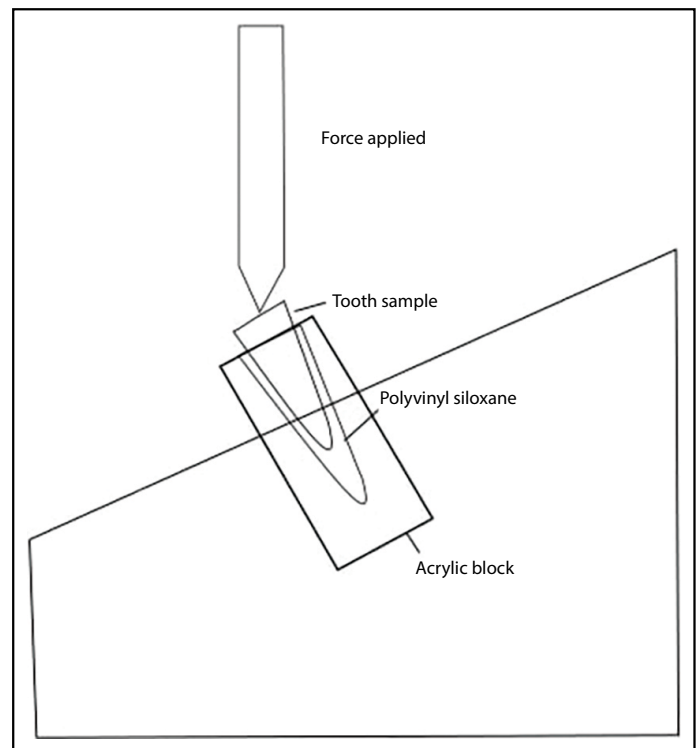

Figure 2. Schematic representation describing the position of the tooth and the tip used in the head of the testing machine

the groups (P<0.05). Among the experimental groups, FSFRRC2 had significantly lower fracture resistance(P<0.05). The positive control group has statistically significant lower fracture resistance than the other groups (P<0.05). Least fracture resistance was observed in positive control compared to all the groups (P<0.05). Figure 3 describes the mean fracture resistance of all groups by box and whisker plot. Figure 4 depicts adhesive, cohesive and mixed types of fractures. Predominantly cohesive (n=23), followed by mixed (n=15) and adhesive (n=12) types of fractures, were observed in all the groups. Furthermore, in

TABLE 1. Mean fracture load values (in Newtons) of the control and experimental group

Groups	n	Mean±SD (n)
I- IN	10	619.94±39.31[ab]
II- P	10	440.50±34.87[bc]
III- FSFRRC2	10	469.94±48.96[b]
IV- FSFRRC4	10	690.06±29.05[a]
V- FSFRRC6	10	626.30±42.42[a]

Different alphabet in superscript indicates significant difference between the groups (P<0.05). IN: Intact teeth, P: Only coronal restoration, FSFRRC2,4,6: Flowable short fibre reinforced resin composite restored intra-radically at varying depths

FSFRRC4, more cohesive fractures were seen than adhesive fractures, whereas, mixed type of fractures was seen in FSFRRC2.

DISCUSSION

Conventional methods of restoring ETT using a post require additional radicular dentine removal to receive a prefabricated post, affecting the fracture resistance of such teeth (21). Hence, our study evaluated using a FSFRRC in place of a post at varying depths within the root canal.

This study showed that positive control group with coronal restoration only had least fracture resistance compared to the intact teeth. This is because resin composite does not provide adequate resistance to the tendency to separate the cusps, especially premolars, where the anatomical shape of these teeth predisposes to cuspal separation (11). However, it may be argued that this cannot be taken as a reason for the results of our study since the teeth were decoronated 3 mm above the CEJ, which was done to standardize the length of the post space preparation and restorative dimensions for all the groups.

The teeth of all groups restored with FSFRRC to varying depths of the root canal showed increased resistance to fracture as compared to positive group, with FSFRRC4 and FSFRRC6 exceeding the toughness of intact teeth. This could be attributed to the change in its chemical composition, substituting Bis-GMA with its ethoxylated version Bis-EMA, which demonstrates an improved degree of conversion and mechanical properties (22, 23). However, FSFRRC2 showed higher values than group P, though statistically insignificant.

Effective stress transfer from polymer to fibre and vice versa depends on its critical fibre length (lcrit), aspect ratio (Ar) (ratio of fibre length to fibre diameter) and orientation in which it is embedded in the resin matrix (18, 24-26). These play an important role in terms of isotropicity-anisotropicity of the material. The optimal lcrit and Ar should be 50 times the diameter of fibre and in the range of 30-94, respectively (18). According to the findings of Lassila et al. (18) and Shouha et al. (27), incorporation of fillers in the form of microfibres ranging from 200-300 in length formed an acceptable fibre network without affecting the flowability of material. Furthermore, the randomly arranged microfibres in FSFRRC are optimised to decrease the stress intensity of a crack by deflecting, resisting, and bridging crack propagation, consequently eliciting closure force on the
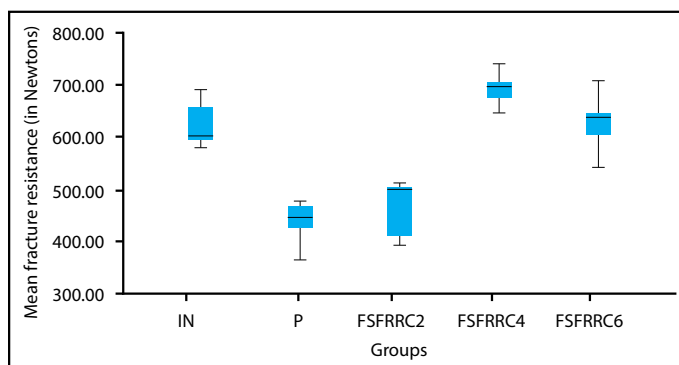

Figure 3. Box and whisker plot of the mean fracture resistance values of all groups

Dark horizontal bar in each box signifies the median(Q2-50th Percentile) fracture resistance of the group. The Lowest point and highest point in each box represented as whiskers with a Q1(25th Percentile) and Q2(75th Percentile) as standard deviation(SD) above and below of the data distribution. IN: Intact teeth, P: Only coronal restoration, FSFRRC2,4,6: Flowable short fibre reinforced resin composite restored intra-radically at varying depths
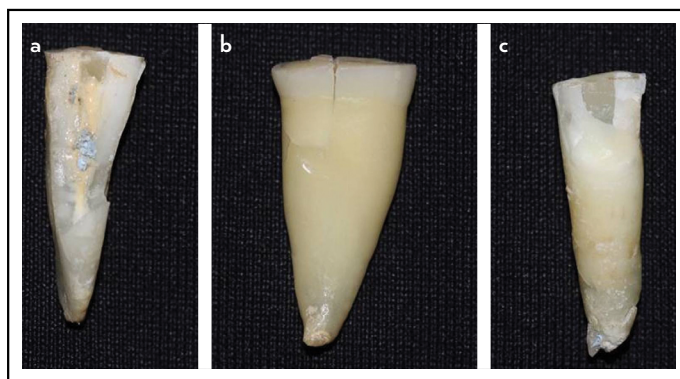

Figure 4. Image showing the fracture patterns after fracture testing of the specimens. (a) Unrestorable fracture (group P). (b, c) Cohesive fractures (FSFRRC4 & FSFRRC6)

FSFRRC: Flowable short fibre reinforced resin composite

crack (18, 28). In addition, the flow property and thixotropism of FSFRRC were advantageous during placement of material into the root canal space.

Interestingly, it has been reported that FSFRRC can be cured to a depth of 5-6.7 mm in contrast to various other resins due to the relatively well-aligned microfibres, allowing scattering of light into deeper areas (26, 29). Furthermore, in our study, FSFRRC6 showed comparable fracture toughness like that of an intact tooth, showing that intra-radicular reinforcement with FSFRRC can be used instead of a post, thus eliminating more removal of radicular dentine instead of post space preparation. However, in the present study, post space was prepared to ensure uniformity in its dimensions.

The maximum fracture resistance among all the groups was found with FSFRRC4. This was found to be statistically higher than the intact group. Numerous factors may contribute to this result, not excluding lesser removal of radicular dentine, length and random orientation of the microfibres, and depth of cure achieved at that level. The randomly oriented micro-E-glass fi-

bres, which are exceptionally well wetted with flowable resin, form a matrix of microstructural semi IPN (Interpenetrating Network) structure and play a vital role by acting as crack stoppers (26, 30). In addition, Barcellos et al. (16) stated that the depth of placement of fibre posts need not be long enough (longer than the depth of the clinical crown, as proposed for post) to increase root fracture resistance. It may especially be beneficial in restoring the root canals of teeth with short roots and a high degree of curvature. Thus, intra-radicular reinforcement with FSFRRC up to 4mm depth seems sufficient to resist fracture.

Hence the null hypothesis was rejected since FSFRRC has a positive influence on the fracture resistance of ETT. Furthermore, since there is a direct correlation between the level of teeth fractures and material's reinforcement effect, the resultant fracture patterns were also evaluated. Most of the specimens in FSFRRC4 and FSFRRC6 exhibited a cohesive failure along with multiple cracks on the remaining tooth structure indicative of absence of a catastrophic failure. On the other hand, groups P and FSFRRC2 specimens exhibited brittle fractures extending to middle third of the root, indicative of an unrestorable fracture.

Based on the results of this study, FSFRRC could be an ideal biomimetic dentine replacement material for ETT. It can be recommended to be used as a suitable intra-radicular reinforcement material in endodontically weakened teeth replacing the existing post systems. Simulation of complex dynamics of oral conditions is of paramount importance for the clinical translation of *in vitro* studies. The application of a continuously increasing load gives an insight on the basic understanding of fracture behaviour and load-bearing capacity of dental materials test. However, this could lead to overestimating the results, as failures in clinical situations occur more due to fatigue. Considering that this is a new approach, further *in vitro* and *in vivo* evaluations are required to consider ageing, enzymatic challenges, microleakage and thermocycling to give more valuable information before extrapolating these results to a clinical scenario.

CONCLUSION
Within the limitations of this *in vitro* study, FSFRRC increased the fracture resistance of endodontically treated teeth when placed to a depth of 4 mm into the root canals, thus providing an alternative technique to post-placement.

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