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(Article begins on next page)



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Original Article

Fiber-post bond strength in canals obturated with a cross-linked gutta-percha core obturator

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Abstract

The aim of this in-vitro study was to evaluate the bond strength of fiber posts cemented in a root canal filled using various root-canal obturation techniques. A total of 33 monoradicular samples, treated endodontically, were randomly assigned to three groups according to the root-canal obturation technique: group 1, continuous-wave technique; group 2, plastic-obturator-core technique; and group 3, cross-linked gutta-percha obturator-core technique. Fiber posts were luted in each sample and each was sectioned perpendicular to the post axis. The push-out test was performed using a universal machine and the maximum failure load was recorded in MPa mm⁻². Several samples were randomly chosen for scanning electron microscopy evaluation. The mean debris and dentinal tubule-opening scores were calculated separately in the coronal and apical portions. Bond strength was significantly higher in group 1 than in groups 2 and 3. Debris scores were significantly higher in the apical portion of groups 2 and 3 than in group 1. Within the limitations of this study it can be affirmed that thermoplasticized alpha gutta-percha seemed to worsen the cleaning of post-space walls and hence reduced fiber-post bond strength.

Article

Endodontically treated teeth with extensive loss of coronal structure may have a considerably reduced capacity to resist functional forces [1]. They frequently require the placement of a root canal post to improve retention and fracture resistance [2] and to show more favorable fracture patterns [3]. Several studies have reported that in comparison with conventional cast posts, fiber posts can reduce the incidence of non-retrievable root fractures [3-5]. Presently, adhesive postendodontic reconstruction with a fiber-reinforced composite (FRC) post is a reliable technique widely supported by in-vitro [6-10] and in-vivo [11-15] studies. Insertion of an FRC post requires resin-based adhesive materials. Effective, durable bonding among the fiber post, root dentin, and adhesive resin cement is essential for the longevity of the restorations [16]. However, luting of the FRC post is often complicated by the difficulty in reaching the most apical areas with the curing light [17, 18], by the incompatibility between acid adhesives and auto/dual-cured composites [19-21], by high polymerization contraction stresses [22], by moisture control for adhesion [23], and by the peculiar characteristics of the root dentine substrate [24]. To reach high bond strength with the root canal walls, the smear layer and debris on the post-space walls must be removed [25-27]. Nevertheless, some studies have reported difficulty in completely removing root-canal filling materials [28, 29] to obtain properly cleaned radicular dentin surfaces. Among root-canal obturation techniques, Thermafil is an effective endodontic obturation system. Previous studies have demonstrated a higher sealing ability of the thermoplasticized alpha gutta-percha of the Thermafil system compared with lateral condensation [30-33] and the vertical condensation [31, 32] techniques. However, difficulty in removing the entire plastic carrier of Thermafil for preparation of the post-space has previously been described [34]. To avoid this problem, an endodontic obturator, Guttacore (Dentsply, Tulsa, OK, USA), in which the plastic carrier is replaced with a hard, cross-linked gutta-percha core, was recently introduced. However, no studies have shown that Guttacore yields better post-space cleaning in terms of root canal to fiber-post bond strength.

This aim of this study was to compare the bond strength of fiber posts cemented in root canals filled using various obturation techniques. The null hypothesis was that fiber-post bond strength is not related to the root-canal obturation technique.

Material and methods

Intact, extracted human single-root teeth were selected for this study. After debriding the root surface, specimens were stored in 0.5% chloramine at 4°C. Each tooth was sectioned at the cemento–enamel junction perpendicularly to the long axis of the tooth, and teeth with oval-shaped canals were excluded from the study. In total, 33 samples with a root-canal length of 12 mm were selected. Samples were endodontically shaped using Pathfile 1-2-3 (Dentsply Maillefer, Ballaigues, Switzerland) and then shaped with ProTaper S1-S2-F1-F2-F3 (Dentsply Maillefer) to the working length. The working length was established under 10× magnification (Pro Ergo; Carl Zeiss, Jena, Germany), when the tip of the file became visible at the apical foramen. Irrigation was with 5% NaOCl (Nicolor 5; Ogna, Muggiò, Italy) alternated with 10% EDTA (Tubuliclean; Ogna), using a 2-ml syringe and 22-gauge needle. Each canal was dried, and the integrity of each apical foramen was ensured under 10× magnification (Pro Ergo; Carl Zeiss).

Specimens were randomly assigned to three groups ($n = 11$ each group) according to the endodontic obturation technique employed (Table 1). After 24 h, an 8-mm post space was prepared in each sample, using the appropriate endodontic obturation technique (Table 1).

Table 1. Materials and techniques employed for root-canal obturation and post-space preparation

Group	Material	Endodontic obturation technique	Post-space preparation technique
Group 1	Medium-sized gutta-percha points (Mynol; Curadent Healthcare, Saronno, Milan, Italy)	Continuous-wave technique: specimens were filled with endodontic cement (Pulp Canal Sealer EWT; Kerr, Sybron, Romulus, MI, USA) and medium gutta-percha points (Inline; B.M. Dentale, Torino, Italy) with DownPack heat source	Largo drills #1 for removing the gutta-percha; size two dedicated drill (Rely-X Fiber Post Drill; 3M ESPE, St Paul, MN, USA) in the first 8 mm of the root canal

Group	Material	Endodontic obturation technique	Post-space preparation technique
		(Hu-Friedy, Chicago, IL, USA). Backfilling was performed using the Obtura III system (Analytic Technologies, Redmond, WA, USA)	
Group 2	Thermafil (Dentsply Maillefer, Ballaigues, Switzerland)	Plastic Obturator Core Technique: specimens were filled with endodontic cement (Pulp Canal Sealer EWT) and #25 Thermafil	ThermaCut drill to remove the plastic core of Thermafil; size two dedicated drill (Rely-X Fiber Post Drill) in the first 8 mm of the root canal
Group 3	Guttacore (Dentsply Maillefer)	Cross-linked Gutta-Percha Obturator Core Technique: specimens were filled with endodontic cement (Pulp Canal Sealer EWT) and	ThermaCut drill to remove the plastic core of Thermafil; size two dedicated drill (Rely-X Fiber Post Drill) in the first 8 mm of the root canal

Group	Material	Endodontic obturation technique	Post-space preparation technique
#25 Guttacore			

Push-out bond-strength test

Eight specimens per group were prepared for the push-out test. Fiber posts (3M ESPE, St Paul, MN, USA) were luted with a three-step etch-and-rinse dual-curing adhesive system (All Bond 3; Bisco, Schaumburg, IL, USA) and a dual-curing resin cement (C&B; Bisco), then light cured for 40 s using a light-emitting diode lamp (Translux Power Blue; Heraeus Kulzer, Hanau, Germany) in direct contact with the posts. After cementation, the samples were stored in physiological solution for 7 d at 37°C. Each sample was sectioned perpendicular to the post axis using a low-speed 0.35-mm diamond saw (Micromet; Remet, Bologna, Italy) under water cooling to obtain five to six 1-mm root slices, representing the coronal and apical regions of the post space [35, 36].

The push-out test was performed by applying an axial load to the post at a crosshead speed of 0.5 mm min⁻¹ using an Instron Machine I (model 10/D; Sintech, MTS, Canton, MA, USA). The most coronal region was turned downward (load direction: apical–coronal). The maximum failure load was recorded in Newtons (N) and converted into megapascals (MPa) by dividing it by the interfacial area of the post fragment, which corresponds to the bonded area, in accordance with JULOSKI *et al.* [37].

Failure mode evaluation

After performing the push-out test, all samples were assessed using a stereomicroscope at 40× magnification, to determine the type of failure. Failure modes were classified into the following categories: type I, adhesive failure between dentin and resin cement; type II, cohesive failure within resin cement; type III, cohesive failure within dentin; and type IV, mixed failure.

Scanning electron microscopy

Three teeth per group were selected. Post space cleaning was performed, in all samples, with 10% EDTA (Tubuliclean; Oгна) for 60 s with a continuous brushing technique. The samples in the post spaces were also treated with 32% phosphoric acid (Bisco) for 30 s, washed with water using a syringe with an endodontic needle, and then gently air-dried with an air-syringe.

Each sample was split longitudinally, and one half of each tooth was chosen at random for scanning electron microscopy evaluation. The halves were fixed for 4 h in 0.2 M sodium cacodylate buffer containing 4% glutaraldehyde, rinsed in cacodylate buffer, dehydrated in an ascending ethanol concentration series (50–100%), air dried, mounted on aluminum stubs (Jeol, Tokyo, Japan) with adhesive carbon sheets (SPI, West Chester, PA, USA), and finally sputter-coated with gold-palladium in an Emitech K550 sputter coater (Polaron, Watford, UK), then observed using a scanning electron microscope (JSM-5200; Jeol, Tokyo, Japan) at up to 5000× magnification.

Each specimen was visualized by scanning electron microscopy using a randomized method [38]. In total, 144 serial images were numbered with a coding system to allow evaluation by two blinded independent investigators, according to the following criteria (Fig. 1). The amount of debris

observed was coded as: 0, no debris particles; 1, a few debris particles with maximum diameter of $<20\ \mu\text{m}$; or, 2, a large number of debris particles and/or the presence of debris with diameters $>20\ \mu\text{m}$ in any direction. The number of open dentinal tubules was coded as: 0, all dentinal tubules open and lacking debris, with a smear layer or sealer/gutta-percha remnants; 1, some dentinal tubules open, with a thin smear layer and a small amount of debris or sealer/gutta-percha remnants covering these openings; or, 2, all dentinal tubules blocked by a thick smear layer with debris and sealer/gutta-percha remnants [39].

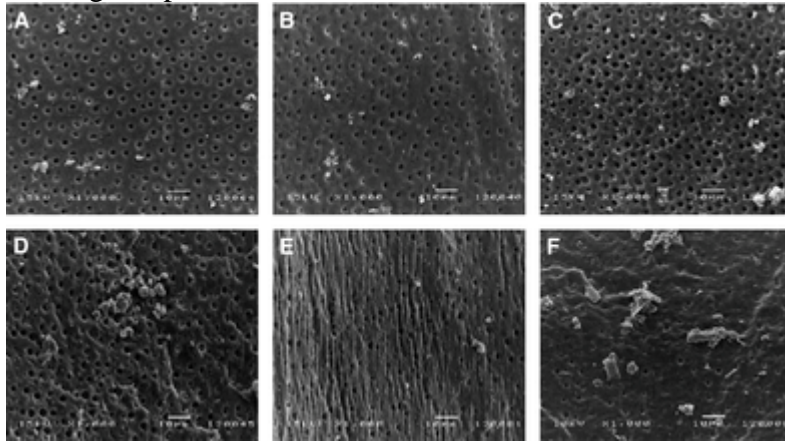


Figure 1.

Scanning electron microscopy analysis (magnification 1000 \times) of coronal and apical portions of root-canal dentin after post-space cleaning. Panels A, B, and C show the amount of debris and the number of open tubules in coronal portions of root-canal dentin after removal of Gutta-Percha Point, Thermafil, and Guttacore respectively. In all groups little debris is visible and the number of open tubules in each is similar. Panels D, E, and F show the amount of debris and the number of open tubules in the apical portions of root-canal dentin after removal of Gutta-Percha Point, Thermafil, and Guttacore respectively. Panel D shows that the endodontic smear layer can be removed more easily from post-space walls when vertical condensation is employed compared with other obturation techniques and, consequently, some open tubules are present compared with panels E and F.

For each tooth, the mean debris and dentinal tubule opening scores were calculated separately for two parts of the radicular dentine (coronal and apical portions). Before beginning the evaluation, the two evaluators were trained in the use of the assessment criteria in a blinded manner. Intra-examiner reliability was assessed using the kappa (κ) test.

Statistical analysis

For each tooth, the mean marks of debris and open tubules were calculated separately for the coronal and apical portions of the post spaces. The final debris and open tubule scores were compared statistically using Kruskal–Wallis by ranks, with a post-hoc Bonferroni test for multiple comparisons as needed.

Bond-strength values were analyzed for normal distribution using the Kolmogorov–Smirnov test and homogeneity of variance. A one-way ANOVA was used, with a Bonferroni test for post-hoc comparisons as needed.

In all tests, the level of significance was set at $P < 0.05$. The data were analyzed using SPSS software (version 19.0 for Windows; SPSS, Chicago, IL, USA).

Results

Push-out bond-strength

Mean bond-strength values (\pm SD) are listed in Table 2. The normal probability plot showed that the residuals followed a normal distribution. Analysis of variance among the groups revealed

that $P = 0.0051$, considered very significant. The Bonferroni test showed a significant difference between group 1 and the other groups only in the apical region of the post space ($P = 0.004$).

Table 2. Bond-strength values (expressed as MPa) in coronal and apical areas in each group

Region	Bond strength		
	Group 1	Group 2	Group 3
Coronal	14.346 ± 2.970^a	12.854 ± 4.925^a	14.331 ± 3.860^a
Apical	13.406 ± 3.740^a	6.130 ± 3.930^b	9.184 ± 3.920^b

1. Values are given as mean \pm SD.
2. The same superscript letters indicate statistically non-significant differences ($P > 0.05$).

Failure modes

Failure modes are shown in Table 3. More than 95% of the failures in each group were either adhesive failures between dentin and resin cement or mixed failures. Cohesive failures within resin cement occurred only rarely. No cohesive failures within the dentin were observed. No differences in failure modes were observed between coronal and apical regions.

Table 3. Failure modes of the test groups

Group/region	Failure mode			
	Type I	Type II	Type III	Type IV

1. Type I, adhesive failure between dentin and resin cement; type II, cohesive failure within resin cement; type III, cohesive failure within dentin; type IV, mixed failure.

Group/region	Failure mode			
	Type I	Type II	Type III	Type IV
Group 1				
Coronal	11	0	0	7
Apical	10	2	0	10
Group 2				
Coronal	12	0	0	4
Apical	17	2	0	6
Group 3				
Coronal	13	1	0	3
Apical	19	2	0	4

Scanning electron microscopy evaluation

Mean values and SD of open tubule and debris scores for each group are reported in Tables 4 and 5. The kappa test confirmed intra-examiner reliability ($\kappa = 0.91$).

Table 4. Open tubule scores in coronal and apical locations in each group

Region	Open tubule score		
	Group 1	Group 2	Group 3
1. Values are given as mean \pm SD.			
2. Superscript letters indicate significant differences according to <i>post-hoc</i> comparison ($P < 0.05$).			
Coronal	0.307 ± 0.480^a	0.462 ± 0.519^a	0.385 ± 0.506^a
Apical	0.615 ± 0.506^a	0.692 ± 0.480^a	0.692 ± 0.480^a

Table 5. Debris scores in coronal and apical locations in each group

Region	Debris score		
	Group 1	Group 2	Group 3
1. Values are given as mean \pm SD.			
2. Superscript letters indicate significant differences according to <i>post-hoc</i> comparison ($P < 0.05$).			
Coronal	0.769 ± 0.599^a	0.846 ± 0.555^a	0.762 ± 0.726^a
Apical	0.923 ± 0.640^a	1.538 ± 0.519^b	1.477 ± 0.640^b

A multiple comparison test revealed that the use of a plastic or cross-linked gutta-percha obturator significantly influenced the debris score, but not the open tubule score. Debris scores were significantly higher in the apical portion of groups 2 and 3 than in group 1 ($P < 0.05$), and open-tubule scores were not influenced by the obturation technique employed.

Discussion

Our results suggest that fiber-post bond strength is significantly influenced by the root-canal obturation technique employed. The apical bond strengths of samples obturated with both plastic and cross-linked gutta-percha carrier systems were significantly lower than those of samples obturated using the vertical condensation technique. Thus, the initial null hypothesis was rejected.

At the present time, FRC posts and composite cores are widely used to restore endodontically treated teeth with structural loss, as a result of their favorable modulus of elasticity, which is much closer to that of dentine. Their retention mechanism is based not only on friction against root canal walls but also on adhesive micro-mechanical and chemical retention [16, 40, 41]. However, proper bonding of the resin cement to both the post and root dentine is mandatory to take advantage of adhesive procedures in placing FRC posts in root-canal spaces [16, 40, 41]. The bond strength between resin cement and root dentine is generally lower than that obtained on the fiber post surface as a result of the surface characteristics of dentine [16, 40-42]. Such strength has been shown to be generally higher at coronal regions of the root-canal space, decreasing apically [43]. The number of dentinal tubules at the apical third is significantly lower than in other dentin locations [40-44]. As adhesion is enhanced by the penetration of resin into dentinal tubules, this anatomical feature could partly explain why the strongest adhesion occurs in the most coronal sections [45]. Other factors could be responsible for the low bond strength in the apical third, such as: incomplete polymerization of cement owing to a lack of light penetration, even with dual-cure cements [46]; easier application of adhesive systems [47]; more difficult distribution of resin cement with void formation [48]; and traces of gutta-percha and endodontic sealer entrapped in the deepest portions after post-space preparation [49]. Moreover, unfavorable C-factor may also play a significant role in overcoming shrinkage stresses in cement curing [3, 6, 16]. The apical third of the root-canal post space is where most of the smear layer, debris, and sealer/gutta-percha particles remain after post-space preparation and acid etching [40, 43]. Previous studies have suggested that the efficacy of the dentine adhesive system depends mostly upon removal of debris to improve the formation of the resin-dentine interdiffusion zone [27, 28, 40, 41]. Moreover, post-space depth is not directly proportional to fiber-post retention [50] or tooth fracture resistance [51]. Therefore, in this study, an 8-mm post space was prepared and two sections (coronal and apical) were evaluated.

In the present study, the number of open tubules visible after etching was similar in all groups, in both coronal and apical sections. By contrast, debris removal was generally better in coronal post-space sections, whereas in apical sections the endodontic obturation technique significantly influenced cleaning of the radicular dentine. Both carrier-based obturation systems showed a comparable amount of debris on post-space walls, which was greater than that observed in samples obturated using a continuous-wave technique. This finding, based on scanning electron microscopy images, is partially corroborated by the bond-strength results. In this study, the push-out test was used to evaluate the bond strength of fiber posts cemented in root canals filled using various techniques, taking into consideration the amounts of open tubules and remaining debris. The push-out test appeared to be more reliable and efficient in terms of evaluating the bond strength of fiber posts adhesively luted than were the trimming and non-trimming versions of the microtensile technique [52]. First of all, the apical post-space dentin surfaces in the Thermafil and Guttacore groups were mostly covered with debris, which acts as a barrier; this may have prevented infiltration of adhesive into the dentinal tubules and also, importantly, within the collagen fibrils network. However, a comparable number of dentinal tubules were observed in all samples; this was not proportional to the bond-strength results. Therefore, within radicular dentine, and particularly in apical sections, it is difficult to infiltrate all opened tubules with adhesive systems to create a uniform hybrid layer with resin tags. Therefore, debris remnants could have a greater influence on bond strength.

In the current study, lower bond strength was demonstrated in the apical regions of samples obturated using the Thermafil and Guttacore systems. A possible explanation of these results is that the carrier, whether in plastic or in cross-linked gutta-percha, does not interfere with post-space preparation using dedicated drills. The thermoplasticized alpha gutta-percha is probably more difficult to remove from dentinal walls, particularly in the deeper post-space area, impairing adhesive procedures in the root canal. Several studies have affirmed that the Thermafil obturation technique yields a significantly greater gutta-percha-filled area compared with the lateral condensation and system B techniques, reducing the sealer component [30, 42]. Moreover, the Thermafil system results in less leakage than the lateral condensation technique as a result of its superior adaptation to root canal walls [53]. Microtags of heated gutta-percha forced into the empty tubules have been observed to create a sort of mechanical bond between the thermoplasticized alpha gutta-percha and the canal walls [31, 42, 53]. Such results suggest two explanations: first, this technique is especially useful in canals of an irregular shape or with lateral dimensions [33, 54]; second, post-space preparation and, above all, effective dentine cleaning can be hindered by the use of thermoplasticized alpha gutta-percha in root canal obturation. Post-space drills may create a smear layer with plasticized remnants of sealer, gutta-percha, and Thermafil carrier, which may reduce bonding predictability as a result of friction heating [25, 26]. The Guttacore obturation system uses a carrier composed of a cross-linked, thermoset elastomer of gutta-percha to facilitate removal of the carrier and its debris during post-space preparation. However, our results seem to contradict this property, especially in the apical region in which the amount of debris directly affected the fiber-post bond strength. By contrast, the coronal portion of the post space is the area most accessible to root-canal-wall cleaning, and thus effective fiber-post adhesion was obtained using all of the endodontic obturation techniques tested in this study [28].

Fracture analysis is an important adjunct to the push-out test. In the present study, most failures were of an adhesive or mixed mode, indicating that the cement–dentin interface represents the weak zone in the bonding interface. This finding is directly related to the traces of gutta-percha and endodontic sealer that may remain on the dentinal walls after post-space preparation [39, 49], which was observed particularly when thermoplasticized alpha gutta-percha was employed.

In conclusion, within the limitations of an in-vitro study, we found that the use of thermoplasticized alpha gutta-percha, with either Thermafil or Guttacore, seemed to hinder cleaning of root-canal post-space walls performed to enhance fiber-post bond strength, and that this was most apparent in apical regions. Additionally, the presence of either a plastic or a cross-linked gutta-percha carrier does not facilitate adhesive procedures for fiber-post luting, leading to reduced bond strength in the most apical regions of the post space. For these reasons, further in-vitro studies should explore the use of a chelating agent before luting to achieve a cleaner dentinal surface before adhesion.

Conflicts of interest

The authors declare no conflicts of interest.

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