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Effect of endodontic sealers on push-out bond strength of CAD-CAM or prefabricated fiber glass posts

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Abstract: This study aimed to evaluate the effect of endodontic sealer (ES) on bond strength (BS) of prefabricated or milled-CAD-CAM (computer-aided design and computer-aided manufacturing) glass-fiber-posts (GFP). Canals of 90 single-rooted teeth were prepared for filling by the single-cone technique with gutta-percha and one of the following ES: AH Plus (epoxy resin), Endofill (zinc-oxide and eugenol), and Bio-C Sealer (calcium-silicate). After post-space preparation, tooth-specimens were equally divided in half according to type of GFP to be used. In the half to receive milled-CAD-CAM posts, tooth specimens were molded with acrylic resin to obtain replicas. These were scanned to enable the laboratory to produce the milled-CAD-CAM GFPs (Fiber CAD Lab, Angelus) by the subtractive technique. The other half of samples received prefabricated GFPs (Exacto, Angelus) (n=15). The GFPs were cemented with dual-cure resin cement (Panavia F2.0, Kuraray). Each root was sectioned into two slices *per* root region (cervical, middle, apical) that were subjected to the push-out BS test, in a universal testing machine. Failure mode (FM) was classified by scores. The BS data were submitted to generalized linear model analyses, while FM was analyzed using the chi-square test (a=0.05). BS showed no significant difference among the three ES ($p > 0.05$). BS was significantly higher for prefabricated (mean 10.84 MPa) versus milled-CAD-CAM GFPs (mean 6.94 MPa) ($p < 0.0001$), irrespective of ES. The majority showed mixed failures. It could be concluded that type of ES did not affect BS of GFPs to dentin, and prefabricated-GFPs had higher bond-strength than customized-milled-CAD-CAM GFPs.

Keywords: Endodontics; Dental pins; Dentin-Bonding Agents.

Introduction

Endodontically treated teeth often exhibit extensive structural loss, and their rehabilitation requires the use of intraradicular retainers. Retainers with cast metal cores are the traditional type, but they have major drawbacks, such as unfavorable esthetics, rigidity, which can lead to catastrophic root failures.[1] Despite having similar clinical performance to metal posts,[2] glass fiber posts (GFPs) have been the choice for rehabilitation of endodontically treated teeth. GFPs are esthetic and have an elastic modulus similar to that of dentin, providing more homogeneous distribution of loading forces throughout the tooth structure.[3] GFPs can either be prefabricated or milled in CAD-CAM (computer-aided design and computer-aided manufacturing). For the latter, impression of the post space may be obtained by laboratory scanning of acrylic resin or silicone replicas or by direct intra-oral scanning, resulting in posts with similar sealing ability.[4] The advantage of the CAD-CAM GFP is its improved adaptation to the root canal with a reduced resin cement thickness.[5,6] The smaller the resin cement thickness, the less polymerization shrinkage occurs, which can lead to higher bond strength between dentin and GFPs.[7]

Adhesion failures may lead to the detachment of post and, consequently, the entire rehabilitation may be lost. Many factors have been associated with the retention of GFPs.[8] One of these may be related to the root third, since reports have stated that resin material polymerization in the most apical regions of the root canal occurs without good light intensity, and commonly leads to lower bond strength in the apical third than in the other thirds.[9] In fact, a systematic review[10] showed that glass fiber posts bond better to the cervical region of the root canal bond than to apical region. Despite this, studies have demonstrated that depending on GFP adaptation[11] and resin cement used,[12] bond strength is not affected by the root third.

Another factor that may affect retention of glass fiber posts may be related to the type of endodontic sealer used to fill the root canal system. Residual cement may adhere to the dentin walls after preparation of the intraradicular space, and adversely affect cementation of GFP.[13,14] Among the endodontic sealers used, the epoxy resin-based types, such as AH Plus (Dentsply), can be considered the gold standard, owing to their physicochemical properties, such as sealing capacity and non-interference in the bond strength of GFPs cemented with resin cements.[14] However, their main limitation is the absence of bioactive properties.[15]

Another option of endodontic sealer is the zinc oxide and eugenol-based material.[13] This material should be avoided when planning to use GFPs, because it may interfere in the adhesion of resin cements.[14] This is because eugenol is a phenolic compound that releases free radicals, and these interact with the monomers of resin compounds, thus they inhibit triggering of the polymerization process, affecting the degree of conversion.[16]

Calcium silicate (bioceramic) sealers have been gaining prominence as endodontic filling materials. Their main advantages are biocompatibility, bioactivity, radiopacity, high pH, and calcium-ion release. Among the calcium silicate sealers, Bio-C Sealer (Angelus) is a relatively new material. Despite being highly soluble, the bioactive potential of Bio-C Sealer occurs as consequence of this property, even after setting. This is because when in contact with humidity, the material hydrates, sets and releases active ions, such as Ca and OH^-, which are responsible for the alkaline pH of this cement. This alkaline environment positively affects apical repair and contributes to the formation of mineralized tissue.[15]

However, bioceramic sealers can also impair bonding of resin agents to the root canal walls.[17] Reports have also stated that micromechanical and chemical interaction between calcium-silicate based sealer and root wall occurs, forming tag-like structures and a "mineral infiltration zone", resulting from the precipitation of calcium phosphate and calcium carbonate within dentin tubules.[18] Despite this apparent drawback of calcium silicate sealers, there is a scarcity of studies in literature that confirm the effect of this type of sealer on the bond strength of glass fiber retainers, particularly with regard to milled CAD-CAM GFPs.

The aim of this study was to evaluate the effect of different endodontic sealers (based on zinc oxide and eugenol, epoxy resin or calcium silicate) on the push-out bond strength of prefabricated or milled GFPs, cemented with dual self-etching resin cement (Panavia F2.0, Half kit, Kuraray, Japan). The null hypotheses in this study were that there would be no difference in bond strength when using different endodontic sealers (H01) or using different GFPs (whether prefabricated or milled) cemented with dual self-etching resin cement (H02), in the cervical, middle or apical thirds of the root canal (H03).

Methodology

Ethical aspects

This research was approved by the Local Research Ethics Committee - CAAE number 22323019.8.0000.5374.

Sample size calculation

Sample size was calculated considering the split-plot design, with the plots being represented by the factors "endodontic sealer" at three levels and "type of intraradicular retainer" at two levels. Sub-plots were represented by the factor "root third" at three levels. The sample size of 15 teeth in each group (90 teeth for the entire experiment) provided a power of 80% (β = 0.20) to detect an effect size (f) of 0.30 for the plots and a f = 0.18 for the sub-plot and interactions. Sample size calculation was performed with G*Power analysis program.[19]

Endodontic treatment

Ninety single-rooted pre-molars, extracted for periodontal or orthodontic reasons, were washed under running water, and stored for up to two months in 0.1% thymol solution.[20,21] Then, they were sectioned below the cemento-enamel junction perpendicular to the tooth axis, using a diamond disk under cooling, leaving a standardized 15 mm length of each root.[2,7]

The roots were instrumented with Hyflex EDM One File Rotary Files (Coltene, Switzerland) 25/~, and X-Smart Plus engine (Dentsply/Maillefer, Ballaigues, Switzerland), as well as LK #10 and #15 (Dentsply/Maillefer, Ballaigues, Switzerland), according to the manufacturer's instructions. A 2.5% sodium hypochlorite solution was used as an irrigating solution, in addition to 17% EDTA (ethylenediamine tetra-acetic acid). The canals were dried with absorbent paper tips. The teeth were divided into three experimental groups, according to the endodontic sealer that was to be applied: Endofill (Dentsply Maillefer, Ballaigues, Switzerland), AH Plus (Dentsply Detrev, Konstanz, Germany) and Bio-C Sealer (Angelus, Londrina, PR, Brazil). The sealers were manipulated according to the guidelines of the respective manufacturers, described in Table 1. The canals were filled using the single gutta-percha cone technique (Odous de Deus, Belo Horizonte, Brazil). An ultrasonic tip (E10, Helse Ultrasonic, Ocoee, USA) was used to cut and vertically condense the gutta-percha material.

Preparation and cementation of GFPs

The roots were kept at 100% humidity and 37°C for 48 hours, until complete polymerization of the endodontic sealers. Next, the most cervical 10 mm of each canal was prepared with #3 and #4 Largo drills (Dentsply-Maillefer, Ballaigues, Switzerland), and then with the drill from the prefabricated GFP kit (Exacto, Angelus, Londrina, Brazil), size # 2, at low-speed. A 5-mm remainder of sealing material was left in the apical region.

At this point, the teeth were subdivided into two experimental groups, according to the type of GFP used: prefabricated GFPs (glass fiber posts), or milled and customized CAD-CAM (computer-aided design/ computer-aided) posts. Therefore, in the present study six experimental groups were proposed (three endodontic sealers x two GFP types) (n = 15).

For the groups to be fitted with the milled CAD-CAM GFPs, Vaseline was applied to the root canals that were molded with red acrylic resin (Duralay, Polidental Cotia, SP, Brazil). In order to obtain the milled CAD-CAM GFPs, the above-mentioned molds were sent to the prosthesis laboratory (L.B. de Aguiar, Salvador, Brazil) to obtain the milled CAD-CAM GFPs. Here the acrylic resin patterns were scanned using a three-dimensional bench scanner (Ceramill Scanner map 400, Ammanngirrbach, Koblach, Austria). Then, the data were processed by a CAD software program (Ceramill Mind, Ammanngirrbach, Koblach, Austria), and a 3D digital model was developed from a block made of glass fiber and epoxy resin (Fiber CAD Post & Core, Angelus, Londrina, Brazil), and milled with a Ceramill Motion 2 milling machine (Ammanngirrbach, Koblach, Austria).

The prefabricated GFPs used in this research were standardized with Exacto model size # 2 posts (Angelus, Londrina, Brazil), irrespective of the tooth specimen in which it would be inserted.

The canal space in all the teeth was cleaned with 1 mL of 17% EDTA (Biodynamics, Ibiporã-PR, Brazil),

Table 1. Materials used and method of application.

Material	Manufacturer	Batch number	Composition	Instructions for use
Endodontic Sealer ENDOFILL	Dentsply	367582M	POWDER: Zinc Oxide, Hydrogenated Resin, Bismuth Subcarbonate, Barium Sulfate and Sodium Borate LIQUID: Eugenol, Sweet Almond Oil and BHT	Dispense 3 drops of the liquid onto a mixing plate, add powder to the liquid gradually, until it reaches a consistency that when the spatula is put on the mixture and it is lifted, a cement thread would be formed, which would break when it reached a length of approximately 2 cm. The working time is 20 minutes at a temperature of 37°C.
Endodontic Sealer AH PLUS	Dentsply	364584L	PASTE A: Bisphenol-A epoxy resin, Bisphenol-B epoxy resin, Calcium tungstate, Silica, Iron oxide pigments PASTE B: Dibenzyldiamine, Aminoadamantane, Tricyclodecane-diamine, Calcium tungstate, Zirconium oxide, Silica, silicone oi.	Using a metal spatula, mix equal volume units of paste A (amber color) and paste B (white color) of the AH Plus root canal sealant on the mixing plate provided in the packaging. Mix until a homogeneous mixture is obtained. Tighten the tube cap firmly after use. Do not change the tube caps. The white cap belongs to folder A; the gray cover belongs to paste B.The working time is 4 hours at 23°C, the setting time is 24 hours at 37°C.
Endodontic Sealer BIO-C SEALER	Angelus	53030	Calcium silicates, calcium aluminate, calcium oxide, zirconium oxide, iron oxide, silicon dioxide and dispersing agents	Ready-to-use product. Working time: 60 minutes. Setting Time: 120 minutes (2 hours) after insertion into the canal.
Self etching primer ED PRIMER II	Kuraray	111	LIQUID A: 2-Hydroxyethyl methacrylate (HEMA), 10-Methacryloyloxydecyl dihydrogen phosphate (MDP), Water, N-Methacryloyl-5 amino salicylic acid, Accelerators. Liquid B: N-Methacryloyl-5 amino salicylic acid, Water, Catalysts, Accelerators. LIQUID B: N-Methacryloyl-5 amino salicylic acid, Water, Catalysts, Accelerators.	Mix 1 drop of Ed primer A and B for 20 seconds and apply inside the canal. Remove excess primer with paper tips. Leave to act for 60 seconds.
Resin Cement PANAVIA 2.0	Kuraray	111	PASTE A: 10-Methacryloyloxidecyl dihydrogen phosphate (MDP), Hydrophobic aromatic dimethacrylate, Hydrophobic aliphatic dimethacrylate, Hydrophilic aliphatic dimethacrylate, Silanized silica particle, Silanized colloidal silica, dl-Camphorquinone. PASTE B: Hydrophobic aromatic dimethacrylate, Hydrophobic aliphatic dimethacrylate, Hydrophilic aliphatic dimethacrylate, Silanized barium glass particle, Surface-treated sodium fluoride, Catalysts, Accelerators, Pigments. The total amount of inorganic particles is approx. 59 vol%. The size of the inorganic particles is between 0.04 μm and 19 μm.	Apply 70% alcohol to the post for 5 seconds, wash and dry. Apply silane, apply a light jet of air to remove the excess and wait for 1 minute. Mix paste A and paste B for 20 seconds in equal proportions. Apply to the post. Position and press. Remove the excess. Light polymerize for 20 seconds.
Prefabricated glass fiber post EXACTO #2	Angelus	101641	Glass fiber (80%), epoxy resin (20%)	Apply 70% alcohol to the post for 5 seconds, wash and dry. Apply silane.
CAD-CAM glass fiber Post FIBER CAD LAB POST & CORE	Angelus	50205	Glass fiber (75-80%), epoxy resin (20-25%)	Apply 70% alcohol to the post for 5 seconds, wash and dry. Apply silane

under agitation, using E1 and R1 ultrasonic tips (Helse, São Paulo, Brazil) and the Piezon Master 200 Portable Ultrasound bath(?) (EMS, São Paulo, Brazil) before cementation of the posts. This cleaning process was performed for approximately five minutes, until no further sealing material could be observed by visual inspection. Then, the samples were washed with 5 ml of distilled water.

After post space preparation, all the teeth were stored at 100% humidity and 37°C for seven days, a period deemed necessary to process the laboratory phase of producing the milled CAD-CAM GFPs. The Groups that received these GFPs required post adjustments to enable them to fit into the canals. The surface of the post was subjected to wear using blue liquid carbon (Kota, Cotia, Brazil) and abrasive discs (Soft-Lex Pop On, 3M ESPE, St. Paul, USA), until the post could be passively inserted into the root canal.

Both prefabricated and CAD-CAM GFPs were fixed in the canals with self-etching dual-cure resin cement (Panavia F2.0, Half kit, Kuraray, Medical, Japan), according to the manufacturer's instructions., A wireless LED light device (Valo Cordless, Ultradent, Indaiatuba, Brazil), operating in standard mode (1000 mW / cm^2) was used for light-curing for 90 seconds. The GFPs were randomly cemented. Then, the teeth were stored for 48 hours, at 100% relative humidity and 37°C.

Push-out test

The teeth were mounted on blocks containing transparent polyester resin, and then sectioned to obtain 1-mm-thick slices. Two slices per root third were obtained (cervical, middle, apical). The slices were adapted onto the testing machine to perform the push-out test (DL 2000; EMIC, São José dos Pinhais, Brazil). They were positioned so as to align the tip of the 1.0-mm diameter load applicator with the center of the post, and the 3.0-mm-diameter hole of the metal base. The load was applied at a speed of 0.5 mm/min until the posts were completely displaced. The value obtained in Kgf (kilogram-force) was used to calculate the bond strength in MPa (Mega Pascals), using the following formula:[13]

$$A = \pi (R + r) \sqrt{h^2 + (R - r)^2},$$

where: $\pi = 3.1416$, R = fiber post radius measured on the cervical side of the slice, r = fiber post radius measured on the apical side of the slice, and h = height of the root slice.

Failure pattern analysis

After the push-out test, the specimens from each group were assessed with the aid of a stereomicroscope at 40x magnification, to establish the failure types. These were classified as: a) adhesive failure between resin cement and GFP, b) adhesive failure between resin cement and dentin; c) dentin cohesive failure; d) resin cement cohesive failure; e) GFP cohesive failure and f) mixed failure.

Statistical analysis

Descriptive and exploratory analyses of the bond strength data were performed. Previous analyses had indicated that the data did not meet the assumptions of variance analysis (ANOVA). A generalized linear model was then applied, considering the study design of subdivided plots. The chi-square test was applied to the failure type analysis. All the analyses were performed using the R program[14] at a 5% level of significance.

Results

There was no significant difference among the three endodontic sealers in terms of bond strength ($p > 0.05$) (Table 2). The bond strength of the three cements was significantly higher for the prefabricated GFP than the CAD-CAM customized GFP ($p < 0.05$). The bond strength for the prefabricated GFP was significantly lower in the apical third than the middle and cervical thirds ($p < 0.05$), with no significant difference between the latter two ($p > 0.05$). As regards the CAD-CAM milled GFP, the bond strength was significantly higher in the cervical third, and lower in the apical third, with a significant difference among the three thirds ($p < 0.05$).

There was a significant association among the Groups and the failure modes considering all root thirds ($p < 0.05$) (Table 3). Considering the analysis of each root third separately, in the cervical third, no association was observed between the Groups

Table 2. Mean (standard deviation) and median (minimum; maximum) of resistance (MPa) considering endodontic cement, intraradicular retainer and root third.

Intraradicular retainer	Root third	Endodontic cement - bond strength values in Mpa					
		Endofill		AH Plus		Bio-C	
		Mean (standard deviation)	Median (minimum; maximum values)	Mean (standard deviation)	Median (minimum; maximum values)	Mean (standard deviation)	Median (minimum; maximum values)
Milled CAD-CAM glass fiber post	Cervical	7.52 (5.31) Aa	6.42 (0.84; 16.95)	9.91 (4.57) Aa	8.60 (3.28; 17.33)	9.68 (3.11) Aa	9.20 (5.55; 14.45)
	Middle	5.00 (4.41) Ab	4.44 (0.34; 13.97)	7.75 (3.83) Ab	7.56 (2.59; 14.75)	8.41 (6.79) Ab	5.39 (0.70; 17.72)
	Apical	4.26 (4.33) Ac	3.62 (0.53; 15.64)	5.00 (3.94) Ac	3.17 (0.89; 13.05)	5.04 (3.36) Ac	5.13 (0.01; 10.72)
Prefabricated glass fiber post	Cervical	*10.41 (4.29) Aa	10.26 (2.99; 19.40)	*12.07 (3.88) Aa	11.50 (4.74; 18.73)	*13.00 (3.74) Aa	11.60 (7.09; 19.79)
	Middle	*10.57 (4.85) Aa	11.51 (2.01; 19.07)	*13.48 (4.19) Aa	13.32 (5.54; 21.27)	*11.08 (4.89) Aa	11.52 (2.44; 20.86)
	Apical	*8.18 (4.51) Ab	7.53 (1.02; 15.13)	*10.34 (5.27) Ab	11.26 (1.43; 17.63)	*8.43 (5.21) Ab	7.80 (1.91; 19.30)

*differs from the milled CAD-CAM GFP in the same endodontic cement and root third ($p \leq 0.05$). Different letters (Capital letters in lines and lowercase in columns comparing thirds within each type of post) differ from each other ($p \leq 0.05$), p (cement) = 0.2004; p (post) < 0.0001; p (third) < 0.0001; p (cement vs. retainer) = 0.6022; p (cement vs. third) = 0.6423; p (retainer vs. third) = 0.0107; p (cement vs. retainer vs. third) = 0.5151.

Table 3. Frequency (%) of the failure type due to endodontic cement, intraradicular retainer and root third.

Endodontic cement	Failure type	Intraradicular retainer					
		Root third					
		CAD-CAM glass fiber post - n (%)			Prefabricated glass fiber post - n (%)		
		Cervical	Middle	Apical	Cervical	Middle	Apical
Endofill	Adhesive: Dentin and cement	3 (11.1)	6 (22.2)	9 (33.3)	3 (10.3)	4 (13.8)	2 (8.3)
	Adhesive: Post and cement	2 (7.4)	0 (0.0)	2 (7.4)	1 (3.4)	2 (6.9)	1 (4.2)
	Cohesive: Post	1 (3.7)	1 (3.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Cohesive: Cement	0 (0.0)	0 (0.0)	0 (0.0)	1 (3.4)	0 (0.0)	1 (4.2)
	Mixed	21 (77.8)	20 (74.1)	16 (59.3)	24 (82.8)	23 (79.3)	20 (83.3)
AH Plus	Adhesive: Dentin and cement	0 (0.0)	1 (3.3)	2 (7.4)	0 (0.0)	0 (0.0)	1 (3.3)
	Adhesive: Post and cement	3 (13.0)	2 (6.7)	3 (11.1)	2 (6.9)	1 (3.3)	0 (0.0)
	Cohesive: Post	0 (0.0)	0 (0.0)	1 (3.7)	0 (0.0)	0 (0.0)	0 (0.0)
	Cohesive: Cement	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Mixed	20 (87.0)	27 (90.0)	21 (77.8)	27 (93.1)	29 (96.7)	29 (96.7)
Bio-C	Adhesive: Dentin and cement	2 (8.3)	6 (21.4)	1 (3.4)	1 (3.7)	0 (0.0)	1 (3.4)
	Adhesive: Post and cement	1 (4.2)	0 (0.0)	1 (3.4)	1 (3.7)	2 (7.1)	1 (3.4)
	Cohesive: Post	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Cohesive: Cement	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (3.4)
	Mixed	21 (87.5)	22 (78.6)	27 (93.1)	25 (92.6)	26 (92.9)	26 (89.7)

p(all thirds) = 0.0217; p(cervical) = 0.5572; p(middle) = 0.0363; p(apical) = 0.0143

and the type of failure ($p > 0.05$). For the middle and apical thirds, the association was significant ($p < 0.05$). For these thirds, although the majority of groups exhibited the mixed-type failure, in the Endofill sealer - CAD-CAM group, over 20% of the posts had adhesive failure between the dentin and the resin cement in the middle and apical thirds. This was also observed for the Bio-C Sealer - CAD-CAM group in the middle third."

Discussion

The results of the present study showed that there was no significant effect of the endodontic sealers on the bond strength of GFP to dentin; hence, the first null hypothesis (H01) was accepted. This lack of effect could have occurred because of the root canal cleaning protocol, since the intraradicular canal was cleaned by ultrasonic agitation with 17% EDTA prior to cementation, followed by washing with distilled water. The mechanical activation with complementary action of EDTA solution, is capable of removing the smear layer by calcium dissolution, without damaging the dentin.[23] According to the research by Bengoa et al.,[22] Bio-C Sealer endodontic sealer impaired the bond strength of prefabricated GFP, when canals were cleaned with ultrasonic agitation using distilled water. In fact, the dentin cleaning protocol adopted by the majority of studies is merely to wash with distilled water, without using ultrasonic agitation.[5,13,14,24,25] This could be why the root canal cleaning was not effective in the case of the cited studies, and negatively influenced the results for endodontic sealers based on zinc oxide and eugenol or bioceramics.

In cases of need for endodontic retreatment, reports have stated that the bioceramic sealers were particularly more difficult to remove from dentinal tubules after months of contact with intraradicular dentin, because they interacted chemically with the dentin walls.[26] In another study, in which bioceramic sealer was removed immediately after its application,[27] calcium silicate-based bioceramic sealer was completely removed from the dentin surface. In the present study, the endodontically treated teeth were stored for a relatively short time, 48 hours, to allow the sealer to set and were subsequently prepared for post placement. So, it is unlikely that residues of endodontic sealer influenced the bond of posts to dentin, especially with the cleaning protocol adopted in the present study.

Despite taking care to perform the cleaning protocol meticulously, the researchers expected the zinc oxide-eugenol cement to have a negative effect on the bond strength, because eugenol prevents adequate polymerization of resin cements.[13,14] However, this was not observed in the present study. In addition to the efficient irrigation achieved with EDTA in completely removing the endodontic sealer residue, the canals were cleaned and stored for seven days until the retainer was cemented. This storage procedure was needed to gain time to undertake the laboratory phase of making the milled retainers. This time factor may have also helped release the residual eugenol, despite other studies did not having confirmed any positive association between time elapsed after endodontic treatment and eugenol-based sealer and post cementation on bond strength to dentin.[14,28]

The predominant type of failure in this study was mixed failure, as corroborated by the research conducted by Garcia et al.[29] with CAD-CAM customized GFP, and RelyX ARC resin cement (3M ESPE, USA). This result was contrary to that of other studies, which showed that the adhesive failure between resin cement and dentin was the most prevalent type.[14,22,23] In their study on dual-cure resin cement (Panavia F 2.0 Kuraray), Dibaji et al.[13] found a predominant mixed failure mode for the group filled with AH Plus, and adhesive failure for the group filled with BC Sealer (calcium silicate) and Dorifill (zinc oxide and eugenol). These results were similar to those of the present study, since the majority of the posts in all the groups had mixed failures. However, over 20% of the posts in the Endofill - CAD-CAM group had adhesive failure between dentin and cement in the middle and apical thirds. This failure was also observed in the Bio-C Sealer - CAD-CAM group in the middle third.

The results of this research indicated that the bond strength of the prefabricated post was significantly higher than that of the CAD-CAM glass-fiber post. Thus, the second null hypothesis (H02) was rejected. Although the present study did not measure the cement thickness, previous studies have reported that CAD-CAM posts showed better adaptation to the root canal, and this led to needing a thinner layer of resin cement with fewer voids of cements.[6,30] This could reflect in higher bond strength to dentin, but the results of the present study demonstrated the contrary. Therefore, some differences in surface properties between prefabricated and CAD-CAM posts could explain the lower bond strength found for the latter type of post. It has been demonstrated that the milled glass-fiber posts have a lower surface roughness, fibers with smaller diameters or overlapped in some regions than the prefabricated glass-fiber posts.[31] Moreover, after milling, the CAD-CAM posts tested needed many adjustments to enable them to adapt to the root canals; this was possibly related to the scanning method used. In the present study, acrylic resin patterns were scanned and not the root canal itself, directly. Scanning the resin pattern resulted in milled posts with worse adaptation[32] and need for using a bigger cement thickness[33] than when posts are made in a complete digital workflow.

The need for CAD-CAM post adjustments, a procedure that was performed in the majority of samples in the present study, was not reported in the study of Garcia et al.,[29] in which the same bench scanner was used to copy the resin acrylic pattern and the same milling machine. Thus, the CAD-CAM GFP adaptation may depend on other variables of the digital system or even on composition of the glass fiber CAD-CAM block.[29] Another important procedure to decrease the need for post adjustment would be to spray the acrylic resin pattern with scanning powder, as done by Eid et al.,[5] who also fixed the resin cement space at 80 µm in the software program, to ensure passive post insertion. In the present research, the CAD-CAM posts had to be adjusted with abrasive paper discs to enable them to fit them into the root canals, and this may have altered the adaptation in some regions of the canal.

Relative to comparison of the apical thirds, there were differences in the bond strength along the root thirds for both GFPs, thus leading to rejection of the third hypothesis (H03). These results may have been related to the lower polymerization level of the dual resin cement (Panavia F2.0, Kuraray Medical, Japan) in the most apical areas of the canal. This could be attributed to the greater distance of the light polymerization device from the most apical areas of the root canal, which resulted in less monomer conversion and lower bond strength.[9] Roots were shortened to 15 mm to standardize the length, and consequently, light distribution within the root canal during light curing, was similar to the methodology performed in previous studies.[35,36] It is possible to think that the procedure of shortening the root may have removed the cervical area, making the comparison between root thirds unfeasible. However, Galhano et al.[34] demonstrated that in single-rooted teeth that were shortened to 16 mm - a value similar to that proposed in the present study, the characteristics of cervical area were still preserved, exhibiting a different morphology with increased tubule density than in the middle and apical regions. In addition, for anatomical reasons the apical third has narrow irregular dentin, and a smaller number of dentinal tubules. Moreover, these tubules are generally sclerotic, which hinders the adhesion of resin cements.[36] Another explanation may be related to the endodontic sealer residues present in greater quantity in the apical region, such as residues containing eugenol, which can also interfere in the polymerization of the resin.[36]

Within the limitations of this in vitro study, the results of this research indicated that GFPs could be cemented in endodontically treated teeth that were filled with any of the endodontic sealers tested (Endofill, Bio-C Sealer or AH Plus), provided that cleaning protocols, such as ultrasound associated with EDTA solution, were applied. Furthermore, in terms of bond strength, the results indicated that prefabricated posts could continue to be an adequate choice for rehabilitating endodontically treated teeth. Apart from the need for adjustments and the lower bond strengths of the CAD-CAM versus the prefabricated GFP posts do not prevent the former from being used. It is important to cite other advantages of the clinical procedure with prefabricated GFP, such as installation in a single session and no need for provisional restorations, which may also increase the risk of root fractures. Future in vitro studies should be focused on long-term bond strength and other mechanical tests, such as fracture to load. Furthermore, comparative studies between prefabricated and customized milled CAD-

CAM posts still need to be conducted, especially comparing the distinct scanning processes that are available at present.

Conclusion

It was concluded that a) the type of endodontic sealer tested did not influence the bond strength of the dual self-etching resin cement; b) prefabricated GFPs showed higher bond strength values to dentin than those of the milled CAD-CAM option; c) there was a decrease in the bond strength of the prefabricated and milled GFPs along the root thirds.

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