Article published online: 2023-04-21

Adaptation of Relined Fiber Post Using Discontinuous Short Fiber-Reinforced Resin Composite to Restore Weakened Endodontically-Treated Premolars

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Eur J Gen Dent 2023;12:89–96.

Abstract

Objective This study aimed to investigate the effect of relining prefabricated fiber-reinforced composite (FRC) posts using bulk-fill, flowable, discontinuous short fiber-reinforced composite (SFRC) on intracanal adaptation in weakened endodontically-treated premolar teeth.

Materials and Methods Forty extracted human premolar teeth were selected and randomly allocated to five groups ($n = 8$) according to the canal preparation method and restorative technique after endodontic treatment: Group 1 (control): nonflared, closed apex root canals; group 2, 4: flared, open-apex root canals; group 3, 5: flared, closed apex root canals. Groups 1 to 3 were restored with standard RelyX fiber post size #1, while groups 4 and 5 were restored with customized RelyX fiber post size #1 and relined with bulk-fill flowable SFRC (everX Flow, GC, Tokyo, Japan). To evaluate intracanal adaptation, the empty root of each sample with the corresponding fiber post (standard or customized) inserted was measured twice using a micro-digital scale and the average value was calculated. The post was then removed, followed by the insertion of a light body polyvinyl siloxane (PVS) impression material into the canal, followed by reinsertion of the post and removal of excess material once the PVS was set. Finally, the sample weight was recorded, and the data were analyzed using one-way analysis of variance and the Bonferroni post hoc test (p-value $= 0.05$).

Results A statistically significant difference ($p < 0.05$) in PVS material weight was identified between the groups. Group 1 (control) had the lightest weight of PVS material, followed by groups restored with customized fiber posts (groups 4 and 5) and standard fiber posts (groups 2 and 3).

Keywords
- adaptation
- relined
- fiber-reinforced composite
- fiber post
- flared
- endodontically treated teeth
- short fiber-reinforced composite

article published online
April 21, 2023

DOI https://doi.org/10.1055/s-0043-57245.
ISSN 2320-4753.

Thieme Medical and Scientific Publishers Pvt. Ltd., A-12, 2nd Floor, Sector 2, Noida-201301 UP, India

Conclusion Anatomically-customized fiber posts with bulk-fill flowable SFRC provided better intracanal adaptation compared with standard fiber posts in teeth with compromised root canals.

Introduction

The restoration of endodontically-treated teeth (ETT) has been extensively researched to identify the best materials, protocols, and parameters. Despite numerous efforts to enhance the mechanical behavior and prognosis following root canal treatment, the discoveries remain controversial. The introduction of carbon or glass fiber post systems since the 1990s provided an alternative to cast or prefabricated metallic posts.[1] These posts are alternatives to overcome the challenges of restoring damaged ETT. Furthermore, these post systems have been developed with a modulus of elasticity closer to that of human dentin, thus, improving the stress distribution along the root and reducing catastrophic failures than the previous metallic posts.[2–5] One of the crucial aspects is the intracanal adaptation of the fiber-reinforced composite (FRC) post to the radicular dentin walls, which influences the retention of the intra-radicular restoration such as fiber posts.[6]

Excessive removal of the radicular and coronal dentinal tissue occasionally occurs during endodontic procedures, such as over-flaring canals or attaining straight-line access. Additionally, several clinical situations are present with flared and wide root canal space, such as endodontic retreatment cases and immature permanent teeth with open apex, thus, requiring intraradicular posts for core retention.[7] Moreover, the adaptation was compromised due to the discrepancy between the shape of the root canal space and the prefabricated post shape. This inconsistency will result in an excessively thick layer of cement between the post and the radicular dentine. Thus, increasing polymerization shrinkage at the different interfaces could lead to bubble formation and debonding/adhesive failure.[8] Subsequently, debonding can lead to a wedging effect by the intraradicular restoration and catastrophic failure.[9,10] Furthermore, studies reported that oval and tapered posts did not improve fracture resistance and adaptation to canal morphology compared with previous cylindrical posts. In addition, reducing the cement film thickness in such clinical scenarios has been proven challenging in the past.[11,12]

Recent studies have proposed an alternative clinical technique to restore structurally-compromised ETT resulting from caries, trauma or congenitally malformed teeth, known as the anatomically customized or relined FRC posts.[6,8,13–15] This technique involves relining the prefabricated FRC post using several conventional[8] and bulk-fill resin composites[6] to enhance adaptation on the walls of noncircular root canals. The adaptation was improved by fabricating anatomically-customized fiber posts that conform to the anatomy and taper of the root canal, thus limiting the thickness of the resin cement[16,17]

Recently introduced bulkfill flowable, discontinuous short fiber-reinforced composite (SFRC) offers advantages and unique properties in restoring large ETT cavities. For instance, SFRC exhibited superior fracture toughness, flexural strength, and modulus compared with conventional resin composite. Furthermore, SFRC possesses specific properties, such as termination of crack propagation, lower polymerization shrinkage stress, reduced microgap formation, and microleakage compared with existing bulk-fill and conventional resin composites.[18,19] The application of SFRC inside the root canal as a post-core material was recommended by some studies.[19,20] However, no available studies have been conducted to evaluate the use of prefabricated FRC post relined with the bulk-fill flowable SFRC. Therefore, this study aimed to investigate the intracanal adaptation of anatomically-customized FRC post relined with bulk-fill, flowable SFRC and compare the performance with the standard FRC post in restoring flared, immature and compromised root canals. The null hypothesis was as follows H_0: There is no significant difference in intracanal adaptation, between standard noncustomized fiber posts used to restore ETT, and customized anatomical fiber posts.

Materials and Methods

Ethical approval was obtained from the University of Sharjah – Research Ethics Committee (Ref no. REC-21–09–20–02-S) and Human Research Ethics Committee of Universiti Sains Malaysia (JEPeM-USM) (USM/JEPeM/21090637). PS software (Dupont and Plummer, 1997) was used to calculate the sample size with standard deviation (σ) assumed to be 4.6 as per previous study by Pitigoi-Aron et al[21] of the mean gamma count with 80% power and α (α) = 0.05. Thirty-five samples were needed for this study. With the anticipation of 10% failure during the procedure, a total of forty samples were prepared for this study.

Forty extracted human premolar teeth were collected from the oral surgery clinic at the University Dental Hospital of Sharjah. The teeth were randomly distributed into five groups consisting of eight teeth per group ($n = 8$). The inclusion criteria were teeth extracted from patients due to periodontal or orthodontic reasons without evidence of hereditary or developmental anomalies as confirmed in the clinical examination and medical history. A single-rooted, single-canal maxillary, and mandibular premolar teeth were used in this study for standardization. Specifically, the root dimensions were: root length = 15–16 mm, buccolingual dimension at the cervical area = 7–8 mm, and mesio-distal dimension at the cervical area = 5–6 mm. Furthermore, the teeth should be sound with straight roots, without evidence of coronal and radicular caries, cracks, or external and internal resorption. Meanwhile, the exclusion criteria involved teeth with previous endodontic treatment and teeth demonstrating signs of erosion, attrition, or abrasion.

Sample Preparation

A single trained operator was assigned to perform all sample preparation, restorative and subsequent experimental procedures. The extracted teeth were rinsed with saline solution to clear any blood residues, debris, and soft tissue attachments using an ultrasonic scaler (Dentsply Sirona Endodontics, Balaigues, Switzerland). The extracted teeth were inspected for fractures and cracks and stored in laboratory test tubes containing distilled water at room temperature. First, the teeth were sectioned using a low-speed diamond saw (IsoMet 1000, Buehler Ltd., Illinois, United States), 2 mm above the cementoenamel junction, under water cooling. Subsequently, the working length was determined using a K-file size 10, which was inserted until it appeared at the apex, followed by subtracting 0.5mm from it. For group 1, group 3, and group 5, the sectioned teeth were embedded in a self-cure acrylic resin (Vertex-Dental, the Netherlands), poured into a cuboidal shape mold, and allowed to set. Simulation of flared root canals (for groups 3 and 5) was made, followed by root canal treatment. the open apex simulation for groups 2 and 4 was performed before embedding the roots in the self-cure acrylic resin blocks, followed by root canal treatment. For simulating the open apex in groups 2 and 4, Peeso reamer size #1 to #6 (Roydent, United States) was used to prepare past the apex of the teeth under water cooling along the long axis of the tooth.

Root canal treatment was conducted on all groups. First, the WaveOne Gold reciprocating file system (Dentsply Sirona Endodontics, Ballaigues, Switzerland) was used to prepare the root canal space; a primary (red) or large (green) file was used according to the predetermined canal size and working length. Subsequently, the obturation was performed using WaveOne Gold gutta-percha (Dentsply Sirona Endodontics, Ballaigues, Switzerland) and AH^{+} resin sealer (Dentsply Sirona Endodontics, Ballaigues, Switzerland) via the single cone technique for groups 1, 3, and 5. On the other hand, the master cone was cut from the apical part and adjusted to working length until tug-back was evident for groups 2 and 4 with open apex, followed by obturation similar to previous groups. The teeth were then stored in distilled water for 72 hours. Subsequently, the post space was prepared by removing the root canal filling using gates glidden drills and RelyX universal drill (3M Oral Care, St. Paul, MN, United States), thus, leaving a 5 mm apical seal.

Fig. 1 Simulated flared root canal preparation.

The RelyX fiber post drills (3M Oral Care, St. Paul, MN, United States) in white–yellow–red–blue were used sequentially for post-space preparation to obtain a standardized simulated flare of the root canals for groups 2 to 5 (►**Fig. 1**). Conversely, the post drill white–yellow was used for group 1. The fiber post length was standardized at three-quarters of the root length of each specimen.[22] Finally, the specimens from all experimental groups (►**Table 1**) received either a

Table 1 Overview of the experimental groups

Group	Description	Preparation	Materials for root canal restoration
1	Nonflared, closed apex root canals	White-Yellow RelyX post drills.	(FRC) post (RelyX, 3M Oral Care, St. Paul, MN, United States)
2	Simulated open apex, flared root canals	Flare: White-Yellow-Red-Blue RelyX post drills. Open apex: Peeso reamer size #1–#6	(FRC) post (RelyX, 3M Oral Care, St. Paul, MN, United States)
3	Simulated flared root canal, closed apex	Flare: White-Yellow-Red-Blue	(FRC) post (RelyX, 3M Oral Care, St. Paul, MN, United States)
4	Simulated open apex, flared root canals	Flare: White-Yellow-Red-Blue Open apex: Peeso reamer size #1–#6	Customized (FRC) posts (RelyX, 3M Oral Care, St. Paul, MN, United States) using flowable E-glass discontinuous short fiber-reinforced composite resin (everX Flow, GC, Tokyo, Japan)
5	Simulated flared root canal, closed apex	Flare: White-Yellow-Red-Blue	Customized (FRC) posts (RelyX, 3M Oral Care, St. Paul, MN, United States) using flowable E-glass discontinuous short fiber-reinforced composite resin (everX Flow, GC, Tokyo, Japan)

Abbreviation: FRC, fiber-reinforced composite.

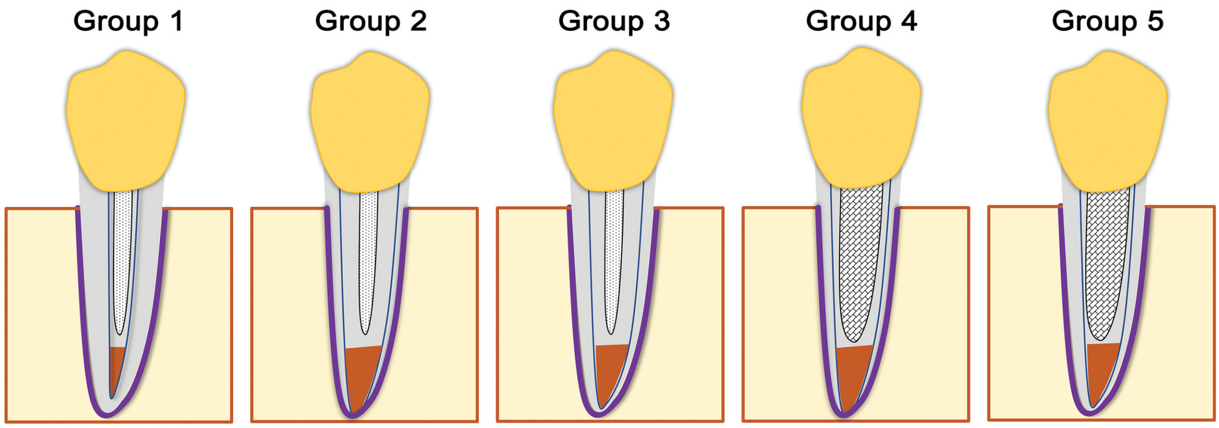

Fig. 2 Graphical representation of the experimental groups. Group 1: Nonflared, closed apex root canal with standard FRC post; group 2: open apex, flared root canal with standard FRC post; group 3: flared root canal, closed apex with standard FRC post; group 4: open apex, flared root canal with customized FRC post using everX Flow Bulk; group 5: flared root canal, closed apex with customized FRC post using everX Flow Bulk. FRC, fiber-reinforced composite.

standard or anatomically-customized fiber post and were assessed for intracanal adaptation. (►**Fig. 2**) presents a graphical illustration of the different experimental groups.

A standard, prefabricated RelyX fiber post (3M Oral Care, St. Paul, MN, United States) size #1 (Yellow) was tried in the canal to ensure the fit and resistance of the post following post-space preparation for group 1. Meanwhile, the post-space preparation was done using post drills size #0 to #3 (white–blue) for groups 2 to 5. RelyX fiber post (3M Oral Care, St. Paul, MN, United States) size #1 (yellow) was tried in the canal and checked for fitment. In groups 4 and 5, the post was removed and cleaned with isopropyl alcohol and air-dried. Subsequently, Scotchbond™ Universal Adhesive (3M Oral Care, St. Paul, MN, United States) with a combined formulation of adhesive resin and silane was applied over the post and scrubbed for 20 second according to manufacturer's instructions, followed by air thinning and light-cured for 40 second using the light curing unit, BluePhase Style (Ivoclar Vivadent, Shaan, Liechtenstein) at an output intensity of 1200 mW/cm^2. The root canal was then coated with a thin microbrush and glycerin-separating agent. everX Flow Bulk (GC, Tokyo, Japan) resin composite was applied around the post. The post was then inserted into the root canal and light-cured for 40 second from the occlusal aspect.

The anatomically-customized post was removed, light-cured for 20 second from all sides, cleaned from any residues of the separating agent using water, and dried. The result is shown in (►**Fig. 3**).

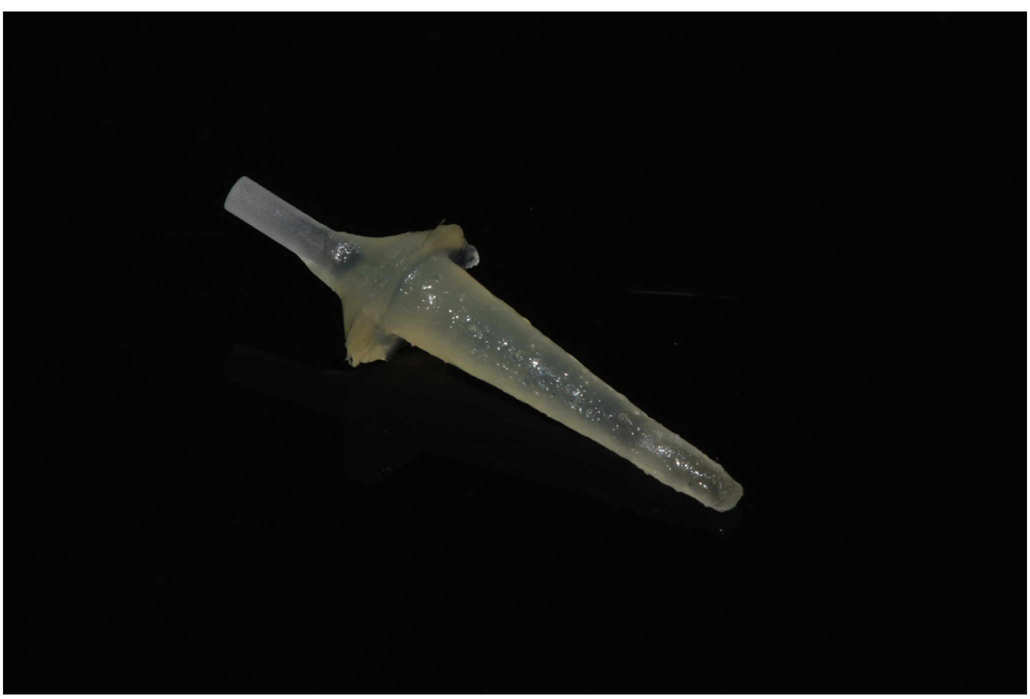

Fig. 3 The customized (FRC) post using bulk-fill flowable E-glass short discontinuous fiber-reinforced resin composite, everX Flow (GC America, United States). FRC, fiber-reinforced composite.

Table 2 One-way ANOVA to assess the intracanal adaptation between groups

	Sum of Squares	df	Mean square	F	Sig.
Between groups	1816.237	4	454.059	1451.097	0.00
Within groups	10.952	35	0.313		
Total	1827.189	39			

Abbreviations: ANOVA, analysis of variance.
$p < 0.05$ is statistically significant.

Intracanal Adaptation Test

The weight of each tooth specimen with the fiber post (standard or customized) inserted into the canal, was measured twice using a micro-digital scale (AND GR200, A&D Company Limited, Japan) with an accuracy of 0.001, and the average was calculated. A light-body polyvinyl siloxane (PVS) impression material was introduced into the canal using an intracanal plastic tip. A dental surveyor (Ney surveyor, Neytech, Bellevue, WA, United States) was utilized to ensure parallelism along the long axis of the tooth during seating of the fiber post the fiber post (standard or customized) with an attached rubber stopper set at ¾ of the working length, was placed into the root canal up to the reference point level represented by the canal orifice., before the PVS material hardened. The excess impression material on the coronal tooth structure was removed using scalpel blade no. 15 after the material had been set completely. Each tooth with the PVS and fiber post still inside the prepared canal space was reweighted twice to determine the average weight, and data were recorded in tabular form. The difference in weight before and after placement of the PVS impression material represents the empty canal space that was not occupied by the post.

Statistical Analysis

Normality of the data was examined through Kolmogorov–Smirnov test, then one-way analysis of variance test was performed as the results showed that the data was normally distributed. Finally, the post-hoc Bonferroni test was performed for multiple comparisons between the experimental groups. A *p*-value was set at 0.05.

Results

A significant difference in the weight of the PVS material was identified between the groups, but there were no differences within the same group (►**Table 2**). Meanwhile, ►**Table 3** presents the descriptive results (mean ± standard deviation) for the weight of the PVS material inside the canal. Group 1 (control) had the lightest weight of PVS material (18.31888mg ± 0.428827), followed by groups restored with customized fiber posts (group 4 = 22.61350mg ± 0.757683, group 5 = 20.61100mg ± 0.703809). In contrast, the groups restored with standard fiber posts had the heaviest PVS material (group 2 = 33.58738mg ± 0.520669, group 3 = 34.36675mg ± 0.200298). Multiple comparisons using the post-hoc Bonferroni test between the experimental groups were statistically significant excluding groups 2 and 3 ($p = 0.085$).

Discussion

The null hypothesis stating that there is no significant difference in intracanal adaptation between standard non-customized fiber posts used to restore ETT, and customized anatomical fiber posts had to be rejected as there were significant differences between the experimental groups ($p < 0.000$). The weight of the PVS material inside the canal represented the space between the post and dentinal wall of different experimental groups restored with either standard or customized fiber posts. This result reflected the intimacy of fit of the fiber post; where a low value indicated close and better adaptation to the radicular walls of the canal, while a

Table 3 Descriptive statistics (mean ± SD) of intracanal adaptation between groups

	n	Mean (mg)	Standard deviation	95% Confidence interval for mean		Minimum	Maximum
				Lower bound	Upper bound		
Group 1- NCSF	8	18.31888^{A}	0.428827	17.96037	18.67738	17.476	18.811
Group 2- FOSF	8	33.58738^{B}	0.520669	33.15208	34.02267	33.214	34.583
Group 3- FCSF	8	34.36675^{B}	0.200298	34.19930	34.53420	34.117	34.663
Group 4- FOCF	8	22.61350^{C}	0.757683	21.98006	23.24694	21.639	23.755
Group 5- FCCF	8	20.61100^{D}	0.703809	20.02260	21.19940	19.639	21.811
Total	40	25.89950	6.844779	23.71043	28.08857	17.476	34.663

Abbreviations: FCCF, flared, closed-apex, customized fiber post; FCSF, flared, closed-apex, standard fiber post; FOCF, flared, open-apex, customized fiber post; FOSF, flared, open-apex, standard fiber post; NCSF, nonflared, closed-apex, standard fiber post; SD, standard deviation.
Note: Values with similar superscript letters indicate no statistically significant difference ($p > 0.05$).

high value suggested otherwise. In this study, the control group (group 1) exhibited the narrowest space between the post and radicular walls, thus demonstrating the best fit of the fiber posts. Meanwhile, groups with flared root canals that were restored with anatomically-customized posts (groups 4 and 5) recorded values close to that of the control group (group 1) and had significantly lighter PVS material than groups with flared canals restored with standard, non-customized posts (group 2, group 3) (see ►**Table 2**). This outcome is consistent with Bhaktikamala et al[17] who reported improved internal adaptation and intimate contact with anatomically-customized FRC posts.

The results of our study can be attributed to the fabrication process of anatomically-customized fiber posts. As the canal for the control group is the narrowest, the fit of the post drill was better; thus, the post fit was in accordance with the drilled space size. Moreover, the manual manipulation involved during the relining process of the post by the operator gives better adaptation of the post and a larger surface contact area to the root canal. This process possibly contributed to the lower mean weight compared of the canal with anatomically-customized FRC post compared with the non-customized group. Likewise, earlier studies have reported that customized post improved intimate contact and adaptation between the customized post and radicular dentin walls, thus, enhancing frictional retention and leading to a homogenous resin cement layer.[17,23] Additionally, Caceres et al[24] conducted purposive microcomputed tomography to evaluate different cementation techniques and found that relined fiber posts presented with improved adaptation with lower void formation than nonrelined fiber posts.

Previous studies have highlighted the benefits of this technique,[8,25–27] which involves replicating the internal canal anatomy and tapering by the resin composite placed externally on a prefabricated fiber post. This method resulted in close adaptation, limited space between the anatomically-customized post and dentinal walls, reduced cement layer thickness and defects, enhanced frictional retention, and a larger surface contact area. Bulk-fill resin composites have many advantages over conventional resin composites, including lower polymerization shrinkage stresses and higher light transmission regardless of filler content, allowing an increment of up to 4 mm and are recommended to restore cavities with high c-factor.[28,29] Furthermore, with the use of bulkfill flowable SFRC, controlled polymerization shrinkage stress is achieved by the presence of the fibers comprising the bulk-fill flowable SFRC.[30]

In this study, a universal adhesive system containing both adhesive resin and silane incorporated into its chemistry was applied over the fiber post. Silane coupling agents are bifunctional molecules, where one end of the molecule can react with the inorganic glass fibers and the other with organic resin composite.[31] Improved bond strength between silanized translucent fiber posts and flowable resin composite core materials was reported by Vano et al.[32] Silane coating was found to provide more uniform adaptation between the post and composite core build up material.[33] The chemical bond formed by silane is achieved between superficial exposed glass fibers of the post and the resin composite.[31] Combined bonding/silane agents can be beneficial in bonding to posts as the siloxane bonds and polymerization of the functional groups in the resin occur simultaneously.[34]

A customized fiber post using discontinuous SFRC material was utilized in several experimental groups to overcome poor fitting and adaptation. Consequently, the material could not shrink along the fiber length during polymerization, and only the polymer matrix shrinks; this leads to the maintenance of horizontal dimension and improved adaptation in groups restored with customized FRC post with flowable SFRC.[19] Similarly, Fráter et al evaluated the adaptation of different fiber-reinforced post-core restorative techniques of the root canal. The authors reported the lowest microgap formation scores and better adaptation to root canal walls restored with 1) directly layered SFRC post using either the packable or flowable form of the material (Bioblock technique) and 2) individually formed FRC posts combined with flowable SFRC as post and core (hybrid technique) compared with conventional prefabricated FRC posts which had the highest microgap scores.[19,35,36]

Relevant literature lacks information and general agreement about the ideal thickness of the cement layer between the fiber post and canal dentinal walls.[6,14,24,37] The cement layer is commonly the area where defects can occur in the form of voids or bubbles, and the junction between the resin cement and dentinal walls is the weakest and prone to failure such as debonding, particularly when there is an excessively thick cement layer in oversized flared root canals that are also associated with increased polymerization shrinkage stress.[14] Multiple studies have been conducted to evaluate the ideal luting cement thickness. For instance, D'Arcangelo et al[37] recommended a thickness between 0.1 and 0.3 mm for the cementation of quartz fiber posts. Other studies[38,39] did not report specific values or ranges but highlighted improvements when cement layer thickness was reduced and vice versa.

Several techniques have been reported in the literature to assess internal adaptation and fitting of fiber posts and other intraradicular dowels used to restore ETT: 1) slicing different regions of the root, followed by evaluation under the optical microscope[6] 2) scanning electron microscopy[25] 3) micro-computed tomography[24] or 4) utilizing PVS light-bodied impression material inserted into the root canal space.[21]

This study evaluated intracanal adaptation as described by Pitigoi-Aron et al.[21] and modified as described in a study by Muttlib et al.[23] The method involved measuring the weight of PVS light body impression material placed into the root canal together with the fiber post inside the root canal of the tooth simultaneously. Subsequently, previous readings of the fiber post placed in the empty root canal of the tooth were subtracted to represent the space available between the fiber post and the radicular dentinal wall. Furthermore, this value indicated the intimacy of fit and adaptation relative to the radicular walls of the canal.

This technique is advantageous due to the excellent indirect representation of the area surrounding the post, usually filled with resin cement. PVS siloxane light body material was utilized because of the excellent accuracy, elastic recovery, dimensional stability, ability to flow under pressure into the relatively small root canal space, and easily removable with good tear strength.[40] In addition, this technique is more convenient, simpler, and cost-effective than sophisticated techniques, such as micro-computed tomography. An intracanal tip attached to the dispensing gun enhances and ensures the material delivery into the root canal space. Nevertheless, this technique has several disadvantages: 1) possible tearing and the lodging of impression material into undercuts and irregularities of the radicular space, 2) air bubbles formation caused by human error in maintaining a constant contact of the tip with the syringe material. In this study, intracanal adaptation was assessed indirectly using light body PVS material that occupied the available space between the fiber post and radicular dentin walls. Sufficient results were provided due to the excellent properties of this material to flow and fill the narrow resin cement space. However, this technique does not provide a detailed three-dimensional visualization with ability to quantify intracanal adaptation of the fiber post inside the radicular region. In consideration of such limitation, further evaluation using a more advanced analysis through micro-computed tomography scan is required to assess the intracanal adaptation of anatomically customized fiber posts.

Conclusion

The anatomically-customized FRC posts relined using bulk-fill flowable SFRC improved the adaptation and intimacy of fit in compromised root canals with flared, wide, and immature anatomy compared with standard noncustomized fiber posts. Nonetheless, the enhancement was not to the extent of adaptation in the control group. Further studies are recommended to evaluate the bond strength of relined FRC posts using bulk-fill flowable SFRC, as well as the fracture resistance of teeth restored with the customized FRC posts.

Clinical Significance

Increased resin cement thickness is correlated with higher incidence of defects formation. Optimum intracanal adaptation is necessary to result in a low resin cement thickness in compromised root canals. For FRC post system, relining with bulkfill flowable discontinuous SFRC achieves this objective and creates an anatomically customized post conforming to root canal taper. Additional benefits associated with the inherent properties, flowability of the relining SFRC material are also obtained making it an excellent option for this technique.

Funding

Submission of this manuscript is funded by Research University Grant, Universiti Sains Malaysia (1001/PPSG/8012367).

Conflict of Interest

None declared.

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