REVIEW ARTICLE

The Use of Fiber-Reinforced Composites for Restoration of Endodontically Treated Teeth: A Review

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ABSTRACT

This review summarized the most recently published literature pertaining to the use of fiber-reinforced composite (FRC) to restore endodontically treated teeth (ETT) and its influence on the mechanical behavior of restored teeth. In-depth¬ literature review in Google Scholar, ScienceDirect and PubMed was performed for these keywords: “fiber-reinforced composite”; “fiber post”; “endodontically treated”; “short fiber-reinforced composite”— only published full-text articles between 2009 and 2021 are included in this review. Fourteen articles were selected for this review. The studies concentrated on laboratory-based research conducted on human and bovine extracted teeth with different restorative techniques. Fatigue survival and load to failure tests with assessment of survival rate and fracture strength values respectively, as well as fracture pattern analysis were done. We concluded that FRC materials have improved fracture strength of restored teeth compared to conventional composites using different restorative techniques, however not to the attained level of an intact natural tooth. In addition, authors recommend a better simulation of oral environment, such as dynamic fatigue-testing.
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Keywords: Fiber-reinforced composite, Fiber post, Endodontically treated, Short fiber-reinforced composite

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INTRODUCTION

The restoration of endodontically treated teeth (ETT) has been a popular area of extensive research in the quest for best materials, protocols and parameters that will improve fracture resistance and prognosis of the tooth following root canal treatment, yet it remains controversial from many perspectives. Fracture of the ETT is a common issue faced in clinical practice (1). It is also observed as the most common type of failure in final restoration compared to formation of caries as demonstrated in long-term studies (2, 3). Excessive removal of coronal and radicular dentinal tissue during endodontic procedures, such as over-flaring of canals or attaining straight-line access impacts the flexural behavior and resistance to failure (4). The chemical agents used in the mechanical preparation of root canals, such as irrigants, intracanal medications and root canal filling materials will affect the collagen structure by triggering a significant effect on mechanical properties of dentin (5).

Fiber-reinforced composites (FRC) are lightweight, esthetic tooth-colored materials, cost effective and compatible with adhesives used in restorative dentistry. The use of fibers to reinforce restorative composites has been studied for years, but their effects only proven since 2003 (6), whereas the use of FRC posts first appeared in the 1990s starting with carbon fiber posts (Composipost/C-post). It is widely used and a suitable choice for restoration of ETT due to its modulus of elasticity that closely resembles natural dentin (7–9). A newly introduced FRCs consist of dimethacrylate resins and glass fibers in their composition. Many types of fibers, including glass, carbon and polyethylene have demonstrated their reinforcing effect in dental polymers. At present, glass fibers are the most widely used in clinical dentistry.

This is unquestionably attributed to their surface chemistry allowing adhesive bonding to other dental polymers. FRCs posts typically consist of a continuous phase matrix where reinforcing fibers and other inorganic fillers are embedded. All components integral to FRC assist in determining its adhesive properties. Silane coupling agents are mainly used to bond glass-based materials (10). In addition, there are many other positive features, such as high tensile strength, low cost and ability to address esthetic demands. FRC posts are available as unidirectional long continuous; either in the form of manufactured prefabricated fiber posts or individually formed customized fiber posts. In addition, discontinuous short fibers-reinforced composites (SFRC) are currently available as dental restorative composite, characterized by their ability to terminate crack propagation and improve mechanical properties (7–9, 11).

METHODOLOGY

The eligibility criteria in this review included full-text articles and peer reviewed, published in English language and dated between 2009 and 2021. The selected articles were connected to terms present in the title of this review. Unpublished articles, case reports, personal communication and background information were excluded. This review utilized scientific literature related web-based search engine, such as Google Scholar, ScienceDirect and PubMed. Keyword searches were carried out on terms, such as: fiber-reinforced composite; fiber post; endodontically treated; and short fiber-reinforced composite for review relevancy. The review process included obtaining relevant literature from the reference section of selected articles. A total of 87 titles were obtained from database search. After screening of titles, 52 articles were removed as they did not meet the scope of the review. The remaining 35 articles were further assessed for any duplicates or repetitive titles and 21 articles were excluded. Finally, 14 articles were fully reviewed and concluded for this study. The summary of data collection process is as in Figure 1.

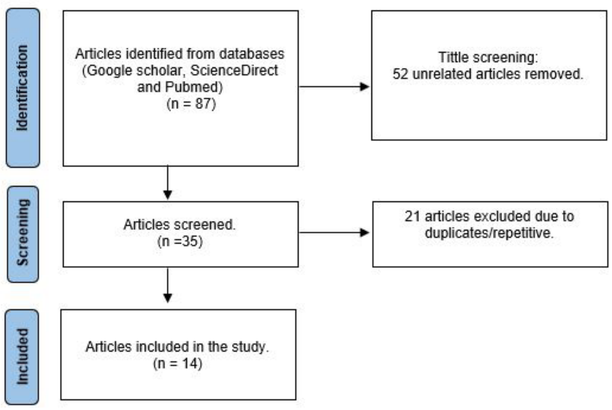

Figure 1: PRISMA flow chart on data search and articles selection

RESULTS

A total of 14 articles met the inclusion criteria for this study and were fully reviewed. From that, four articles investigated the study of FRC materials application as coronal restoration, while the remaining ten articles discussed FRC materials application to restore the radicular region. A summary of the restorative techniques and findings for coronal region and radicular region were tabulated in Table I and Table II respectively. Majority of the studies found the use of FRC materials allowed better and added positive outcomes.

Table I: The use of fiber reinforced composites for coronal restoration.

Article	Area of Study	Findings/Remarks
Garlapati et al., 2017 (12) Bijelic-donova et al., 2020 (13)	Evaluating the use of short fiber-reinforced restorative composite in endodontically treated molar teeth.	The use of SFRC as a reinforcing base and veneered with conventional direct composite resin restoration (bilayer biomimetic design) was discovered to improve the fracture resistance and tooth integrity in molar teeth with extensive cuspal damage, whether endodontically treated or not, resulting in more favorable/repairable fracture patterns.
Nicola et al., 2016 (14)	Effect of fiber-glass reinforced composite restorations on fracture resistance and failure mode of ETT	Reinforcing extensive composite restorations with ultra-high molecular weight UDMA-TEGDMA based pre-impregnated parallel glass fibers had significantly increased the fracture resistance of ETT molars compared to other restorative techniques.
Eapen et al., 2017 (15)	Fracture resistance of ETT restored with different conventional and fiber-reinforced core build-up materials	Teeth restored with SFRC showed the highest fracture resistance compared to a positive control group of non-endodontically treated natural teeth.

Abbreviations:
UDMA: Urethane dimethacrylate; TEGDMA: Triethylene glycol dimethacrylate

DISCUSSION

Figure 2 represents the summary of the use of FRC material in restoring ETT.

FRC restoration of the coronal region for ETT

Biomimetic SFRC based direct restorations

The use of SFRC material such as everX Posterior as a reinforcing base and veneered with conventional direct composite resin restoration (bilayer biomimetic design) was found to improve the fracture resistance and tooth integrity in molar teeth marred by extensive cuspal damage. Irrespective of any endodontic treatment, the fracture ceased to propagate towards cementoenamel junction and the root (12, 13). As a result, a favorable

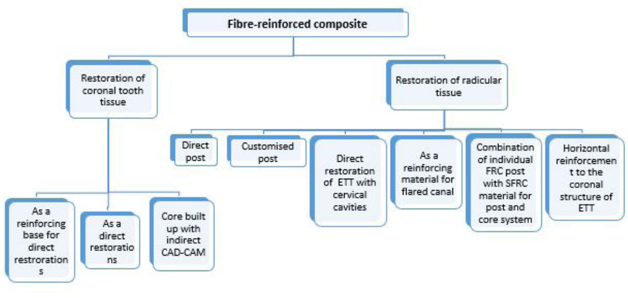

Figure 2: The use of FRC materials in restorative dentistry

Table II: The use of fiber reinforced composites for radicular restoration.

Article	Area of Study	Findings/Remarks
Wang et al., 2017 (16)	Use of a novel SGFR post with enhanced anatomical configuration.	Teeth restored with SGFR posts presented a significantly different higher values of fracture resistance and endurance limitation with cyclic fatigue loading, and more favorable fracture patterns compared to other commercially available FRC posts.
Sary S et al., 2019 (17) Barcellos et al., 2013 (18) Ferro et al., 2016 (19)	Effect of anatomical customization of FRC posts on fracture strength and failure patterns of endodontically teeth (ETT).	Samples tested on relining with composite resin presented higher fracture strength values and favorable fracture patterns. The likelihood of success and survival also increased for customized glass fiber posts compared to non-customized glass fiber posts.
Xiong et al., 2015 (20)	Use of a combined fiber sleeve with prefabricated fiber posts to restore ETT with flared root canals.	Improved interfacial adaptation and highest fracture resistance when a fiber sleeve was combined with prefabricated fiber post compared to a control group using fiber post alone.
Abduljawad et al., 2016 (21)	Use of glass and carbon fiber posts to restore endodontically treated maxillary central incisors presented with cervical cavities.	Teeth restored with fiber posts showed higher fracture resistance and more favorable fracture patterns compared to a control group and other experimental groups
Kubo et al., 2018 (22)	The effect of glass fiber posts and ribbons on fracture strength of ETT with flared root canals.	The results indicate effective reinforcement using glass fiber ribbons in composite resin post and core system which align with findings of other previously published studies.
Tangsripongkul & Jearanaiphaisarn, 2020 (23)	Use of fiber post and resin composite core to restore ETT with wedge-shaped cervical lesions.	Teeth restored with fiber post and resin composite core demonstrated fracture resistance values comparable to intact natural teeth, however with no fracture patterns improvement.
Fr6ter et al., 2021 (24)	Fatigue behavior of endodontically treated premolars restored with different FRC materials.	A restorative technique that combines individually formed unidirectional FRC posts with flowable SFRC as luting-core material provided the highest survival rate and fatigue resistance when exposed to normal biting forces in the range of 100-500N.
Karzoun et al., 2015 (25)	Fracture strength of endodontically treated maxillary premolars supported by a horizontal glass fiber post.	The fracture strength results were highest for a control group of intact natural teeth. Then followed by an experimental group with fracture restored by horizontal prefabricated FRC post and conventional composite resin core, however the specimens in this group presented with catastrophic fracture patterns.

Abbreviations:
SGFR: short glass fiber-reinforced

outcome is achieved enabling clinicians to restore a compromised tooth to its original function. The SFRC is a dentin-like material that absorbs and disseminate occlusal stresses. The short fibers resemble the collagen network presents in dentin, which contribute to the mechanical behavior in terms of tensile strength, fracture modulus and fracture toughness (13).

Additional evidence provided by Eapen et al., (2017), stated that upon subsequent investigation of the fracture resistance of ETT restored with different conventional composites (MultiCore Flow, Filtek P60) and fiber-reinforced core build-up materials (Interlig Glass Fibers, everX Posterior) revealed that teeth restored with SFRC exhibited the highest fracture resistance compared to a positive control group of non-endodontically treated natural teeth. This was mainly attributed to the support of short fiber-reinforced substructure where stresses are transferred to fibers (15).

Fiber-reinforced direct composites restorations

The use of ultra-high molecular weight poly-ethylene fibers (PWT) appeared to have reinforced polymer based dental materials (26). Perhaps this can be an alternative option to increase the fracture resistance of the ETT. The presence of a woven network type of material leads to better fiber wetting and infusion of bonding resin, thus enhances the transfer of stresses acting on PWT. Nicola et al., (2016) conducted a study to evaluate the fracture resistance of ETT restored with extensive composite restorations, and the reinforced restoration with UDMA-TEGDMA pre-impregnated parallel glass fibers (GranTEC) demonstrated significant increase in fracture resistance of endodontically treated molars (14). However, this outcome did not match the fracture resistance of a sound tooth. This result was consistent with previously published literature (27, 28, 29).

Fiber-reinforced core build-up with indirect Computer-aided design (CAD)/Computer-aided manufacturing (CAM) restorations

Past studies revealed that FRCs have strengthened indirect cusp-replacing restorations for vital and non-vital teeth (30, 31), leading to more favorable fracture patterns. FRCs have been integrated into the resin composite core build-up as a substructure below the indirect Computer-aided design/ Computer-aided manufacturing (CAD/CAM) restoration. Rocca et al., (2015) studied the effect of a fiber-reinforced cavity configuration using bidirectional E-glass fibers (everStickNET), and short fiber-reinforced resin composite (everX Posterior) on load bearing capacity and failure pattern of CAD/CAM resin composite overlays for ETT (32). This study discovered no significant differences in load bearing capacity between the control group that was without any fiber reinforcement and other experimental groups with different forms of fiber reinforcement in addition to catastrophic failures in all specimens. The authors explained this uninfluential behavior of the FRC core build-up was caused by elevated thickness of indirect resin composite-nanoceramic overlay restoration and the high loads needed to break them. We recommend further studies to better realistically describe fatigue behavior of FRCs instead of relying on a load to fracture test.

FRC posts in restoration of the radicular region for ETT

Anatomic configuration of fiber-reinforced posts

The use of a novel anatomical short glass fiber-reinforced (SGFR) post was reported from a solitary study. This post was a better fit for a root-filled teeth and had added retentive means from serrations in the coronal third of the post. Furthermore, teeth restored with a novel anatomical SGFR fiber post from semi-crystalline polyamides material using injection moulding technique were reported to have higher values of fracture resistance and endurance limitation with cyclic fatigue loading resulting in better long term mechanical performance, and more favorable fracture patterns compared to other commercially available FRC post (X- Post Radix Fiber Post) (16).

Customized FRC posts

ETT presented with wide and flared root canals caused by carious lesions, over-instrumentation, or from previous metallic posts placement posted a challenge in the form of discrepancies between the geometry of the root canal and the shape of the prefabricated fiber posts which is unlike the shape of root canal. A systematic review and meta-analysis by Silva et al., (2021) (33) reported that majority of the published literature described two available techniques for customization, either using multiple auxiliary fiber posts or anatomization using composite resin. Most studies that adopted the method of relining the posts [(RelyX (17), Reforpost Fiber Glass (18-19)] with composite resin in their sampling reported higher fracture strength values and favorable fracture patterns. The possibility of success and survival increases with this result and encourages the support for customized glass fiber posts compared to non-customized glass fiber posts (17-19). Moreover, the use of customized post showed better adaptation between the canal wall and the post itself, leading to better retention (17, 34, 35). Limitations in the study of anatomically customized posts necessitated the need for further long-term detailed study of longevity techniques in enlarged root canals, and a standardized approach to data implementation and reporting (33).

Xiong et al., (2015), in his study, reported an alternative method in restoring ETT with flared root canals using a hollow tubular fiber sleeve (i-TFC Fiber sleeve) wrapped around a prefabricated fiber post (i-TFC fiber post). This resulted in improved interfacial adaptation and greatest fracture resistance compared to a control group and other experimental groups using a lone fiber post. The authors explained that the increased fiber material volume had improved post material fitting, and reduced cement volume in post space preparation (20).

Using prefabricated FRC posts to restore ETT with cervical cavities

Abduljawad et al (2016) investigated the use of glass fiber post (Cytec blanco) and carbon fiber post (Cytec carbon) cemented with resin-based cements as a material of choice for endodontically treated maxillary central incisors presenting with cervical cavities. This study showed a statistically significant difference among different groups of ETT. Teeth restored with fiber posts showed higher fracture resistance and more favorable fracture patterns compared to a control group of ETT without cervical cavities and endodontic posts; and other experimental groups: ETT without endodontic posts, ETT with cervical cavities only, ETT with cervical cavities and carbon fiber posts, ETT with cervical cavities and glass fiber posts, ETT with cervical cavities and composite resin posts (21). Other studies also explained that this occurrence is mainly due to modulus of elasticity of FRC posts closely resembling the dentin. It was also reported that there was a shift in failure patterns for glass fiber posts compared to catastrophic failures with metallic posts resulting in favorable and repairable failure pattern in the form of debonding (15, 23).

Glass fiber ribbons with prefabricated FRC posts

ETT restored with composite resin restoration, which served as abutments in fixed and removable partial dentures, continuously reported to develop horizontal fractures at the cervical region when subjected to lateral stresses (36, 37). A study by Kubo et al. (2018) reported that in teeth impaired by flared root canal, the practice of FRC post (Clearfil Fiber Post) reinforced using cylindroid glass fiber ribbons (Construct Ribbon) presented a better outcome compared to teeth restored with fiber post only (22). The findings reported that the glass fiber ribbons were effective in reinforcing the composite resin post and core system by providing added fiber-reinforced material around the prefabricated fiber post simulating an enlarged dentin wall was aligned with the findings from other previously published studies (20, 38).

Individually formed FRC posts with SFRC

SFRC's beneficial properties include termination of crack propagation, high fracture toughness and adequate depth of cure (39). The use of SFRC in the intra-radicular region is endorsed by Forster et al., (2017)(40), as well as in the bioblock technique treatment by Fr6ter et al., (2020)(41). In the bioblock technique, the coronal and radicular regions of specimens were restored by SFRC and the specimens displayed superior fracture resistance compared to other teeth restored with prefabricated FRC post alone. Fr6ter et al., (2021) investigated multiple restorative techniques used to restore endodontically treated premolar teeth. This study involved the use of different types of FRC materials: packable and flowable versions of SFRC (everX Posterior, everX Flow); individually formed unidirectional FRC posts (everStick Post) ; and conventional FRC posts (GC Fiber Post). From this study, they recommended a restorative technique that combines individually formed unidirectional FRC posts with flowable SFRC as luting-core material. This combination provided the greatest survival rate and fatigue resistance when exposed to normal biting forces in the range of 100-500N. The authors also proposed the future studies which include a fatigue survival test after long term water storage and thermal aging for a better simulation of clinical condition (24).

Horizontally placed prefabricated FRC posts

Karzoun et al., (2015) conducted a study on the use of prefabricated FRC post (White Post DC) to restore endodontically treated premolar teeth with mesio-occluso-distal (MOD) cavities (25). In this study, they laid the post in a horizontal direction between the buccal and palatal cusps. This technique eliminated the need to remove excessive tooth structure from radicular dentin. The fracture strength was reported to be the highest for a control group with intact teeth followed by an experimental group restored with a horizontal prefabricated FRC post and conventional composite resin core. The authors explained that the high fracture strength value, in the experimental group, arose from the preserved tooth structure that improves fracture resistance under occlusal loading. They also recommended further studies with thermocycling and dynamic fatigue loading to better simulate clinical condition.

CONCLUSION

This literature review summarized recent studies of restorative techniques for ETT at coronal and radicular regions. Various fiber reinforced materials are commercially available, readily and practically utilized in clinical practice. Results of previously published studies concluded that fiber-reinforced composite materials have improved the restored teeth's fracture strength. However, the strength was inferior to the fracture strength of an intact natural tooth. The available studies were lack of comparative studies and recommendation for the most effective restorative techniques in relation to practical application and functional restoration. Furthermore, the use of FRC materials transformed better (repairable) fracture patterns and lessen catastrophic fracture failures. It is recommended that future studies should incorporate better simulation of clinical condition and the use of thermo-mechanical aging as well as dynamic loading. Furthermore, as in line with the development of digital technology, more studies on the use of FRC material constructed using digital technology such as CAD-CAM and digital printing are suggested in a future study.

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