Systematic Review
Endodontic therapy

Can intra-radicular cleaning protocols increase the retention of fiberglass posts? A systematic review

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Abstract: The presence of residues within the root canal after post-space preparation can influence the bond strength between resin cement and root dentin when using fiberglass posts (FGPs). Currently, there is no consensus in the literature regarding what is the best solution for the removal of debris after post-space preparation. This systematic review involved *"in vitro"* studies to investigate if cleaning methods of the root canal after post-space preparation can increase the retention of FGPs evaluated by the push-out test. Searches were carried out in PubMed (MEDLINE) and Scopus databases up to July2017. English language studies published from 2007 to July 2017 were selected. 475 studies were found, and 9 were included in this review. Information from the 9 studies were collected regarding the number of samples, storage method after extraction, root canal preparation, method of post-space preparation, endodontic sealer, resin cement, cleaning methods after post-space and presence of irrigant activation. Five studies presented the best results for the association of sodium hypochlorite (NaOCl) and ethylenediamine tetra-acetic acid (EDTA), while in the other 4 studies, the solutions that showed improved retention of FGPs were photon-induced photoacoustic streaming (PIPS), Qmix, Sikko and EDTA. The results showed heterogeneity in all comparisons due to a high variety of information about cleaning methods, different concentrations, application time, type of adhesive system and resin cements used. In conclusion, this review suggests that the use of NaOCl/EDTA results in the retention of FGPs and may thus be recommended as a post-space cleaning method influencing the luting procedure.

Keywords: Resin Cements; Root Canal Irrigants

Introduction

In the rehabilitation of endodontically treated teeth with extensive dental structure losses, the use of fiberglass posts (FGPs) is a viable alternative.[1] FGPs exhibit similar physical properties to dentin, such as elastic modulus, compressive strength, flexure, thermal expansion coefficient, and advantages, such as aesthetics and biocompatibility.[2,3,4]

The retention of the FGPs depends on the adhesive interaction and better adaptation between the resin cement and root dentin.[5] Failures of FGPs occur by root fracture or debonding between post and resin cement

while frequently occurring on the resin cement and root dentin.[4,6,7] These interfaces could be affected by several factors, such as orientations of dentinal tubules, presence of residues, endodontic sealers, type of adhesive system and cementation strategies.[8,9] Resin-based luting cements are used to promote mechanical adhesion between the monomers of the material and the collagen fibers of dentin, with consequent formation of the hybrid layer.[10] Cements and adhesive approaches have been proposed to bond FGPs to root dentin in the main available techniques, including conventional or self-adhesive resin cements. Dual polymerizing resin cements associated with previous dentin conditioning on etch and rinse adhesive systems have demonstrated good results; however, self-adhesive cements appeared as an alternative to avoid the critical drying step with less time for cementation because there is no requirement for pretreatment on root dentin.[11] In this sense, the chemical interaction between the acidic hydrophilic monomers and hydroxyapatite modifies the smear layer, thus ensuring the adhesion of the self-adhesive cements to dentin.[11,12]

The presence of residues in root canal walls, composed of the remaining sealer, gutta percha and smear layer debris, must be removed to open dentinal tubules to enhance the intertubular penetration of the adhesive system and avoid weakened areas in the bonding interface as to increase bond strength.[8,9,13,14] NaOCl, EDTA, phosphoric acid, and chlorhexidine are the most routinely used agents and have different chemical properties.[15] Moreover, activation methods of irrigation solutions have been used as an additional method to increase their effectiveness, such as the use of ultrasonic systems and laser devices.[16,17,18]

Despite the large number of *in vitro* studies in the literature, there is currently no consensus on the best solution for removing debris after post-space preparation, while it remains unclearif this can affect the bond strength of FGPs to root dentin.[19] Therefore, the objective of this study was to systematically review the literature using *in vitro* studies to investigate if cleaning methods of root canal after post-space preparation can increase the retention of FGPs evaluated by push-out test. The null hypothesis was that cleaning methods of the root canal after post-space would not influence the bond strength of FGPs to root dentin. The following research question was investigated: Does the method of root canal cleaning after post-space preparation influence the retention of a fiber post evaluated by push-out tests?

Methodology

Search strategy

This systematic review was conducted by following the guidelines of Transparent Reporting of Systematic Reviews and Meta-analyses (PRISMA-statement).[20] The review question was formulated by the following PICO[21] framework (Patient Population, Intervention, Comparison, and Outcome). The following keywords and their combinations were used: "Root Canal Preparation"[Mesh] OR "Canal Preparation, Root" OR "Canal Preparations, Root" OR "Preparation, Root Canal" OR "Preparations, Root Canal" OR "Root Canal Preparations" OR "root canal cleaning" OR "root canal irrigation" OR "post-space cleaning" OR "post-space preparation cleaning" OR "mechanical cleaning root space" OR "intracanal cleaning"; AND "fiber post" OR "fiber glass" OR "Post and Core Technique"[Mesh] OR "Post-Core Technic" OR "Post-Core Technics" OR "Technic, Post-Core" OR "Technics, Post-Core" OR "Post and Core Technic" OR "Post Technique" OR "Post Techniques" OR "Technique, Post" OR "Techniques, Post" OR "Post Technic" OR "Post Technics" OR "Technic, Post" OR "Technics, Post" OR "Dental Dowel" OR "Dowels, Dental" OR "Dental Dowels" OR "Dowel, Dental" OR "fiber glass post" OR "glass fiber post"; AND "post-space preparation" OR "post-space preparation" OR "endodontic procedures root canal" OR "deep post-space" OR "post-space".

Eligibility criteria

Literature on the topic in the English language, published from 2007 to July 2017, was selected. All *in vitro* studies that evaluated the method of root canal cleaning tested by push-out were included.

The inclusion criteria were as follows: *in vitro* studies that used human teeth, the push-out test was included in the methods, a fiber glass post was cemented, resin cement was used to fill the canal, and some irrigant solution method to clean the canal was used, whether activated or not. The exclusion criteria were as follows: studies that did not use human teeth, the push-out test was not described, use of eugenol endodontic sealer, use of solutions for pretreatment after the post-space to improve adhesion, and use of dental canal surface treatment prior to cleaning methods. Duplicated and published studies that did not meet the inclusion/exclusion criteria were excluded from this systematic review.

Screening and selection

A comprehensive electronic search was performed through PubMed (MEDLINE) and Scopus databases up to July 2017. A hand searching process was applied based on the references of selected articles. Two endodontic specialist reviewers (L.V.O. and C.C.G.M.) independently ran the described search for eligibility. The lists were then compared, and a definitive consensus regarding the inclusion of articles was reached by discussing each individual article

Data extraction and risk of bias

A data extraction form was developed by the authors to collect general information (title, year of publication, journal, authors, impact factor, aim of study, number of samples, storage after extraction, root canal preparation, method of post-space, moment (time) of post-space before FGPs cementation, endodontic sealer, post resin cement, method of cleaning of root canal after post-space, groups analyzed, presence of final activation, storage/aging, methodology of analysis of samples, hypothesis accepted or rejected, statistical results, conclusion). The JADAD scale[22] assesses the methodological quality of the studies, reporting any potential risk for bias. Each question of this three-point questionnaire needed to be answered with either a yes or a no. Authors elected to exclude all papers on the topic with a JADAD score of 3 or less. Two endodontic specialist reviewers (L.V.O. and C.C.G.M.) evaluated all of the selected studies.

Results

Based on this systematic review objective, the lack of information and the heterogeneity of the selected studies, it was not possible to perform valid quantitative analyses of the data or a subsequent meta-analysis. Therefore, a descriptive presentation of the data was adopted.

An initial electronic search identified 473 studies (Figure 1), and the hand searching process identified 2 studies[8,23] (total of 475 studies). The initial screening of the titles and abstracts resulted in 20 full-text papers that were read in full. The characteristics of the 9 included studies are summarized in Table 1.[8,17,19,23,24,25,26,27,28] Eleven studies that did not meet the inclusion criteria (Figure 1) were excluded.[29,30,31,32,33,34,35,36,37,38,39]

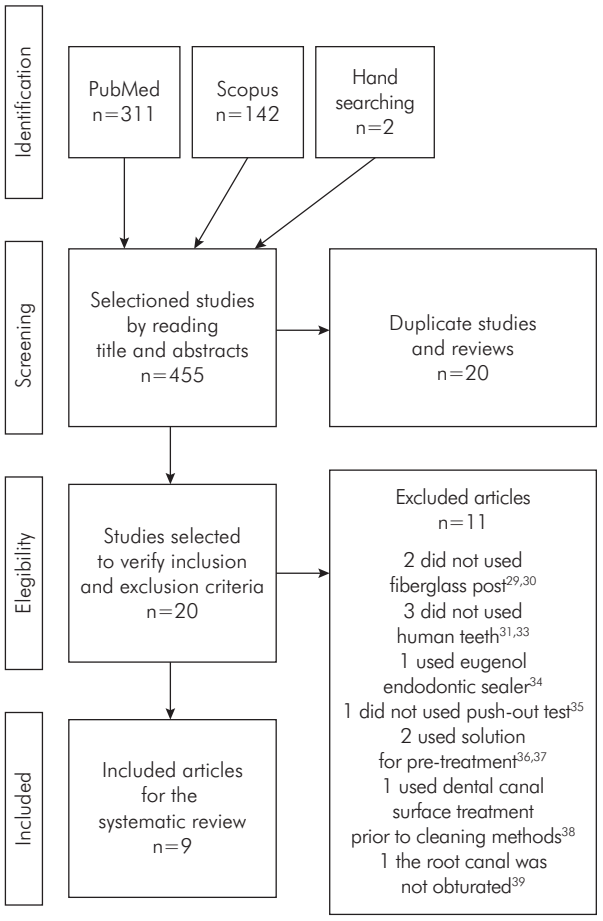

Figure 1. Flow diagram of the systematic review according to the PRISMA Statement.

Table 1. Summary of the characteristics of the 9 included studies.

Title	influence of root dentin treatment on the push-out bond strength of fibre-reinforced posts	Effect of different post space irrigation procedures on the bond strength of a fiber post attached with a self-adhesive resin cement	Effect of different irrigant activation protocols on push-out bond strength	Effect of QMix irrigant on bond strength of glass fibre posts to root dentine.	Effect of post-space treatments on the push-out bond strength and failure modes of glass fibre posts.	Various irrigation protocols for final rinse to improve bond strengths of fiber posts inside the root canal	Effect of different surface treatments on the push-out bond strenght of fiber post to root canal dentin	Does endodontic post space irrigation affect smear layer removal and bonding effectiveness?	Effect of post-space treatment on retention of fiber posts in different root regions using two self-etching systems.
Year	2017	2016	2015	2014	2013	2013	2009	2009	2008
Journal	brazilian Oral Research	The Journal of Prosthetic Dentistry	Lasers Med Sci	International Endodontic Journal	Australian Endodontic Journal	European Journal of Oral Sciences	Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology	European Journal of Oral Sciences	European Journal of Oral Sciences
Impact factor	0.937	1.515	2.461	2.842	0.885	1.607	1.262	1.607	1.607
Authors	moura et al.,	Kul et al.,	Ekim SNA, Erdemir A	Elnaghy AM.	Ansu et al.,	Bitter et al.,	Demiryurek et al.,	Gu et al.,	Zhang et al.,
Aim of study	to investigate the influence of different root dentin treatment protocols in experimentally weakened roots.	To compare the effects of different PSI procedures on the bond strength of fiber posts attached with selfadhesive resin cement (SARC).	To investigate the effects of irrigant activation techniques on the push-out bond strengths of fiber posts.	To investigate the effect of QMix irrigant compared with several other irrigating solutions on the bond strength of glass fibre posts to root dentine and on smear layer removal after post space preparation.	To evaluate the effects of different post-space treatments on push-out bond strength of glass fibre posts.	To analyze the effects of five different irrigation protocols (IPs) on the bond strengths of fiber posts luted using three different adhesive strategies.	To evaluate the effects of different surface treatments on the bond strength of a fiber post to dentin.	To evaluate smear layer removal, RDIZ, resin tags, and bond strength of the selfetch adhesive bonding to root canal dentin, using different irrigating solutions, and to test whether there is a relationship between smear layer removal and bond strength.	To evaluate the effect of different postspace treatments on the retention of fiber posts in different root regions when two self-etching systems are used.
Number of samples	42 maxillary canines	40 premolars	32 central incisors (n:4)	90 (n:15)	40 premolars	150 incisors (n:5)	60 maxillary incisors	66	48 premolars
Storage after extraction	0.1% thymol solution	distilled water	0.2 % thymol solution	0.5% chloramine T	0.5% chloramine T solution	0.5% chloramine-T solution for at least 1 yr after extraction.	5,25% NaOCl for 5 min, 0.9% saline solution at room temperature until the use	0.1% thymol solution	x
Root canal preparation	reciproc system in an electric motor	Rotary system -ProTaper NiTi; Dentsply	ProTaper rotary files - Denstply	ProTaper rotary system	Rotary system Protaper F3	Rotatory Mtwo, fille Flex master size 60	Mannualy shaped with K-files	Step-back filing to ISSO size 60	Manual K type files (Dentsply) and Gates Glidden drills
Method of post-space	heated endodontic pluggers and post drills	Peeso 1 reamer (Mani Inc), drill 1 of post (DT Light-Post system, Bisco Inc)	post drills size 1 (White Post DC, FGM drill)	post drills of the system (Rebilda post; VOCO)	drill of post system	100 roots: drill of post 4(Dentsply De Trey); 50 roots: drill of system FRC 3 (Ivoclair Vivadent)	post drills of the system	post drills	Pesso reamer, drill of post system
Moment (time) of post-space before gfps cementation	—	after 7 days of storage at 37° C in 100% humidity	after 1 week of storage at 37° C in 100% humidity	after 1 week of storage at 37° C in 100% humidity	after 24 hours of storage at 37° C in 100% humidity	after 24 hours in water	after 1 week of storage at 37° C in 100% humidity	thymol solution for 2 weeks	in water after 72 h
Endodontic sealer	aH Plus - Dentsply	AH Plus - Dentsply	AH Plus - Dentsply	AHPlus - Dentsply	AH26 - Dentsply	AHPlus - Dentsply	AH Plus - Dentsply	AH Plus - Dentsply	AH Plus - Dentsply
Resin cement	half of posts: RelyX U200 (3M ESPE, St. Paul, MN, USA) and the other half with Panavia F (Kuraray Noritake, Tokyo, Japan)	RelyX U200, 3M ESPE	Panavia F 2.0 - Kuraray	Dual-cure self-adhesive resin cement - i CEM; Heraeus Kulzer	Panavia F 2.0 - Kuraray	Multicore Flow (Ivoclair); Core X Flow(Dentsply); SmartCem (Dentsply);	Panavia F - Kuraray	Panavia F - Kuraray	dual-cure composite resin cement -Clearfil DC Core Automix; Kuraray
Method of cleaning after post-space	will be the experimental groups	Will be the experimental groups	procedure irrigant + 3 mL distilled water	Will be the experimental groups	Will be the experimental groups	Will be the experimental groups	Will be the experimental groups	Will be the experimental groups	Will be the experimental groups

Continue

Continuation

Groups analyzed	group 1: NaOCl: 2.5% NaOCl for 1 min; Group 2: NaOCl + EDTA: 2.5% NaOCl for 20 s, 17% EDTA for 20 and 2.5% NaOCl for 20s; Group 3: NaOCl + EDTA+US: three 20-s irrigation cycles with 2.5% NaOCl followed by 17% EDTA and 2.5% NaOCl for 20 s each	Group 1: 15 ml of distilled water. Group 2: 5ml of 5,25% NaOCl + 5 ml of 17%EDTA + 5ml of distilled water Group 3: 15 ml of 2% chlorhexidine Group 4: 35% phosphoric acid.	Group 1 (control): 6ml distilled water. Group 2: conventional syringe irrigation with no activation: 2.5 % NaOCl and 17 % EDTA. Group 3: 2.5 % NaOCl and 17 % EDTA + activated using passive ultrasonic irrigation. Group 4: 2,5% NaOCl EndoVac apical negative pressure. Group 5: diode laser. Group 6: neodymium:yttrium–aluminum-garnet (Nd:YAG) laser. Group 7: erbium:yttrium–aluminum-garnet (Er:YAG) laser. Group 8: Er:YAG laser using with photon-induced photoacoustic streaming (PIPS™) technique.	Group 1: 5 ml sterile distilled water. Group 2: 5 ml of 5.25% NaOCl. Group 3: 5 ml of 2% chlorhexidine digluconate (CHX). Group 4: 5ml of 17% EDTA. Group 5: 5 ml of 17% EDTA followed by 5 ml of 2% CHX. Group: 5ml of QMix.	Group 1: distilled water for 1 min. Group 2: 5 mL 2.25% NaOCl for 1 min. Group 3: 5mL 2.25% NaOCl for 1 min+ 5mL 17% EDTA for 1 min followed with distilled water for 1 min. Group 4 : 915 nm diode laser.	Group 1 (control): 5 ml of distilled water for 1min. Group 2: 5ml of 5.25% NaOCl applied with passive ultrasonic irrigation (PUI) for 1 min. Group 3: 5ml of 1 % NaOCl applied with PUI followed with distilled water. Group 4: 18% EDTA followed by 5.25% NaOCl for 1 min followed with distilled water; Group 5: 5ml of 2% chlorhexidine (CHX).	Group 1 (control): 10 ml of 5%NaOCl for 15 s. Group 2: ethyl acetate and acetone- based cleansing agent (Sikko-Tim, VOCO) for 15 s followed by 10 ml of 5% NaOCl for 15s. Group 3: 17% EDTA for 60s, followed by 10 ml of 5% NaOCl for 15 s. Group 4: 37% orthophosphoric acid for 15s, followed by 10 ml of 5% NaOCl for 15s. Group 5: 10% citric acid for 15s, followed by 10 ml of 5% NaOCl for 15s.	Group 1: irrigated with 14% EDTA for 60 s. Group 2: irrigated with 5.25% NaOCl for 60 s. Group 3: irrigated with 0.9% sodium chloride (NaCl) for 60 s.	Group 1: 10 ml water irrigation (control). Group 2: etching with 35% phosphoric acid for 30 s. Group 3: irrigation with 17% EDTA followed by 5.25% sodium hypochlorite (NaOCl). Group 4: ultrasonic agitation associated with 17% EDTA and 5.25% NaOCl irrigating solutions. Two subgroups (n = 5) and assigned to either one of the two self-etching systems, namely Clearfil SE Bond or Clearfil DC Bond
Presence of final activation	yes, in a third group.	None	Yes. It was used passive ultrasonic irrigation, EndoVac apical negative pressure, and various types of laser	None	Yes, in laser group.	Yes. It was used ultrasonic activation	None	None	Yes. It was used ultrasonic activation on group 4.
Storage / aging	Thermal cycling regimen of 3,600 cycles in water at 5 °C/55 °C with a dwell time of 5 s between baths before the post-space	100% humidity at 37 C for 24 hours.	At 37 °C in 100 % humidity for 24 h	at 37 °C and 100% humidity for 1 week.	in saline solution in light proof boxes for 1 week at 37°C.	x	at 37 °C and 100% humidity for 24 hours.	deionized water at 37 C for 1 wk	x
Methodology of analysis of samples	push-out BS test, confocal laser scanning microscopy and microhardness (Knoop) analysis.	Push-out test at 0.5 mm/ min. 1-way ANOVA with the post hoc Tukey honest significant differences test (a=.05).	Push-out test. Failures were examinaded by a stereomicroscope.	Micropush-out test. Debonding specimens were examined with a scanning electron microscope. Scanning electron microscopy was also used to examine and score the treated specimens for debris removal and dentinal tubule opening.	Push-out test. For the fracture analysis, a stereomicroscope was used. Data were statistically analysed with ANOVA ($P = 0.05$) followed by Tukey test.	Push-out test, a stereomicroscope determine the failure mode and confocal laser scanning microscopy.	Push-out bond strenght. Dentine surface were examined under scanning electron microscopy after different surfacce treatments.	Push-out test analysis. A microscope determine a type of failure.	Push-out test and dentin surface were examined under SEM after pos-space treatments.
Stastically results	NaOCl + EDTA provided highest BS values than NaOCl ($p < 0.0001$). Specimens cemented with Panavia presented significantly higher BS than those with RelyX in the three root thirds ($p < 0.0001$). The highest BS values occurred in the cervical third ($p < 0.001$). Ultrasound-activated NaOCl + EDTA promoted the greatest reduction in dentin microhardness, followed by NaOCl/EDTA and NaOCl.	No statistically significant differences were found among the root regions (P=.583) (apical, coronal, middle). The NaOCl+EDTA treatment yielded a significantly higher bond strength than those in the other 3 groups and no significant differences were found in the mean bond strength among the 3 other(P>.05).	The highest bond strength was observed with the PIPS technique and there were no statistically significant differences among PUI, the Nd:YAG laser, and the Er:YAG laser ($p>0.05$). When the experimental groups were compared, CSI showed the lowest bond strength values. With the exception of the PIPS group, there were no significant differences among the experimental groups ($p>0.05$). Total comparisons of bond strength values revealed significant differences between the cervical and apical thirds ($p<0.05$).	QMix and 17% EDTA/2% CHX demonstrated the highest mean bond strength values in all root levels amongst the groups. QMix, 17% EDTA and 17% EDTA/2% CHX performed significantly better than the other groups on smear layer removal and dentinal tubule opening.	A statistically significant difference between Group 3 and Group 2 ($P = 0.03$). The bond strength values of cervical segments were significantly higher than the middle segments regardless of pretreatment regimens ($P < 0.05$). The highest bond strength values were obtained from Group 3 and the lowest bond strength values were obtained from Group 2 in both regions.	Bond strength was significantly affected by the luting material ($P < 0.0005$) and the IP ($P = 0.001$). The interaction between material and IP was also significant ($P = 0.013$). The failure modeswere affected by the material ($P < 0.0005$) and by the IP ($P < 0.0005$; chi-square test.	ANOVA revelead that canal surface treatment affected the bond strenght ($P < 0.001$). The highest bond strenght was obtained in the Sikko group. The results also showed that surface treatment methods incresead the bond strenght to dentin when compared with the control group.	Statistical analyses revealed that EDTA was significantly more effective at removing the smear layer than NaOCl or NaCl at each regional third of the post space (P £ 0.01).The push-out bond strength was significantly affected by the different irrigants.	Both etching with 35% phosphoric acid, and ultrasonic treatment in combination with EDTA/ NaOCl irrigation, significantly improved the apical push-out strength ($P < 0.05$). The apical push-out strength of the EDTA/NaOCl group was significantly lower than that of the 35% phosphoric acid group and the ultrasound/EDTA/NaOCl group.
Conclusion	dentin treatment with NaOCl + EDTA and cementation with Panavia F was the protocol that promoted the highest bond strength of fiber-reinforced posts in experimentally weakened roots.	Different irrigation procedures affect fiber post bond strength. The NaOCl+EDTA combination positively affected bond strength; however, no differences were found among the CHX, PA, and DW groups.	PIPS laser-activated irrigation showed higher efficiency as a final irrigant activation protocol on push-out bond strength of fiber post.	QMix is an effective irrigant that can remove smear layer, open dentinal tubules and simplify the irrigation protocol, without compromising the bonding strength of glass fibre posts cemented with a self-adhesive resin cement to root dentine.	The highest bond strength values were obtained from NaOCl/EDTA and the lowest bond strength values were obtained from NaOCl. Bond strength was higher in the cervical root segments than in the middle root segments for all groups.	Irrigation with 18% EDTA/5.25% NaOCl significantly increased the bond strength of the self-adhesive resin cement and improved resintag formation compared with the control group. This IP significantly decreased bond strength for the etchand-rinse adhesive system compared with the control, while IP3 (1% NaOCl) significantly enhanced bond strength for the same system.	Sikko Tim group was the more effective surface treatment agent compared with EDTA, orthophosphoric acid, citric acid, and control groups; however, it could not remove the smear layer and sealer remannants effectively on radicular dentin surfaces. Removal of the smear layer and opening of dentin tubule not recommended when a self-etching/self-priming adhesive system is used.	EDTA removed the smear layer extremely effectively and, as a result, increased the bond strength. Irrigation with EDTA after post space preparation is therefore a valuable procedure when a self-etching adhesive resin luting system is used for fiber post cementation.	35% phosphoric acid or ultrasonic agitation associated with EDTA/ NaOCl irrigation on the post space improves the retention of fiber posts in the deep region. A solo irrigation with an EDTA/NaOCl solution is not recommended as a post-space treatment when luting a fiber post.

Description of studies

All studies were *in vitro*, of which a high number of the selected studies had low methodological quality, revealing a high risk of bias, which precluded any statistical analysis of the data.

This systematic review included studies that analyzed the influence of cleaning methods of root canal after post-space preparation on the performance of FGPs evaluated with the biomechanical push-out test. For this investigation, all studies used a fiberglass post in a root canal that was filled with resin-based endodontic sealer. The studies used human teeth, of which the most frequent were premolars, canines or incisors. The most frequently resin-based endodontic sealer used was AH Plus (Dentsply, York, PA, USA). The timing of post-space after obturation revealed certain heterogeneity, where 4 studies were relieved after 7 days, 2 after 24 hours, 1 after 72 hours, and 1 after 2 weeks post-obturation. One study did not show the period for post-space preparation. Seven studies used the association of NaOCl/EDTA in some of their experimental groups.[8,17,23,24,25,26,27,28] Chlorhexidine appeared in 3 studies,[18,25,26] although in one of these studies, there was also the presence of chlorhexidine in the composition of a commercial solution called Qmix.[26] Other solutions that were also tested included NaOCl and EDTA used individually, with some variations of time and concentration,[8,16,18,26,27] of which the most used concentrations were 5.25% NaOCl and 17% EDTA both for a maximum of 1 minute. Regarding the methods of activation of the irrigating solutions, 5 studies[18,23,24,27,28] reported using some type of activation method to potentiate the cleaning effect. Most failure modes were of the adhesive type at the junction of the root dentin and resin cement, which is the retention region of the FGPs. All studies were classified as having a high risk of individual bias.

Discussion

To the best of the authors' knowledge, this systematic review is the first to summarize *in vitro* data on the influence of cleaning methods on root canals after post-space preparation on the performance of FGPs luting by dual resin cements. The retention between root dentin and resin cement is a critical point for luting FGPs, since interference in the resin-dentin diffusion zone affects the longevity of the FGPs.[23,40,41] Although several studies have evaluated the effect of post surface treatments and cementation strategies on the retention of FGPs, the presence of the smear layer and debris along the post-space canal walls can also affect the optimal dentin adhesion.[8] The role of cleaning methods after post-space supports clinicians in terms of evidence-based decision making. Therefore, the tested hypothesis was rejected.

For anatomical reasons, the apical third of the root presents deep, narrow irregular dentin and a fewer number of dentinal tubules, which are often sclerotic and render any adhesive application protocol difficult to control.[42] In addition, another reason that explains the lower bonding potential at the deeper root canal dentin is the distance from the light activation, resulting in a lower monomer conversion and reduced resin cement polymerization.[8,41,43] Endodontic sealer residues might also interfere with the polymerization of the resin cement.[44] The presence of the smear layer impairs an adequate contact between the acidic methacrylates of self-adhesive resin cements and the underlying dentin during adhesive procedures, thus interfering with bond strength.[19] The partial or total debris removal previous to resin cement insertion into the root canals might improve post retention and, consequently, the bond strength.[34] Acidic solutions such as EDTA have shown good results in removing the smear layer but do not adequately demineralize dentin or enhance the contact of the self-adhesive resin cements with dentin.[45] In contrast, NaOCl solution alone partially removes the smear layer, causing removal of dentinal proteins and making the dentin surface hydrophilic, which could impair resin cement polymerization.[46]

The current study was conducted by *in vitro* studies due to the difficulty of evaluating this parameter *in vivo*. Only human teeth were included in this study because they are closest to the clinical conditions in which the posts are installed. However, bovine teeth or artificial devices could be used to evaluate FGPs retention. Although there is a wide variability of endodontic sealers in the dental market with different compositions, studies that did not use endodontic

resin sealers were excluded from the present study because canals obturated with eugenol-containing sealers may have reduced polymerization of resin cements used in GFPs cementation.[47-49] To standardize the samples, only studies that performed the bond strength test by using push-out test were included, since it is a commonly used test to evaluate FGPs as it provides a better estimate of the bond strength.[50]

In relation to the treatment of the dentin surface for the removal of debris previous to FGPs cementation, there are several forms, such as aluminum oxide blasting, rotary brushes and irrigating solutions that are activated or not.[17] Regarding the irrigation solutions, we verified the use of NaOCl, EDTA, chlorhexidine, distilled water, QMix (Dentsply Tulsa Dental), phosphoric acid, alcohol, Sikko Tim (VOCCO, Germany), and citric acid.[8] These irrigant solutions promote flushing of the flue and dissolve the tissues, while theydisplay antimicrobial characteristics in the removal of the smear layer formed during the post-space of the root canal.[51] Considering these criteria, only nine studies were included, of which five studies showed better results for the combination of NaOCl/EDTA, regardless of the sequence of the use.[17,23,25,27,28] The increased FGP bond strength after the combination of NaOCl/EDTA solutions[17,23,25,27] may be attributed to the ability of the solutions to remove the smear layer, thus improving cement contact and penetration into dentinal tubules.[25] Recently, the use of irrigation activated by ultrasonic, lasers, and negative apical pressure (Endovac) has been discussed.[52] However, the activation does not necessary imply a better bond strength.[23,24]

In addition, the association of NaOCl/EDTA with ultrasonic agitation had a better performance when compared with non-activated NaOCl/EDTA on the removal of debris capacity.[28] Ultrasonic application showed good results in the most important retention areas, since it is possible to reach the entire length of the root canal with irrigant solutions.[53] In addition, distilled water was used frequently as the final irrigation.[17,24,25,27,28] Boosting the effect of cleaning methods may reduce precipitate formation.[54] The higher bond strength by using this protocol was explained by the removed smear layer and opened dentinal tubules.[28]

The association of non-activated NaOCl/EDTA also showed satisfactory results when using self-adhesive resin cement for FGPs cementation.[17] However, when cemented with an etch-and-rinse adhesive system, the best results were assigned to NaOCl 1% with ultrasonic activation,[17] which leads us to believe that each adhesive strategy should be adapted to each irrigant procedure. Knowing that self-adhesive cement has been widely used because of its chemical or micromechanical retention on the dentin surface,[55] the association of NaOCl/EDTA can be considered as an excellent choice for root canal cleaning after post-space on self-etch and self-adhesive strategies involving adhesive cementation, as the acid-resin monomers of these cements may not be as effective as phosphoric acid in penetrating and modifying the smear layer of the root canal. The resin cement type and the composition can negatively interact with the cleaning agents. This aspect is more sensitive for the self-adhesive system, since it does not use phosphoric acid. The same irrigants may influence the polymerization reaction and, consequently, the bonding interaction.[23] There is a scarcity of studies testing different irrigants with different self-etching resin cements. In general, the RelyX U200 is less sensitive with the use of NaOCl and EDTA irrigation.[23,45]

On the other hand, the isolated or alternate use of the NaOCl and EDTA solutions, intensified by some methods of activation, was not as effective as the distilled water activated with PIPS.[24] PIPS is a novel laser agitation technique used with an erbium:yttrium-aluminum-garnet (Er:YAG) laser.[56,57] The higher efficiency of this technique is based on photoacoustic and photomechanical action without the need to extend the root apex; each propellant reacts with the water molecules, constituting expansion and succession waves that create intermittent fluid.[56] Such results support the use of Er:YAG laser activation or PIPS to improve the effectiveness of the final irrigation after post-space preparation; however, more studies are needed to confirm this finding.[24]

Another cleaning method option that also exhibited good results was a commercial product named Sikko Tim (VOCCO, Germany), which is an ethyl acetate and acetone-based cleaning agent. The group treated with Sikko showed the highest bond strength values

compared to NaOCl/EDTA.[8] However, it could not remove the smear layer effectively and differed with an association of 17% EDTA for 60 s and 5% NaOCl for 15 s, which appeared to be satisfactory. The product Sikko did not show satisfactory results regarding the opening of the dentin tubules, as well as the removal of the smear layer and cement remnants, and thus has not been indicated for the self-etching system.[8] Therefore, more studies are needed to evaluate the use of this solution. Another study using NaOCl and EDTA independently found better GFP bond strength when 14% EDTA irrigation and the self-adhesive resin cement were used.[19] This fact can be attributed to the low pH of EDTA, in addition to its ability to act as a chelator by removing the smear layer and cleaning the root canal.[58] EDTA removes calcium from hydroxyapatite and is linked to non-collagenous protein. Thus, collagen fibrils are preserved, and they subsequently improve the infiltration of the resin material, resulting in higher adhesion strength between resin cement and root dentin.[59] Chlorhexidine has also been used as a possible irrigation solution post-space preparation[17,25,26]. Three studies used chlorhexidine, but only one had satisfactory results by using a commercial formulation named QMix.[26] It is composed of EDTA, chlorhexidine and a surfactant, supporting the removal of the smear layer while opening dentin tubules and simplifying the irrigation protocol.[26,60]This solution decreases the surface tension of the root dentin, thus increasing its wett ability, as well as its capacity to contact the smear layer and the underlying dentin to improve irrigation.[19,60]

The result of the present systematic review should be interpreted with caution considering that *in vitro* studies have limitations regarding simulating *in vivo* conditions. The variety of cleaning methods, different concentrations, application time, type of adhesive system and resin cements used result in heterogeneous comparisons, which reduce standardization and demonstrate a high risk of bias. Therefore, more attention should be placed on the influence of root canal cleaning methods after post-space on the cementation of FGPs because the presence of residues may negatively interfere with the adhesion of the fiber post to the root canal. [8,13]

Conclusion

Based on the findings of this systematic review, it is possible to conclude that root canal cleaning methods after post-space, whether activated or not, can affect the bond strength of FGPs. Despite the variability of irrigation protocols in most of these studies, the current findings may suggest that the use of NaOCl/EDTA could be recommended for post-space irrigation when luting a fiber post, since it demonstrated a better performance compared to other irrigation solutions.

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