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Protocols for Mechanical Cleaning of the Post Space on the Bond Strength Between Root Dentin and Cementation System

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Clinical Relevance

Mechanical protocols can be promising alternatives to chemical protocols for cleaning the root dentin surface before cementation of fiberglass posts.

SUMMARY

Objective: To evaluate the effects of mechanical versus chemical cleaning protocols for cleaning the root dentin surface before cementation of fiberglass posts for their effect on the bond strength, failure mode, and dentinal penetration of the cementing agent using an etch-and-rinse adhesive system on dentin prepared to receive a fiberglass post.

Methods: Forty roots of bovine teeth were endodontically treated and prepared for fiber post cementation. The specimens were randomized into 4 groups of 10: Control group (CO) - irrigation with

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http://doi.org/10.2341/20-194-L

2.5% NaOCl; DW group- irrigation with distilled water; RB group - rotating brush for cleaning root canals, and CUI group - continuous ultrasonic irrigation. The fiberglass posts were cemented, and the specimens were immersed in distilled water for 6 months. A push-out test was performed on the cervical, middle, and apical thirds of the samples. Dentinal penetration of the cementing agent and the fracture pattern were evaluated by laser confocal microscopy. Statistical analysis was performed using analysis of variance (ANOVA) and post hoc Tukey tests (α=0.05). Results: The RB and CUI groups showed significantly higher bond strength values when compared to the Control and DW groups ($p<0.05$). In addition, in the control and DW groups, the apical third presented lower bond strength values when compared to middle and cervical thirds.

Conclusion: While DW showed the highest incidence of adhesive type failure, CUI resulted in the highest dentinal penetration of the cementing agent ($p<0.05$). RB and CUI resulted in the highest bond strength between cementation system and root dentin. In addition, CUI favored greater dentinal penetration of fiberglass post cementing agent.

INTRODUCTION

A residual-free dentin surface is crucial for the formation of a suitable adhesive interface when an etch-and-rinse adhesive system is used.[1-4] However, during the preparation of the post space for cementing a fiberglass post, heat is generated in the root canal that leads to plasticization of the endodontic filling materials used.[5,6] These materials precipitate on the dentin surface to form a layer comprising gutta-percha residue, endodontic cement, and dentin debris.[7]

Several chemical protocols have been proposed for cleaning and disinfecting the intraradicular space prior to cementation of the fiberglass post.[8-10] Certain substances such as peroxides that are routinely used in the irrigation of root canals generate oxidative radicals.[9,11] These peroxides have a negative impact on the degree of conversion of the resinous compounds, thereby impairing the adhesion of the etch-and-rinse adhesive system on the dentin substrate.[12-14] It was previously reported that the use of chemical protocols without mechanical agitation showed less removal of dentin residues compared to irrigation associated with mechanical agitation.[15,16]

Mechanical protocols using ultrasonic agitation, lasers and intracanal brushes combined with irrigation solutions have shown promising results in cleaning intraradicular dentin.[17,18] However, the use of irrigation solutions, such as NaOCl, polyacrylic acid, chlorhexidine, or silver nanoparticles influenced the bond strength and interface permeability of adhesive material to dentin substrate.[19] To our knowledge, no studies to date have investigated the effectiveness of mechanical methods without chemical irritants for dentin post space cleaning prior to cementing fiberglass posts using etch-and-rinse adhesive or conventional dual resin cements.

In addition, although ultrasonic agitation of the irrigant is considered effective in cleaning root dentin,[20,21] it is an expensive alternative due to the need for specific equipment and supplies. A root canal cleaning brush that is activated in continuous rotational movement can be a cheaper alternative. Due to direct contact with the dentin surface, it easily removes debris from the plasticization of the materials used in endodontic filling.[17,22]

Therefore, the aim of this study was to evaluate the effects of cleaning the post space using 2.5% NaOCl (Control), distilled water (DW), rotating brush (RB) in continuous motion with distilled water, and continuous ultrasonic irrigation (CUI) with distilled water on the bond strength, fracture pattern, and dentinal penetration of the cementation system at the cervical, middle, and apical thirds of the root canal. The null hypothesis was: There is no difference in bond strength, fracture pattern, and the extent of cementation system penetration among the tested intra-root dentin cleaning protocols.

METHODS AND MATERIALS

Sample Preparation

The study was approved by the animal research ethics committee of the local university (Protocol No. 1,201,002). Forty healthy bovine incisors with similar root anatomy and devoid of structural changes were selected; they were stored in 0.1% thymol solution at 4°C for a maximum of 1 month.

The roots were standardized for length and measured 17 mm from the root apex. The root canals were prepared using the Universal ProTaper System (Dentsply Maillefer, Ballaigues, Jura-Nord Vaudois, Switzerland). Chemical-mechanical preparation and root canal filling were performed according to the protocol proposed by Aranda-Garcia and others[23] Vertical condensation of the root canal filling material was done and the root canals were provisionally restored with a temporary cement (Coltosol; Coltene, Rio de Janeiro, RJ, Brazil). The roots were kept in 100% relative humidity, at 37°C for seven days. The post space (length of 11 mm) was prepared with a #1

wide bur (Dentsply) supplemented by a #1 bur (White Post DC; FGM, Joinville, SC, Brazil). The preparation was performed without coolant. Periapical radiographs were performed to verify that the root filling was correctly removed.

Treatment With Cleaning Protocols

Following post space preparation, the specimens were randomly allocated into three groups based on the cleaning protocol. These included:

- Control group: The post space was irrigated with 10 mL of 2.5% sodium hypochlorite using a 30 G endodontic irrigation cannula (NaviTip; Ultradent, South Jordan, UT, USA). Cervical to apical movements were performed at an amplitude of 3 mm. Following a 1-min irrigation, aspiration was performed with the aid of a vacuum tip (Capillary tips; Ultradent). After that, 17% EDTA was applied to the root canal for 3 min and then dried with absorbent paper tips (Maillefer, Dentsply Sirona, York, Pennsylvania, USA).
- Distilled water (DW): The post space was irrigated with 10 mL of distilled water using a 30 G endodontic irrigation cannula (NaviTip; Ultradent). Cervical to apical movements were performed at an amplitude of 3 mm. Following a 1-minute irrigation, aspiration was performed with the aid of a vacuum tip (Capillary tips: Ultradent).
- Rotating brush (RB): The post space was initially filled with distilled water followed with a root canal cleaning brush (MKLife, Porto Alegre, RS, BR) (Figure 1A), which was used in continuous rotational movement (1200 rpm, 4 N) for 15 seconds using a specific device (XSmart Plus, Dentsply Sirona). The same operation was repeated three times.
- Continuous ultrasonic irrigation (CUI): The ultrasonic tip (AE12; Adiel, Ribeirão Preto, SP, BR) (Figure 1B) adapted in an ultrasonic unit (Ultrawave XS; Ultradent) was used at a power level of 5. The insert was introduced 1 mm short of the length of the post space and moved from cervical to apical direction for 1 min under continuous irrigation with distilled water.

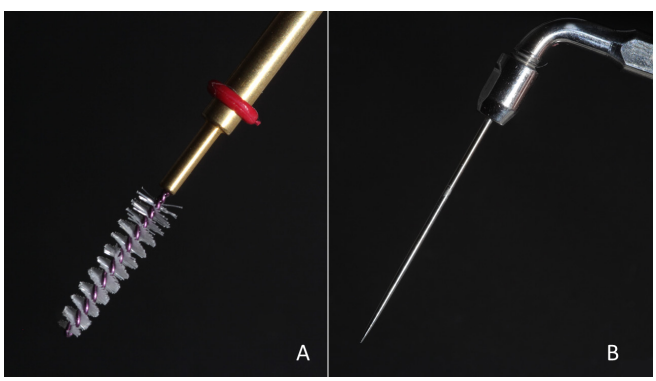

Figure 1. *(A): Root canal cleaning brush. (B): The ultrasonic tip.*

After completion of the cleaning protocols, the post space was irrigated with 5 mL of distilled water and dried with absorbent paper tips (Maillefer, Dentsply Sirona). The external surface of the fiber post (White Post DC # 1; FGM) was cleaned with 95% alcohol and conditioned with 37% phosphoric acid (Condac 37; FGM) for 1 minute. Silane (Prosil; FGM) and an etch-and-rinse adhesive (Ambar; FGM) were subsequently applied, and light cured for 60 seconds (Valo, Ultradent).

Fiber Post Cementation

The dentin post space was conditioned using 37% phosphoric acid for 15 sec and irrigated with distilled water for 30 sec. Subsequently, the dentin was gently dried with absorbent paper tips (Maillefer, Dentsply Sirona). The etch-and-rinse adhesive system Ambar; FGM) was applied to the post space and photoactivated for 20 seconds. The conventional dual resin cement (AllCem Core; FGM) was manipulated according to the manufacturer's recommendations and inserted into the root canal using specific intracanal tips of the cementation system. Thereafter, the fiberglass post was positioned and photoactivated for 40 seconds on each side of the specimen. The specimens were stored in distilled water for 6 months at 37°C; the water was renewed every 15 days.

Bond Strength and Failure Mode Evaluation

Subsequently, the specimens were included in polyester resin (Maxi Rubber, Diadema, SP, Brazil) and sectioned into apical, middle, and cervical thirds of 2.0 ± 0.1 mm in thickness. Irregularities generated during the sectioning procedures were removed with 1200 water-wet sandpapers (3M Oral Care, Saint Paul, MN, USA) in a polishing machine (Buehler, Lake Bluff, IL, USA). A universal testing machine (EMIC, São José dos Pinhais, PR, Brazil) was used for the push-out test at a crosshead speed of 0.5 mm/min. The slices were inserted into a metal device with a central hole (Ø=3 mm) larger than the diameter of the canal. The push-out test was performed as outlined by Magro and others.[24]

Failure mode was assessed using a confocal laser microscope (LEXT OLS4100; Olympus, Shiniuki-ku, Tokyo, JP) as described by Ramos and others.[8] An image of each quadrant of the perimeter of the post space was obtained (four images per specimen). The

failure mode was classified as type 1 (adhesive) when it occurred between the fiber post and the cement; type 2 (adhesive) when it occurred between the dentin and the cement; type 3 (cohesive) when it occurred inside the cement; and type 4 (mixed) when several failure modes occurred in combination.[8,25] Figure 2 shows adhesive 1 and 2, cohesive and mixed failure modes.

Intratubular Cement Penetration

Intratubular cement penetration was examined using an Olympus FluoView Confocal Laser 1000 microscope (Olympus Corporation, Tokyo, Japan) at 20× magnification. Prior to fiber post cementation, 0.01% of rhodamine dye was incorporated into the resin cement, as described by Ramos and others.[8] Cervical, middle, and apical samples were assessed. The images were recorded as quadrants; 10 measurements were taken in each quadrant of the dentin post space. Dentin samples were analysed using a 10× oil lens at 100× magnification. The image depth was 70 μm and the dimension was 800 × 800 pixels. Image J software (Softonic International S.L., Barce, Spain) was used to analyse the images as described by Ordinola-Zapata and others.[26] The average (in μm) of the 40 measured values was calculated to measure the extent of dentinal penetration of the cementing agent.

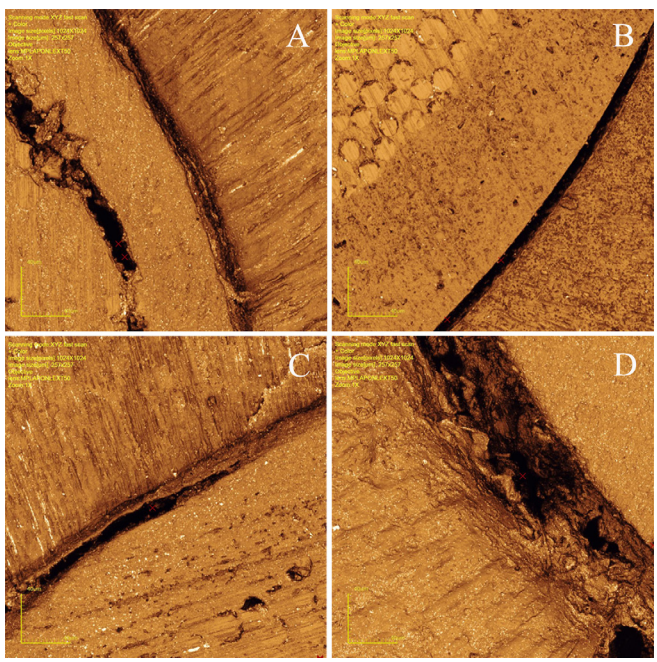

Figure 2. *Representative image of the failure mode: type 1 (A), adhesive, between post and cementation system; type 2 (B) adhesive, between dentin and cementation system; type 3 (C) cohesive, inside the cementation system; type 4 (D) mixed, combination of fracture pattern. Scale: 1024×.*

Statistical Analysis

The data obtained were initially subjected to a Shapiro-Wilk normality test. The results of the push-out test and that of the dentinal penetration of the cementation system were analysed using the analysis of variance (ANOVA) and Tukey tests. All tests were evaluated with a significance level of 5%.

RESULTS

Bond Strength and Failure Mode Evaluation

Table 1 shows the arithmetic mean and standard deviation of the bond strength values (in MPa) of the cementing system, after using the cleaning protocols in all the thirds of the post space. There was no statistically significant difference between the CO and DW groups, regardless of the root region ($p<0.05$). There was no difference in the bond strength values between the RB and CUI groups ($p>0.05$). The RB and CUI groups showed significantly higher bond strength values when compared to the CO and DW groups ($p<0.05$). In addition, in the CO and DW groups, the apical third showed lower bond strength values when compared to middle and cervical thirds.

Regarding the failure mode, the CO and DW groups presented the highest incidence of type 2 failure. However, the RB and CUI groups presented the highest incidence of type 3 failure. Figure 3 shows the fracture pattern distribution for the different groups.

Intratubular Cement Penetration

Figure 4 shows representative images of the cementation system penetration inside dentin based on the protocol adopted for cleaning the post space (500×). In all post space thirds, the CO and DW groups showed the lowest and the CUI group showed the highest penetration of the cementation system ($p<0.05$) (Table 2). In addition, in the CO and DW groups, the apical third showed less cementation system penetration when compared to the middle and cervical thirds.

DISCUSSION

In this study, all the cleaning protocols resulted in different values of bond strength, failure mode, and dentinal penetration of the cementation system using the etch-and-rinse adhesive. The null hypothesis was thus rejected. Bond strength values were higher after mechanical cleaning of the intraroot space compared to the irrigation protocols alone. Possibly, the superiority of mechanical cleaning is due to the absence of interaction between irrigators for chemical cleaning with cementation systems, which could negatively

Table 1: *Bond Strength Values of the Cementing System by Dentin Cleaning Protocols and Thirds of the Post Space*

Root Region	Groups Mean in MPa (SD)			
	CO	DW	RB	CUI
Cervical	20.14 (6.95) Ab	21.46 (4.37) Ab	36.71 (2.77) Ca	35.20 (3.37) Ca
Middle	19.64 (3.62) Ab	19.87 (4.93) Ab	34.08 (3.71) Ca	32.18 (3.13) Ca
Apical	15.07 (1.96) Bb	14.43 (4.45) Bb	31.14 (2.24) Ca	31.23 (5.09) Ca

Note: Different uppercase letters in the same column indicate a statistically significant difference ($p<0.05$); Different lowercase letters on the same line indicate a statistically significant difference ($p<0.05$). Abbreviations: CO, cleaning protocol with 2.5% sodium hypochlorite; DW, cleaning protocol with distilled water; RB, cleaning protocol with rotating brush; CUI, cleaning protocol with continuous ultrasonic irrigation.

interfere with adhesion to the dentin substrate.[19, 27] The preparation of the post space after endodontic treatment generates the formation of a smear layer on the instrumented dentin. This smear layer is impregnated with residues of materials such as endodontic sealants and pasted gutta-percha. This residue has specific characteristics different from a standard smear layer generated during endodontic treatment.[7,28,29] In the present study, endodontic treatment was performed followed by the post space preparation to simulate this condition.

Obtaining clean dentinal surfaces after mechanical preparation of the post space is a critical step towards the ideal retention of the fiberglass post when resin cement is used. Therefore, an adequate removal of the residual layer is necessary.[30] Sodium hypochlorite solution (NaOCl) is the most recommended irrigant for root canals[24] and it is known for its antibacterial and proteolytic actions, dissolution capacity, and debridement properties.[31] However, it degrades into sodium hydroxide and hypochlorous acid, thereby promoting the release of *singlet* oxygen.[32] Sodium hypochlorite thus acts as an oxidizing agent that creates an oxygen-rich layer on the dentin wall that inhibits resin polymerization and increases marginal microleakage.[33,14] This effect hinders polymerization of the methacrylate chain of resinous compounds.[2,6] Furthermore, NaOCl can cause collagen dissolution by

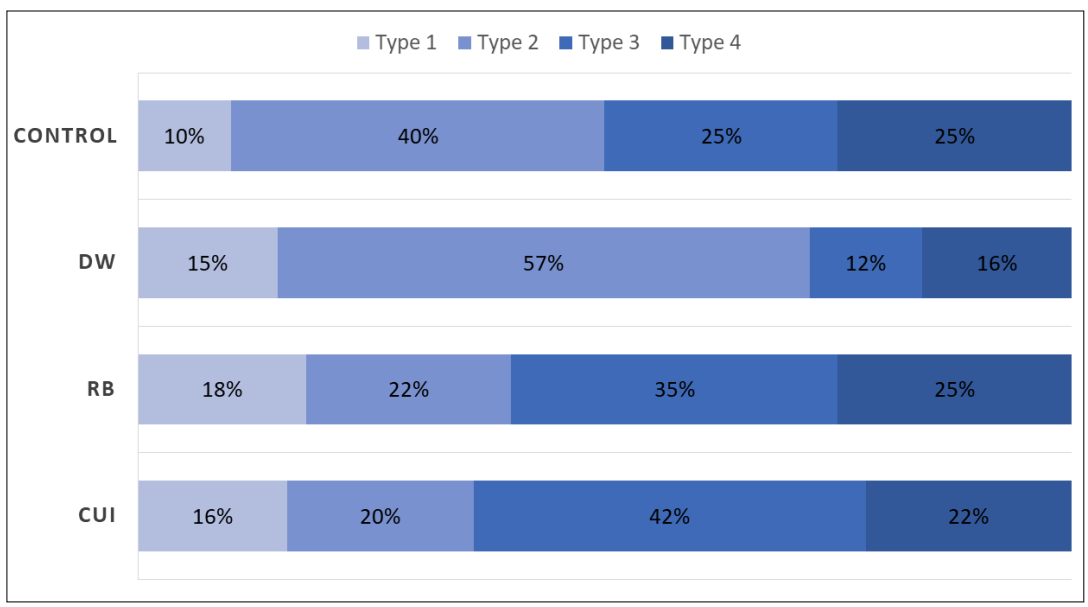

Figure 3. *Incidence of the failure mode demonstrated after using the cleaning protocols. Type 1 (adhesive, cement/post); Type 2 (adhesive, cement/dentin); type 3 (cohesive); type 4 (mixed). Abbreviations: CI, conventional irrigation; CUI, continuous ultrasonic irrigation; RB, rotating brush.*

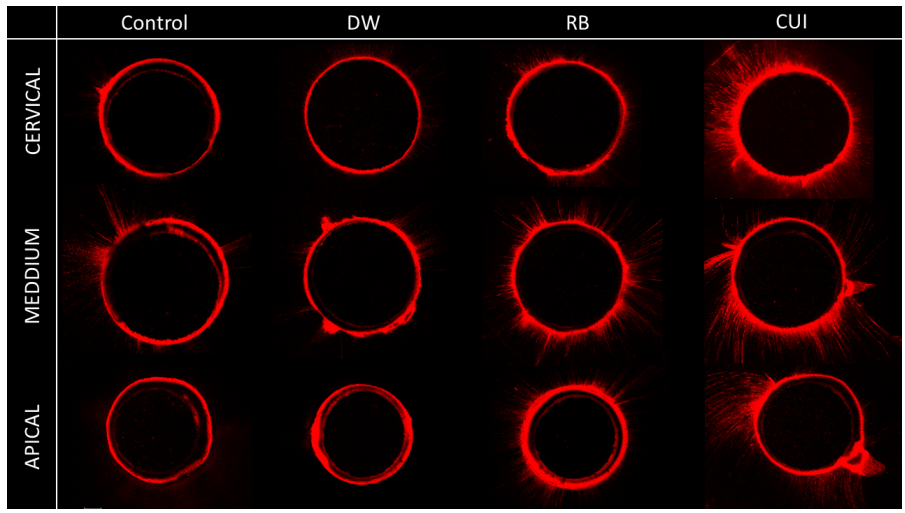

Figure 4. *Representative image of dentinal penetration of the cementation system, depending on the thirds and cleaning protocols of the post space. Abbreviations: CI, conventional irrigation; CUI, continuous ultrasonic irrigation; RB, rotating brush. Scale: 100x. 600 µm.*

breaking carbon bonds and disorganizing the protein's primary structure, which results in degradation of the dentinal tissue.[34] Therefore, only distilled water was used as an irrigator in the mechanical cleaning protocols of this study.

In the present study, the groups that used mechanical cleaning showed the best results, both for bond strength and penetrability of resin cement in intratubular dentin, even when compared to irrigation with NaOCl. These results indicate that mechanical cleaning with ultrasonic irrigation and rotating brushes can be an effective alternative for dentin cleaning without the interference of chemical solutions. It is likely that the ultrasonic agitation of the distilled water and the brush attrition over the dentin surface resulted in a greater removal of dentin debris. Consequently, there was greater exposure of intertubular dentin in these groups. Previous studies showed that continuous ultrasonic irrigation showed better dentinal cleaning of the post space when compared to conventional irrigation using only irrigation solutions.[35,36] However, the effectiveness of continuous ultrasonic irrigation combined with distilled water or saline solution has been little investigated to date.

A previous study conducted by Jamleh and others[35] showed that the CUI can effectively clean the root canal system. However, it was not possible to avoid combining it with irrigators. On the other hand, Spoleti and others[37] found that ultrasonic activation with sterile saline was able to disinfect the root canal effectively. This issue should be further investigated in future studies, seeking alternatives for cleaning the post space, without the interference from chemical irrigation substances.

In this study, the two-step etch-and-rinse adhesive system was used after acid conditioning of the

Table 2: *Dentinal Penetration of the Cementation System Depending on the Dentin Cleaning Protocols and Thirds of the Post Space*

Root Region	**Dentinal Penetration by Method Used µm (SD)**			
	CO	**DW**	**RB**	**CUI**
Cervical	36.01 (1.46) Ac	39.63 (5.61) Ac	98.94 (11.63) Cb	191.27 (11.34) Ea
Medium	39.14 (9.82) Ac	42.69 (6.40) Ac	93.50 (9.76) Cb	199.82 (19.58) Ea
Apical	29.85 (6.81) Bc	23.04 (5.09) Bc	73.23 (4.80) Db	107.52 (9.34) Ca

Note: Different uppercase letters in the same column indicate a statistically significant difference (p<0.05); Different lowercase letters on the same line indicate a statistically significant difference (p<0.05). Abbreviations: CO, cleaning protocol with 2.5% sodium hypochlorite; DW, cleaning protocol with distilled water; RB, cleaning protocol with rotating brush; CUI, cleaning protocol with continuous ultrasonic irrigation.

dentin. This system renders a more effective form of hybridization, which allows efficient cleaning of smear layer and higher adhesion values.[38] Due to this cleaning potential of the etch-and-rinse adhesive system, it can be indicated to assist the mechanical cleaning of the root canal during the preparation of the post space. A study conducted by Saraiva and others[39] showed that only the pretreatment with NaOCl did not improve the bond strength of the adhesive cement to the root canal dentin. However, it suggested that the use of 37% phosphoric acid for 60 seconds presented a beneficial effect on bond strength in the apical third of the root. For this reason, this type of adhesive system was used in this study.

Regarding the bond strength in the different root regions, it was found that the CO and DW groups showed lower values in the apical third compared to the middle and cervical thirds. This result can be expected due to the greater difficulty of access and polymerization in this region.[40] In addition, the penetrability of the cementation system was also lower in the apical third when compared to the cervical and middle thirds. This may possibly be related to poor cleaning in the apical third.

Confocal microscopy makes it possible to ascertain the depth and extent of penetration of materials into the root dentin.[27] In this study, in all thirds of the post space, the cleaning protocol with CUI resulted in the greatest penetration of the adhesive system into the dentinal tubules. This result suggests that the CUI effected greater dentinal cleaning. A recent study conducted by Neelakantan and others[41] showed that ultrasonic irrigation was able to significantly remove more smear layer and yield open dentinal tubules when compared to the sonic activation. However, the endodontic literature is inconsistent with regard to the effects of ultrasonic irrigation on smear layer removal.[41,42] On the other hand, a greater dentinal penetration depth obtained when CUI was used did not appear to have interfered with the bond strength values. This question can be justified due to the reduced extent of penetration of the adhesive system in the dentinal tubules, approximately 15%.[2,43]

Concerning the failure mode, it was observed that in the CO and DW groups the most frequent type of failure was the type 2, wherein the rupture occurred more frequently at the interface between dentin and adhesive system. It is likely that a greater amount of dentin residue on the surface reduced the micro-retention following hybridization.[3] Thus, the significance of the results of this study was to demonstrate the relevance of mechanical protocols in assisting the cleaning of the dentinal surface and its potential contribution in improving adhesion of the fiberglass post to root dentin.

Although it is difficult to reproduce *in vivo* conditions *in vitro*, the present study was designed based on several parameters that were previously established in the literature. However, variations in the temperature of the oral cavity and the impact of masticatory forces are factors that were not considered in this study. Therefore, randomized clinical trials analysing the longevity and quality of these protocols must be encouraged. In addition, new materials and mechanical cleaning devices for the root canal must be developed and analyzed to elucidate the impact of cleaning protocols on the bond strength of the resin.

CONCLUSIONS

Following post space preparation, cleaning the dentin surface with a rotational brush in continuous motion or continuous ultrasonic irrigation yielded the highest bond strength of the cementation system to the root dentin. However, ultrasonic agitation resulted in a greater penetration of the adhesive system in dentin when compared to the other modalities. In addition, groups with mechanical treatment had the highest incidence of cohesive failure when compared to the others.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company presented in this article.

(Accepted 04 October 2020)

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