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FRACTURE RESISTANCE OF ROOT CANAL TREATED TEETH RESTORED WITH DIFFERENT TYPES OF FIBER REINFORCED RESIN COMPOSITE RESTORATIONS: AN IN-VITRO STUDY

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ABSTRACT

Aim: This study aimed to compare the fracture resistance of root canal treated (RCT) teeth restored with different types of resin composite restorations.

Methods: A total of 40 freshly extracted human intact mature permanent maxillary premolars were selected and randomly assigned into 4 groups (n = 10 each); the EXF group in which teeth were RCT and restored with a fiber-reinforced bulk-fill flowable composite (Ever-X flow) and covered with a nanofilled resin composite (Filtek Z 350), the RBF group in which teeth restored with polyethelene fibers (Ribbond) with a bulk-fill flowable composite (Filtek bulk-fill flow) covered with the same nanofilled composite, the FBF group in which teeth restored with a bulk-fill flowable composite without fiber reinforcement (Filtek bulk-fill flow) also covered with the same nanofilled composite and the control group in which teeth remained intact without any preparation. All teeth were subjected to a thermo-mechanical cycling after which a static fracture test was performed using the universal testing machine to record the load at failure.

Results: The significantly higher mean value of fracture resistance was recorded in the control group than other experimental groups ($P < .05$). The EXF group showed the highest and followed by RBF group, and the lowest mean value was found in FBF group ($P < .05$).

Conclusion: Within the limitation of the present study, either short fiber-reinforced composite and polyethylene fiber-reinforced composite may have superior resistance to fracture and could reinforce RCT teeth compared to nanofilled composite without fiber reinforcement.

KEYWORDS: Fiber reinforced; resin composite; root canal treated teeth; fracture resistance.

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INTRODUCTION

It is well known that, when compared to healthy teeth, root canal treated (RCT) teeth have altered biomechanical qualities.[1,2] A long-term restoration on RCT teeth should be able to preserve and protect the residual tooth structure in addition to having an adequate retention (CPR principle.[3,4] In restorative dentistry, the appropriate restorative therapies of RCT teeth remain a major challenge.

During post-endodontic restoration, it's crucial to use the right material that can withstand fracture while restoring RCT teeth. These structurally and chemically weakened teeth could be strengthened with the invention and improvements of dentin bonding techniques and the enhanced strength of the newer fiber-reinforced composite materials.[5]

Recently, fiber-reinforced composite (FRC) was introduced. It is a substance that has impact on polymerization shrinkage, improves the composite's physical attributes, and may even serve as a crack-suppressing mechanism.[6] The fiber type, orientation relative to the load, position within the restoration, volume, and impregnation of the fiber to the resin matrix all affect the mechanical properties and reinforcing capability of FRC used in dentistry. Bulk-fill flowable resin composites are employed with conventional composites for aesthetic restorations in posterior teeth because they offer less polymerization shrinkage, flowability for simple placement, greater marginal adaptation, and decreased microleakage. Additionally, they have a low elastic modulus, which might lessen the tension placed on the cavity walls. Therefore, giving structure support to the weakened teeth.[7]

For the direct restoration of structurally challenged teeth that demand for the use of a significant volume of composite, chair-side integration of ultra-high molecular-weight polyethylene fiber (UHMWPE) into resin composite has attracted new attention. In addition to providing reinforcement, the reinforced polyethylene fiber is intended to reduce material shrinkage during setting. A composite resin matrix including polyethylene fiber has been shown to enhance gingival marginal adaptation in class II cavities in prior research.[8] Due to accessibility issues and curing light restrictions, the gingival seat in class II cavity designs is particularly vulnerable to marginal leakage.[9]

The choice of a material as a restoration material is influenced by its mechanical qualities. A material's resistance to cracks that propagate as a result of pressure on the restored tooth area is determined by its fracture resistance, which is a mechanical property. Because it establishes the maximum strength and pressure that a restorative material can withstand before suffering damage, fracture resistance is one of the accepted and advised tests for determining how fragile a material is.[10] Reduction of fracture resistance of RCT teeth can caused by caries, erosion, trauma, in addition to non-conservative endodontic access cavity preparation and removal of the roof of pulp chamber resulting in more fragile teeth.[11,12] Coronal restorations that support the remaining tooth structure, replace the stiffness of the tooth, and lessen coronal micro-leaks are essential to the success of endodontic treatment.[13,14]

Therefore, the aim of this study was to evaluate the fracture resistance of RCT teeth restored with different types of fiber reinforced resin composite restorations. The null hypothesis was that there would be no differences between different types of FRC restorations in terms of strengthening the RCT teeth (increasing the fracture resistance of RCT teeth).

MATERIALS AND METHODS

Ethical regulation

This study was approved by the Ethics Committee of Faculty of Dentistry, Minia University, Egypt (Meeting no. 88 & Decision no. 621). The information of the materials used for teeth restorations with different methods presented in Table 1.

TABLE (2) The specification, composition, manufacturer, and lot number of the materials used in this study:

Material	Specifications	Composition	Manufacturer & lot number.
Ever X flow	Short Fiber reinforced bulk-fill flowable resin composite	Resin matrix: contains Bis-MEPP, TEGDMA and UDMA. Inorganic filler particles: E-glass fibers and barium glass. Average length of fibers 140μm diameter 6 μm. Filler content: 70 wt %	GC 1309111
Ribbond	Polyethylene fibres	Leno Weave Ultra High Modulus polyethylene fibre ribbon.	Ribbond 9560
Filtek Z 350	Light cured nanofilled resin composite	Resin matrix: Bis-GMA, Bis EMA, UDMA, TEGDMA. Inorganic filler particles: Zirconia/silica, Non agglomerated/ non-aggregated 20 nanometer surface-modified silica particles. Filler content: 82 wt %	3M N600679
Filtek bulk-fill flow	Light cured bulk-fill flowable resin composite	Bis-GMA, Bis EMA, UDMA, TEGDMA, Ethyle 4 dimethayle amino benzoate, substituted dimethaacrylate, silane treated ceramics, Ytterbium fluoride.	3M 4862A1
GC Fuji II LC	Light-cured resin-modified glass ionomer	Liquid: water, polyacrylic acid, HEMA Powder: fluoroaluminosilicate glass, polyacrylic acid	GC 276480

Teeth selection

A total of 40 freshly extracted human intact mature permanent maxillary premolars exhibiting a buccolingual dimension of 9.5 (± 0.5) mm and a mesiodistal dimension of 7.5 (± 0.5) mm. Teeth dimensions were measured using a digital calliper (Vernier, Sichuan, China) with an accuracy of 0.01 mm. The teeth were collected from the outpatient clinic of Minia University Dental Hospital which were extracted for orthodontic reasons. The teeth were cleaned from soft and hard tissues attachments and immersed in sodium hypochlorite solution for 30 min. The teeth were washed under running water and immersed in 0.1% thymol solution (Formula e Acao, Sao Paulo, Brazil) till the time of use.

Sample size calculation

A pilot study was conducted on three teeth in each group and results of the pilot study was used for sample size calculation. Based upon the results of the pilot study; the effect size (f) for repeated measures analysis of variance (ANOVA) design was 0.6. Using alpha (α) level of 5% and Beta (β) level of 20%, i.e. power = 80%; The total sample size was forty teeth (n = 40). Sample size calculation was performed using G* Power software ver. 3.1.9.2 (G*Power, University of Kiel, Kiel, Germany).

Teeth mounting

Two half split Teflon mold with dimensions of 30 mm diameter and 25 mm height was used in the study. The mold was filled with a self-curing resin, each tooth was then immersed in the acrylic resin until the level of cemento-enamel junction (CEJ) was reached. A dental surveyor (Ney Dental Surveyor, Anaheim, CA, USA) was used to mount each tooth to ensure that it was centralized and aligned perfectly parallel to the long axis of the tooth.

Endodontic procedures

Access cavity A conventional access cavity was prepared in 30 premolars by a round diamond bur (Dentsply, Maillefer, Switzerland) and the cavity walls were refined by using a safe-ended tapered carbide fissure bur to establish a straight line access to the root canal (Fig. 1A, B).

Chemo-mechanical preparation: Patency was ensured by using a manual stainless-steel (SS) K-file ISO size #10 (MANI, Tochigi, Japan). Occlusal reduction was performed to standardize the tooth length for all the samples. All root canals were scouted by using a manual SS K-file ISO size #10 till it became visible at the major apical foramen, then 1 mm was subtracted from the measurement to determine the working length. Glide path was established by using a manual SS K-file ISO size #10 and 15. Canals were instrumented by using an endomotor (WISMY endomotor, Bomedent, China) with ProTaper NEXT system (Dentsply Sirona, Ballaigues, Switzerland) according to manufacturer's instructions in the following sequence: X1, X2, X3 and X4. Root canals were irrigated using 5.25% sodium hypochlorite (NaOCl) during root canal preparation. NaOCl was delivered using a 30-gauge side-vented closed end irrigation needle (Shanghai Fanta Dental Materials, Shanghai, China) and accomplished by an alternate use of NaOCl and 17% EDTA solution (Ethylene di-amine tetra-acetic acid; Prevest DenPro Limited, Jammu & Kashmir, India) with an intermediate rinse using saline.

Obturation: Root canals were obturated after drying with paper points (DiaDent, Cheongju, Korea). As directed by the manufacturer, the root canal sealer (ADseal, Metabiomed, Cheongju, Korea) was blended. The root canals were filled with gutta-percha (GP) master cones (40/.02) and accessory GP cones by using the cold lateral compaction technique. Obturation was evaluated radiographically, and the pulp chambersealed with a resin modified glass ionomer (Fuji II LC; GC, Tokyo, Japan).

Cavity preparation

Using a carbide bur (#245 Straight Round End Fissure; Kerr, Kloten, Switzerland), operated in a high speed handpiece (Sirona, Erlangen, Germany), mesioocclusodistal (MOD) cavities were prepared down to the level of canal orifice maintaining the following thickness of the walls, based on previous research by Garlapati et al., [15] : Buccal wall at the occlusal surface was 2 mm, while, at the CEJ, it was 2.5 mm. Lingual wall at the occlusal surface was 1.5 mm, and at the CEJ, it was 1.5 mm. [15,16] The widths of the remaining wall thickness were measured using a digital calliper (Fig. 1).

Grouping of the specimens

The prepared 40 premolars were classified into four groups (n = 10 for each) according to the different restorations as follow: the EXF group (Fig. 1E) was restored with a fiber-reinforced bulk-fill flowable composite (Ever- X flow; GC) and covered with a nanofilled resin composite (Filtek Z 350; 3M, St. Paul, MN, USA), the RBF group (Fig. 1F) was restored with polyethelene fibers (Ribbond; Seattle, USA) with a bulk-fill flowable composite (Filtek bulk-fill flow) covered with the same nanofilled composite, and the FBF group (Fig. 1G) was restored with a bulk-fill flowable composite (Filtek bulk-fill flow) without fiber reinforcement also covered with the same nanofilled composite Filtek Z 350. The remaining ten premolars remained intact without any preparation, served as control group.

Post endodontic restorative procedures

For all the 30 prepared premolars, the enamel cavity walls were etched by a Scotchbond Universal Etchant (3M) applied for 15 seconds then rinsed off with water for 15 seconds before gently air drying. The bonding agent (Single Bond Universal; 3M) was then evenly applied to the cavity walls using a micro brush (3M™ XS Applicator Brushes; 3M) and rubbed for 20 seconds before being gently dried with oil-free air to evaporate solvents, followed by light curing for 20 seconds with a light emitting diode curing unit (3M Elipar Deep Cure-S LED Curing Light; 3M).

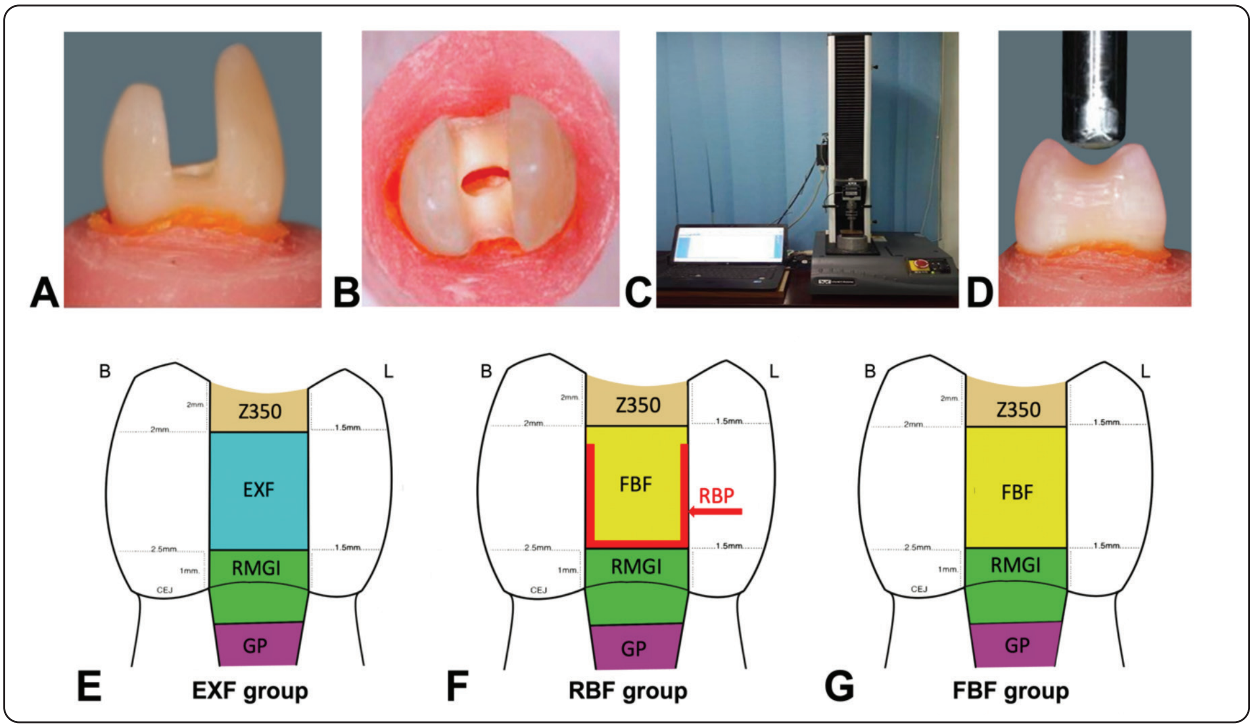

Fig. (1) Materials and methods with group desigations of defferent restoration methods in this study. (A, B) Proximal and occlusal aspects of conventional access cavity. (C) Universal testing machine used in this study to make compressive load. (D) The compressive load was applied to the center of the occlusal surface by a stainless-steel ball (3.6 mm in diameter). (B: buccal, L: lingual, Z350: Filtek Z 350, EXF: Ever- X flow, RMGI: resin modified glass ionomer (Fuji II LC), GP: Gutta-Percha, RBP: polyethelene fibers (Ribbond), FBF: Filtek bulk-fill flow).

In EXF group, fiber reinforced bulk-fill flowable composite (Ever-X flow) was applied to fill most of the cavity and light cured for 20 sec leaving only 2 mm for the final nanofilled composite filling (Filtek Z 350) to overfill the cavity in order to develop correct mesiodistal and occlusal contours.

For RBF group, the cavity surfaces were etched and bonded as described in EXF group, polyethylene fiber (Ribbond) was cut by to a length of 10 mm and a width of 3 mm, and embedded in the universal bond and excess adhesive was removed from the fiber surface using a dry hand instrument towards the direction of the fibers. A 1 mm layer of flowable composite (Filtek bulk-fill flow) was applied to the cavity surfaces, then the fiber was inserted inside the cavity and adapted over the pulpal floor, buccal and lingual walls and light cured for 20 sec. Another layer of Filtek bulk-fill flow was applied to fill the cavity leaving 2 mm. for Filtek Z 350 composite as in EXF group.

For FBF group, the cavity surfaces were etched and bonded, then Filtek bulk-fill flow composite was applied to fill most of the cavity without any fibers addition, leaving 2 mm for Filtek Z 350 composite as in EXF and RBF groups.

Finishing and polishing for all specimens was done using TOR VM Finishing and Polishing Kit (TOR VM, Moscow, Russia) and stored in distilled water at 37 °C for 24h.

Cyclic Loading fatigue

The mechanical aging test was performed using a four-station multi-modal ROBOTA chewing simulator (ACTA Fatigue tester, Amsterdam, Netherlands) with a thermo-cyclic protocol and servomotor control (Model Ach-09075dc-T, Ad-Tech Technology, Berlin, Germany). The simultaneous movements of vertical and horizontal directions under thermodynamic conditions was simulated with ROBOTA. Each chamber is composed of a lower plastic sample holder where the specimen can be implanted and an upper hardened steel stylus holder that can be fastened with a screw to be used as antagonistic materials. A weight of 5 kg was used, which was equivalent to 49 N of the chewing force. Chewing simulation was applied with the following parameters: 3 mm of rising / vertical movement, 1 mm of horizontal movement, 90 mm/s of rising / forward speed, 40 mm/s of descending / backward speed, and 1.6 Hz of cycle frequency. To simulate 6 months of intraoral aging, the specimens were subjected to 75,000 cycles with 600 thermal cycles (5˚/55˚C, dwell time 25 seconds). [17]

Fracture resistance measurement (static fracture test)

Static fracture test was accomplished using the universal testing machine (Instron model 3345; Instron, Norwood, MA, USA). The roots were wrapped with a stretch film and embedded vertically in a self-curing acrylic resin (Acrostone Dental Manufactuer, Egypt) up to 2 mm apical to the CEJ. To ensure the vertical alignment of the long axis of the roots, a protractor was employed. After the setting of the acrylic resin, the roots and stretch film were removed. A light-body silicone (Elite HD; Zhermack SpA, Badia Polesine, Italy) was placed into the roots cavity to simulate periodontal ligament, and the roots were reinserted. A #12 scalpel blade was used to remove any excess impression material. The mounted roots of each group were fixed into the lower jaw of the universal testing machine (Fig. 1C). Then, a compressive load was applied to the center of the occlusal surface by a stainless-steel ball (3.6 mm in diameter) with the cross-head speed of 1 mm/min parallel to the long axis of the root till fracture (Fig. 1D). An audible crack that was associated with the load at failure was confirmed by a significant fall in the load-deflection curve as estimated by computer software (Bluehill Lite Software Instron Instruments). The force required to fracture was recorded in Newtons.

Statistical analysis

The mean and standard deviation values were calculated for each group in each test. Data were explored for normality using Kolmogorov Smirnov and Shapiro-Wilk test, data showed parametric normal distribution. One-way ANOVA test was used to compare all groups, followed by Duncan's post hoc test for pair-wise comparison between the mean values with IBM SPSS Statistics (ver. 20 for windows). The significant level was set at 95%.

RESULTS

Table 2. The fracture resistance (N) for the different groups (mean ± standard deviation)

EXF group	RBF group	FBF group	Control group
957.73 ± 69.12 ^{B}	794.35 ± 54.87 ^{C}	612.64 ± 94.23 ^{D}	1110.41 ± 85.39 ^{A}

^{A,B,C,D}; Significant difference was shown by means with different capital letters in the same row ($P < .05$). EXF group: restored with a fiber-reinforced bulk-fill flowable composite (Ever- X flow) and covered with a nanofilled resin composite. RBF group: restored with polyethelene fibers (Ribbond) with a bulk-fill flowable composite (Filtek bulk-fill flow) covered with the same nanofilled composite. FBF group: restored with a bulk-fill flowable composite (Filtek bulk-fill flow) without fiber reinforcement also covered with the same nanofilled composite.

The control group without any preparation showed significantly higher fracture resistance (N) than other tested groups with different methods of restoration ($P < .05$).

Among the tested groups, the EXF group restored with a fiber-reinforced bulk-fill flowable composite (Ever-X flow) and covered with a nanofilled resin showed significantly higher fracture resistance and followed by RBF group and FBF group ($P < .05$).

DISCUSSION

The As the structural strength of dentin tissue depends on the integrity and quality of its anatomic structure, it is crucial to protect the sound dentin tissue that holds and supports the restoration in cavity preparations. [18] The key element affecting a tooth ability to resist fracture is how much sound dentin is left over after cavity preparation. [19] Large cavity preparations and/or teeth with severe tissue loss have both been linked to a significant reduction in fracture strength. Due to extensive tooth structural loss during MOD cavity preparation and root canal therapy, the tooth's fracture strength is decreased. [11,20]

Because the MOD cavity design with a long cusp in maxillary premolars exhibits considerable cuspal deflections, teeth that had undergone endodontic treatment and a significant MOD preparation were chosen for this study because it acting as the worst-case scenario. [21]

It is well recognised that the outcome of endodontic therapy is influenced by the quality of the coronal restoration. [22] Additionally, residual dental tissue needs to be strengthened in order to support the cavity with restorative materials.[23] Adhesive restorations are better to disperse functional loads across the tooth and restorative material and have the ability to sustain the fragile dental structur. [24] The composite restorations that adhere directly to dentin increase the durability of unsupported tooth structures.[25] However, in complex direct composite restorations, polymerization shrinkage plays a significant role in the debonding of the restorative material. This can be avoided by employing a flowable resin with a low viscosity that serves as a stress breaker.[26] Direct composite restoration, however, might not perform at its best in large access preparations.[27]

As a result of these vulnerabilities of resin composite, additional modifications would appear to be required to improve the durability of resin-based materials used for the final restoration of root canal treated teeth. [11,14] As the insertion of fibers, which are increasingly employed for the reinforcing of resin-based dental materials, is an alternate way for enhancing the fracture strength of root canal filled teeth, it seemed to be valuable to assess the fracture resistance of root canal treated and restored with different types of fiber-reinforced resin composite restorations.

Short fiber-reinforced composite (FRC) was introduced to the market to imitate the stress-absorbing qualities of dentine. The short FRC material is designed to be utilised as a bulk base for both vital and non-vital tooth restoration in high stress areas.[28] Compared to other bulk-fill materials, it has a higher fracture resistance and flexural modulus, but it may be applied readily in increments of 4 mm and may be able to match dentin's fracture resistance.[29,30]

Because of the link between polymerization shrinkage and restoration weakening, bulk-fill flow composites can lessen polymerization shrinkage in posterior teeth [24], bulk-fill flow composite was selected in this study. As a result of their low elastic modulus, which functions as a flexible layer and may reduce cavity stresses during polymerization. This explains why the bulk-fill flow composite could assist in improving the fracture resistance of teeth with MOD cavity preparations. [31]

We used a biomimetic composite structure, a restoration that combines FRC and particle filler composite, as an alternative bi-layered approach (PFC), the FRC substructure supported the composite restoration and acted as a layer to avoid cracks, according to numerous investigations. [32] In order to support the remaining tooth structure and to increase the longevity of the final biomimetic composite restoration, short FRC was developed as a dentine-replacing substance (bulk base). [32]

Two types of fiber reinforcement were used in this study, the first one was FRC material called Ever X flow, which was primarily filled with short E-glass fibers. These fibers have the ability to control polymerization shrinkage and microleakage due to the orientation of their fibres. [33] Another crucial role for this short fiber composite is to support the surface particle filler composite layer to stop cracks from spreading, in addition to dispersing the stresses. [33,34]

The second one was Ribbond which was a polyethylene longitudinal fiber. This polyethylene fiber has a unique pattern of cross-linked, locked-stitched threads that improve the fiber's stability, strength, and durability. These fibers are preimpregnated, silanized, and plasma-treated, have the ability to adjust stress when a high amount of load is given to the tooth structure by absorbing and dispersing the pressures to the tooth. [21] The monoblock formed between dentin and the restorative material makes this possible. [25] Under a composite restoration, adding Ribboned polyethylene fiber to the flowable composite substrate strengthens the tooth by raising its elastic modulus and preventing fracture. [15]

The results of this study showed that the highest mean value of fracture resistance was recorded in the control group, followed by the value of EXF group and RBF group with a significant difference found between both groups. The lowest mean value found in FBF group with a statistically significant difference between the four tested groups ($P < .05$). So, the null hypothesis was rejected.

These findings were similar to that found by Garlapati et al.[15] and Ashly et al.[35] as they found that there was a significant difference between fracture resistance of teeth restored by FRC and other types of resin composite with the highest resistance value was recorded in intact teeth group, followed by teeth restored with short FRC. They also explained that samples restored with composite resin showed lower resistance to fracture because of more shrinkage stresses leading to marginal break down and gaps, which is very minimal in FRCs. [17]

The results from presnet study were contradictory to those by Ataly et al. [36] and Hakan et al. [37] The former study concluded that there was insignificant difference between the fracture resistance of teeth restored with a conventional nanohybrid resin composite and that restored by either bulk-fill/flowable bulk-fill or fiber-reinforced resin restorative. While the latter study found that there were no significant differences between the fracture resistance of the different groups restored with fiber-reinforced and other tested resin composite. This distinction could be explained by the significant diversity in sample preparation. [36]

CONCLUSION

Within the limitation of this study, it can be concluded that either short FRC and polyethylene FRC showed superior fracture resistance and can reinforce RCT teeth compared to nanofilled composite without fiber reinforcement.

RECOMMENDATIONS

It is recommended that short FRC restorations be tested in a variety of clinical settings, such as endodontically treated teeth in patients who experience high occlusal stresses, or that to be compared to traditional layered resin composite restorations or indirect restorations to assess their overall performance.

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