

Ultrasonic activation of different self-etch adhesive systems – Dentin tubule penetration and push-out bond strength of fiber posts

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Abstract

Objectives: The objective of this study was to evaluate the dentin tubule penetration of three self-etching adhesive systems and the bond strength of fiber post cementation using standard protocols and ultrasonic activation of the adhesive system.

Materials and Methods: Sixty extracted bovine teeth samples had their canals prepared and the apical thirds filled. Six groups were selected from the total sample. Clearfil SE, Prime and Bond, and Single Bond Universal adhesive systems were applied in two groups each. The standard adhesive application protocol was executed in one group, and ultrasonic activation of the adhesive system was executed in one group for each adhesive system. Afterward, fiber posts were cemented in all canals using resin cement (RelyX ARC). The samples were prepared and analyzed under confocal laser scanning microscopy and submitted to a push-out test to observe the adhesive's dentin tubule penetration and evaluate the bond strength values of the posts, respectively.

Results: The dentin tubule penetration of the adhesives was more visible on the ultrasonic-activated adhesive groups. Using the standard adhesive protocol, Prime and Bond Universal presented the lowest bond strength values on the apical and cervical thirds and mean value ($P < 0.05$). Clearfil SE presented the highest bond strength values among ultrasonic-activated adhesive system groups ($P < 0.05$).

Conclusions: Ultrasonic activation improved self-etch adhesive dentinal tubule penetration and bond strength of Clearfil SE and Prime and Bond Universal. Ultrasonic activation of self-etch adhesive systems influenced the prevalence of adhesive failure patterns.

Keywords: Confocal laser scanning microscopy; push-out; self-etch adhesive; tubule penetration; ultrasonic activation

INTRODUCTION

Fiber posts have been used as an alternative in rehabilitating endodontically treated teeth with little structure remaining.

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The adaptation of the posts into the root canal is achieved using resin-based cement with an adhesive system.^[1-4]

Adhesive systems can be classified as two- or three-step or self-etch. Conventionally, the adhesive system's first step consists of the application of phosphoric acid in order to demineralize the smear layer and the dentin's top layer. This demineralization exposes collagen fibers that will bond to the adhesive's resin monomers and form the

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so-called hybrid layer.^[5-7] Self-etch adhesive systems are those that do not require a phosphoric acid step. In this system, an acid primer performs a partial demineralization. The smear layer's residual portion on the dentinal surface is incorporated into the hybrid layer.^[8-10]

Adhesive failure between resin cement and the dentinal surface is the most prevalent failure observed in the fiber post cementation process, mainly because of the hybrid layer's composition and weaknesses. In order to improve adhesive techniques, different technologies and protocols have been studied and developed.^[10-12]

Ultrasonic devices in dentistry are widely studied and applied in different dentistry areas. In endodontics, ultrasonic activation can be used on irrigation solutions, intracanal medications, endodontic sealers, mechanical canal preparation, and surgeries.^[13-20] There are a few studies that evaluated the sonic application of adhesive systems.

Knowing the characteristics of adhesive systems and the ultrasonic activation effects on materials' physical and chemical properties, Verdum *et al.* (2022) tested the ultrasonic activation influence on different adhesive systems in resin cementation of fiber posts. They concluded that this technique improved bond strength and dentinal tubule penetration of a self-etch adhesive, unlike a three-step adhesive system and glass ionomer cement.

Ultrasonic activation of different self-etch adhesive systems used on resin cementation of fiber posts has not been studied to date, so this study aims to observe and evaluate the influence of this protocol on dentinal tubule penetration and bond strength of different self-etch adhesive systems on fiber post cementation.

The null hypothesis was that ultrasonic activation of self-etch adhesives would not influence the dentinal tubule penetration and bond strength of fiber posts to root dentin.

MATERIALS AND METHODS

This study was approved by the Research Committee of the University, approval number 42716.

The parameters indicated by Rosa *et al.*^[21] were considered for the sample size calculation, referring to the bond strength test. ANOVA test and Tukey's test were used. The number of treatments was 6. The minimum difference between the treatment means was 1.65, and the standard deviation of the error was 0.92. The power of the test was 0.80, and the significance level was 0.05.

The study was conducted using 60 extracted bovine mandibular incisors ($n = 60$). The bovine teeth were

extracted from slaughtered animals from a slaughterhouse in Rio Grande do Sul. These were cleaned and sectioned at the cemento-enamel junction to obtain a standardized root length of 15 mm. The roots were examined and radiographed to confirm the complete root formation, the presence of a single canal, and the absence of fractures, cracks, lacerations, and internal or external resorption.

The root canals were instrumented using #15 K-file (Dentsply-Maillefer) until the file tip was visualized at the foramen. The file measure was noted at this point, and the working length was determined of 1 mm shorter of the apex. The root canal was prepared with an R50 instrument (Reciproc Blue, VDW Dental) and irrigation with 10 mL of 2.5% sodium hypochlorite (NaOCl). After the preparation, the canals were irrigated with 5 mL of 17% EDTA solution for 3 min, followed by 2 mL of saline solution. The irrigation was performed with a 5 mL syringe (Ultradent Products Inc.) and a 27-gauge tip (Endo-Eze, Ultradent Products Inc.). The canals were dried with paper points the same size as the final apical diameter.

The prosthetic canal length was determined by dividing the working length measure by 3. The obturation of the apical third of the canal was performed using the single-cone technique with Sealer Plus (MK Life Products) endodontic sealer and gutta-percha cones (MK Life Products). The roots were stored in a stove at 37°C and 100% humidity for 15 days to allow the sealer polymerization.

Before adhesive protocols and post cementation, final irrigation of the prosthetic canal was performed with 3 mL of 2.5% NaOCl, followed by paper points drying. The prosthetic canal preparation was made using the fiberglass post's matching drill, and the dentin's surface was cleaned with 70% ethyl alcohol. The fiberglass posts (Exacto #2, Angelus) were cleaned with 70% ethyl alcohol and coated with silane (Angelus), and the solvent was allowed to evaporate for 5 min.

The roots were randomly divided into six groups according to the adhesion strategy [Table 1].

The adhesives were handled according to the manufacturer's guidelines; however, 0.1% Rhodamine B dye was added to provide fluorescence for visualizing the adhesive penetration into dentinal tubules during confocal laser scanning microscopy under Olympus Corp. FV1000 microscope.

In the CFS group, the primer was applied using a microbrush (KG Sorensen) for 20 s, followed by 5 s of the air jet. The bond was also applied by microbrush for 10 s, and light polymerized (Valo Cordless Grand, Ultradent Prod. Inc.) for 10 s. In the CFU group, the same adhesive strategy was applied in CFS; however, after microbrush application,

ultrasonic activation was performed for 20 s on the primer and 10 s on the bond.

In PBS and SBS groups, the adhesives were applied using a microbrush for 20 s and light polymerized for 20 s. In PBU and SBU groups, after 20 s of microbrush application, the adhesives were ultrasonically activated for 20 s before 20 s of light polymerization.

For ultrasonic activation, a 0.2 mm diameter tip (E1 Irrisonic, Helse) was placed in a device (UDS-E LED Woodpecker) and used in the endo setting, with a potency of 5. The ultrasonic tip was positioned 1 mm shorter than the prosthetic canal length and moved toward the canal walls.

After adhesion protocols, the resin cement RelyX ARC (3M ESPE, Sumaré, São Paulo, Brazil) was handled according to the manufacturer’s guidelines and inserted into the canal with a Lentulo drill. The fiber post was immediately placed, the cement excess was removed with a microbrush, and light polymerization was performed for 40 s.

All roots were stored in a stove at 37°C and 100% humidity for 24 h.

All roots were sectioned by using a section machine (LabCut 1010, Extec Corp.) [Figure 1] to obtain three slices (2 ± 0.3 mm thick), each one corresponding to the apical, middle, and cervical thirds of the fiber post. The slices had their surfaces polished in a polishing machine using Arotéc paste (Arotéc) under water cooling.

The adhesive systems dentin tubule penetration was evaluated by CLSM (Olympus Corp.). The apical slices of all roots were placed, one by one, under the microscope, and the wavelength absorption and emission of the Rhodamine B dye were 540 nm and 494 nm, respectively. The images were obtained at x10 using a software program (FluoView 10 ASW 4.2, Olympus Corp.) and examined with the Adobe Photoshop 25.1 (Adobe Inc.) software program for a descriptive analysis.

After dentin tubule penetration analysis of the apical slices, all the cervical, middle, and apical slices of all roots went through a push-out test performed in a universal test machine (EMIC, Instron). Each slice coronal portion was placed in contact with a metallic device with a central opening larger than the root canal diameter. A metallic

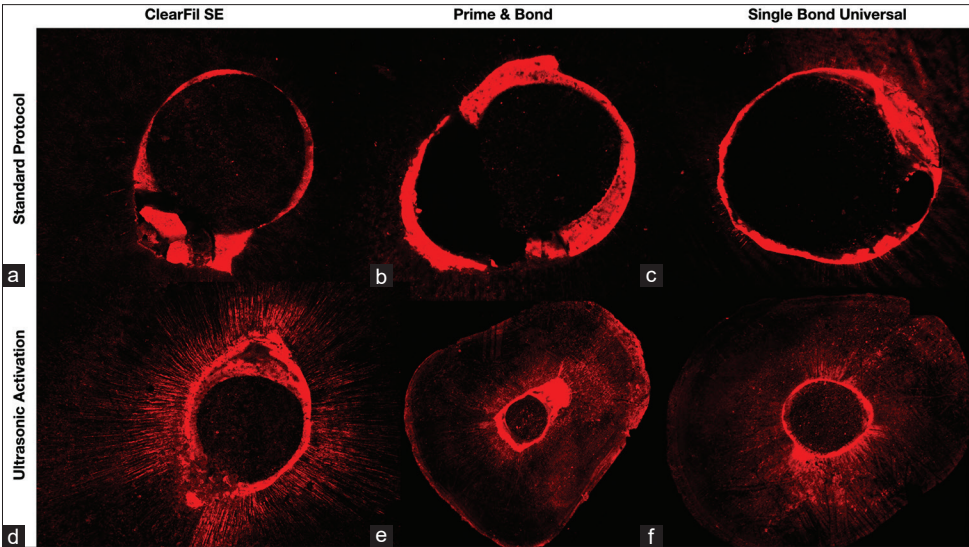


Figure 1: Representative image of dentinal tubule penetration of adhesives in experimental groups apical slices in CLSM (a) Clearfil SE (Standard Protocol), (b) Prime Bond (Standard Protocol) (c) Single Bond Universal (Standard Protocol), (d) Clearfil SE (Ultrasonic Activation), (e) Prime Bond (Ultrasonic Activation), (f) Single Bond Universal (Ultrasonic Activation)

Table 1: Experimental groups according to adhesive system, brand, composition, and adhesion strategy

Adhesive system	Brand	Composition	Adhesion strategy	n
Clearfil SE	Kuraray Medical Inc.	Primer: MDP, HEMA, dimethacrylate monomer, water, catalyst	Standard (CFS)	10
		bond: MDP, HEMA, dimethacrylate monomer, microfiller, catalyst	Ultrasonic activation (CFU)	10
Prime and bond universal	Dentsply Sirona	Bi- and multifunctional acrylate, phosphoric acid modified acrylate resin, initiator, stabilizer, isopropanol, water	Standard (PBS)	10
			Ultrasonic activation (PBU)	10
Single bond universal	3M	MDP phosphate monomer, dimethacrylate resins, HEMA, Vitrebond copolymer, filler, ethanol, water, initiators, silane	Standard (SBS)	10
			Ultrasonic activation (SBU)	10

SE: Self-etch, HEMA: Two-hydroxyethyl methacrylate, MDP: Methacryloyloxydecyl dihydrogen phosphate, CFS: Clearfil SE standard, CFU: Clearfil SE ultrasonic activation PBS: Prime bond standard, PBU: Prime bond ultrasonic activation SBS: Single bond standard SBU: Single bond ultrasonic activation

cylinder ($\varnothing = 0.8$ mm) induced a load on the fiber post surface at a 0.5 mm/min speed. The bond strength values (mPa) were obtained by the ratio between the required load for specimen rupture (in Newton) and the adhesive area (mm²).

The experimental groups were compared for push-out bond strength using one-way ANOVA and Tukey's *post hoc* tests. The comparison between the thirds of the prosthetic canal within the same group was also made using a one-way ANOVA test. The Student's *t*-test compared the groups that used manual adhesive protocols and those that added ultrasonic activation of the adhesive systems.

The failure patterns were classified as adhesive between cement and dentin (ACD), adhesive between cement and post (ACP), cohesive for the cement (CC), cohesive for the post (CP), and cohesive for the dentin (CD). After the push-out test, all specimens were analyzed under an optical microscope (B $\times$ 60M, Olympus Corp.) with x10 magnification to determine their predominant failure pattern.

RESULTS

Dentin tubule penetration

The ultrasonic activation of the adhesive systems improved its dentin tubule penetration in apical slices of experimental groups. Dyed adhesives appear red in the CLSM images presented in Figure 1.

Push-out bond strength

The intragroup analysis showed no significant difference in bond strength values between the fiber post's three levels in the experimental groups ($P > 0.05$). About standard adhesive protocol groups, PBS presented lower bond strength values in the apical and cervical thirds of the post ($P < 0.05$), and there was no difference in the middle third ($P > 0.05$). PBS showed the lowest bond strength mean value ($P < 0.05$). Between ultrasonic-activated adhesive protocol groups, there was no difference in the cervical third of the post ($P > 0.05$). PBU presented no difference compared to CFU and SBU in the apical third and the mean value of the three-thirds ($P > 0.05$). In the middle third, CFU

presented higher bond strength values when compared to PBU and SBU ($P < 0.05$). CFU's bond strength values were higher than SBU in the apical third and the mean value ($P < 0.05$). Ultrasonic activation improved bond strength when applied to Clearfil SE and Prime and Bond in the apical and middle thirds of the post and the mean value of the three-thirds ($P < 0.05$).

Table 2 presents the values of bond strength after the push-out test.

Failure pattern

The adhesive failure between cement and dentin was the most commonly observed failure mode in all groups (59.44%), followed by an adhesive failure between cement and post (30%) [Table 3]. The adhesive failure between cement and dentin had a 65.55% prevalence in manual adhesive protocol groups. This value decreased to 53.33% in the ultrasonic activation groups [Table 4].

Figure 2 presents the pictures of each failure mode observed under the optic microscope.

DISCUSSION

This study evaluated the effect of ultrasonic activation on dentinal tubule penetration and bond strength on fiber post cementation. The null hypothesis was rejected.

Bovine teeth can be used as a substitute of human teeth in studies that aim to assess bond strength, once its dentin and enamel present similar results.^[22]

The study of Verдум *et al.* (2022) is the only one observe different adhesion techniques, including ultrasonic activation and different adhesive systems tubule penetration in fiber post cementation. In this study, the authors observed that ultrasonic activation increased the bond strength of a self-etch adhesive system (Clearfil SE) for resin cementation of fiber posts. The present study method was designed to observe if Clearfil SE's results found by Verдум *et al.* (2022) would also be seen in different self-etch adhesive systems.

Verдум *et al.* (2022) performed a statistical analysis of the adhesive's dentinal tubule penetration and concluded

Table 2: Mean and standard deviation for bond strength values after push-out test (mPa)

	CFS	PBS	SBS	CFU	PBU	SBU
Apical	10.9250 ^{a,A,B} ±4.9164	7.4156 ^{a,B} ±4.4896	13.6189 ^{a,A} ±4.9485	19.7513 ^{a,A,*} ±4.5585	14.6930 ^{a,A,B,*} ±8.7412	10.8220 ^{a,B} ±4.7759
Middle	12.6610 ^{a,A} ±4.4707	8.1189 ^{a,A} ±4.9905	11.7833 ^{a,A} ±5.0357	19.7075 ^{a,A,*} ±6.6145	13.2280 ^{a,B,*} ±5.7839	11.4630 ^{a,B} ±3.9160
Cervical	14.9930 ^{a,A} ±6.5405	9.1678 ^{a,B} ±2.9212	14.8611 ^{a,A} ±3.6461	17.5075 ^{a,A} ±5.6981	12.6890 ^{a,A} ±7.3889	12.7290 ^{a,A} ±4.0827
Mean	12.8730 ^a ±4.4796	8.1311 ^B ±3.8461	13.2478 ^A ±2.9423	18.9888 ^{A,*} ±4.5948	13.5550 ^{A,B,*} ±6.1366	11.8960 ^B ±3.7744

*Differences between the manual and ultrasonic activation protocols for each adhesive system after *t*-test ($P < 0.05$). Lowercase letters compare the thirds of the prosthetic canal within the same group after one-way ANOVA test ($P < 0.05$). Uppercase letters compare standard and ultrasonic activation protocol groups separately within each third of the prosthetic canal after one-way ANOVA and Tukey's *post hoc* test ($P < 0.05$). CFS: Clearfil SE standard, CFU: Clearfil SE ultrasonic activation, PBS: Prime bond standard, PBU: Prime bond ultrasonic activation, SBS: Single bond standard, SBU: Single bond ultrasonic activation

Table 3: Failure patterns observed after push-out bond strength test

Adhesion protocol	ACD	ACP	CC	CP	CD
CFS					
Apical	6	4	-	-	-
Middle	5	4	-	1	-
Cervical	4	6	-	-	-
CFU					
Apical	5	3	-	-	2
Middle	5	2	-	1	2
Cervical	3	3	1	2	1
PBS					
Apical	5	3	1	-	1
Middle	10	-	-	-	-
Cervical	9	1	-	-	-
PBU					
Apical	6	3	1	-	-
Middle	3	6	1	-	-
Cervical	6	3	-	1	-
SBS					
Apical	7	2	-	1	-
Middle	6	2	1	1	-
Cervical	7	2	-	-	1
SBU					
Apical	8	2	-	-	-
Middle	5	5	-	-	-
Cervical	7	3	-	-	-
Total, n (%)	107 (59.44)	54 (30)	5 (2.78)	7 (3.89)	7 (3.89)

ACD: Adhesive between cement and dentin, ACP: Adhesive between cement and post, CC: Cohesive for the cement, CP: Cohesive for the post, CD: Cohesive for the dentin, SBU: Single bond ultrasonic activation, SBS: Single bond standard, PBU: Prime bond ultrasonic activation, PBS: Prime bond standard, CFU: Clearfil SE ultrasonic activation, CFS: Clearfil SE standard

Table 4: Prevalence of failure patterns in standard adhesive protocol groups and ultrasonic activation adhesive protocol groups

	Standard protocol (%)	Ultrasonic activation (%)
ACD	59 (65.55)	48 (53.33)
ACP	24 (26.67)	30 (33.33)
CC	2 (2.22)	3 (3.34)
CP	3 (3.34)	4 (4.44)
CD	2 (2.22)	5 (5.56)

ACD: Adhesive between cement and dentin, ACP: Adhesive between cement and post, CC: Cohesive for the cement, CP: Cohesive for the post, CD: Cohesive for the dentin

that ultrasonic activation improved Clearfil SE's dentinal tubule penetration in apical and cervical fiber post thirds. Our study's dentinal tubule penetration of adhesives was performed by observing CLSM images of standard adhesive and ultrasonic activation protocols and their visual comparison. Our choice to perform a descriptive analysis of the adhesive's dentinal tubule penetration was due to the different diameters of the roots. In some root slices, it was impossible to observe its hole surface on CLSM, which could lead to underestimated values of dentinal tubule penetration if a statistical analysis was done.

The bond strength of self-etch adhesive systems can be compromised by the lower dentinal and smear layer demineralization and the smear layer's incorporation in the adhesive hybrid layer.^[6-9] These facts can explain the

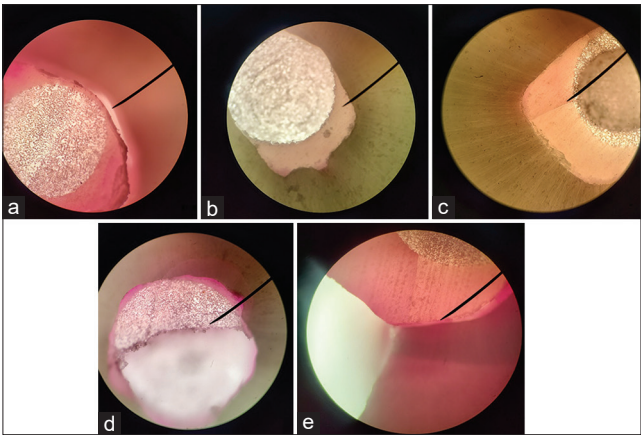


Figure 2: Representative pictures of failure patterns after push-out test. (a) adhesive between cement and dentin, (b) Adhesive between cement and post, (c) Cohesive for the cement, (d) Cohesive for the post, (e) Cohesive for the dentin

lower bond strength values found on the standard adhesive protocol groups in the present study ($P < 0.05$). About bond strength values of Clearfil SE, Prime Bond Universal, and Single Bond Universal in standard application protocols under push-out test, Single Bond Universal presented the higher values, and Prime Bond Universal presented the lowest bond strength values in our study, in disagreement with other authors^[23] that observed the lowest values in Single Bond Universal and the highest values on Clearfil SE. However, these studies compared different adhesive systems in composites bond to coronal dentin.^[23] They differ from our aim to observe the adhesives on resin cementation of fiber posts to root dentin.

Despite the results on bond strength of standard adhesive protocols, the ultrasonic activation groups reached different mean values. Clearfil SE and Prime and Bond Universal had their bond strength improved after ultrasonic activation ($P < 0.05$), while Single Bond Universal did not ($P > 0.05$). Verдум *et al.* (2022) also observed the improvement of Clearfil SE bond strength after ultrasonic activation. It might be related to the fact that this adhesive system is a two-step self-etch, and the primer was separately ultrasonic activated before the bond's activation. Single Bond Universal is an adhesive system that has a large and varied formulation. The effects of ultrasonic activation on its composition may have influenced the results of this system.^[7,8,17,24]

Ultrasonic vibration causes a local pressure and temperature increase and also solution agitation. These properties may lead to a more efficient solution spread through dental tissues and consequently increase the primer's dentinal and smear layer demineralization and adhesion capacity of the system. The increase in local temperature during ultrasonic activation may have improved adhesive's solvent volatilization, improving the polymerization of the adhesives.^[22-26]

Cementation of fiber posts is a technique with some technical fragile points. In the present study, only the apical thirds of the canals were filled after chemical-mechanical preparation, leaving less residual tissue and materials on the canal walls before adhesive system application, which is different from what usually occurs in clinical practice.^[27,28] The difficult access to adhesive system application is another challenge on post cementation, especially in deeper portions of canal walls. An adhesive protocol that requires fewer steps, like the self-etch adhesives, is an attempt to minimize this adversity. Despite being one more step in the process, ultrasonic activation of the adhesive system could reduce the technical difficulties of fiber post resin cementation, possibly increasing its longevity and decreasing its clinical failures. More studies must be performed to confirm these hypotheses.

Other studies evaluated techniques applied to adhesive systems, including sonic application and ultrasonic agitation.^[29-32] However, sonic application differs from ultrasonic according to each frequency range. The frequency of sonic devices ranges from 1000 to 6000 Hz, different from ultrasonic devices which are 20,000 Hz or higher.

Bagis *et al.* observed no difference in the bond strength of fiber post's cementation when self-etch adhesive systems were ultrasonically activated. However, Bagis *et al.* performed a high-frequency (1 MHz) ultrasonic activation of self-etch adhesives and observed improved bond strength. It is essential to mention that the ultrasonic agitation performed by Bagis *et al.* in 2008 and 2009^[31,32] observed this event on the coronal dentin surface. To date, no studies other than ours have evaluated the effects of ultrasonic activation on self-etch adhesive systems on fiber post cementation.

The present study observed that the most prevalent failure after the push-out test of resin-cemented fiber posts was ACD, followed by ACP in all groups, in line with other author's similar studies.^[10-12] Interestingly, after ultrasonic activation of adhesive systems, the incidence of adhesive failure between cement and dentin had a 12.22% decrease, and adhesive failure between cement and post and cohesive failures had increased. These findings may be explained by the higher adhesive penetration in the dentinal tubule and higher bond strength of fiber posts resin cementation on dentin after ultrasonic activation, leading to a more adhesiveness between resin cement and dentinal surface.

Despite the limitations of this *in vitro* study, our findings are a starting point for new studies in this promising research topic. Further investigation should be developed to compare and confirm our results, and posterior clinical trials and long-term follow-up of clinical protocols must be done to evaluate and observe its results.

CONCLUSIONS

The findings of this *in vitro* study lead to the following conclusions about the resin cementation of fiber posts:

1. Ultrasonic activation improved self-etch adhesives dentinal tubule penetration
2. Ultrasonic activation improved the bond strength of Clearfil SE and Prime and Bond Universal
3. Ultrasonic activation of self-etch adhesive systems influenced the prevalence of adhesive failure patterns.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Maccari PC, Cosme DC, Oshima HM, Burnett LH Jr., Shinkai RS. Fracture strength of endodontically treated teeth with flared root canals and restored with different post systems. *J Esthet Restor Dent* 2007;19:30-6.
2. Carvalho MA, Lazari PC, Gresnigt M, Del Bel Cury AA, Magne P. Current options concerning the endodontically-treated teeth restoration with the adhesive approach. *Braz Oral Res* 2018;32:e74.
3. Öztürk C, Polat S, Tunçdemir M, Gönüldaş F, Şeker E. Evaluation of the fracture resistance of root filled thin walled teeth restored with different post systems. *Biomed J* 2019;42:53-8.
4. Jana S, Desai PD, Das D, Mazumdar P, Majumdar TK. Comparative evaluation of adhesion of glass fiber post to the root dentin after surface treatment of post and using universal bonding agent: An *in vitro* study. *J Conserv Dent* 2022;25:636-41.
5. Ozer F, Blatz MB. Self-etch and etch-and-rinse adhesive systems in clinical dentistry. *Compend Contin Educ Dent* 2013;34:12-4, 16, 18.
6. Dressano D, Salvador MV, Oliveira MT, Marchi GM, Fronza BM, Hadis M, *et al.* Chemistry of novel and contemporary resin-based dental adhesives. *J Mech Behav Biomed Mater* 2020;110:103875.
7. Saikaew P, Sattabanasuk V, Harnirattisai C, Chowdhury AF, Carvalho R, Sano H. Role of the smear layer in adhesive dentistry and the clinical applications to improve bonding performance. *Jpn Dent Sci Rev* 2022;58:59-66.
8. Sofan E, Sofan A, Palaia G, Tenore G, Romeo U, Migliau G. Classification review of dental adhesive systems: From the IV generation to the universal type. *Ann Stomatol (Roma)* 2017;8:1-17.
9. Digole VR, Warhadpande MM, Dua P, Dakshindas D. Comparative evaluation of clinical performance of two self-etch adhesive systems with total-etch adhesive system in noncarious cervical lesions: An *in vivo* study. *J Conserv Dent* 2020;23:190-5.
10. Scotti N, Forniglia A, Bergantin E, Paolino DS, Pasqualini D, Berutti E. Fibre post adaptation and bond strength in oval canals. *Int Endod J* 2014;47:366-72.
11. Duarte Santos Lopes L, da Silva Pedrosa M, Beatriz Melo Oliveira L, Maria da Silva Costa S, Aguiar Santos Nogueira Lima L, Lucisano Botelho do Amaral F. Push-out bond strength and failure mode of single adjustable and customized glass fiber posts. *Saudi Dent J* 2021;33:917-22.
12. Verdum I, Abreu de Bem I, Marks Duarte PH, Machado LS, Pereira JR, Reis Só MV, *et al.* Effect of ultrasonic activation of the adhesive system on dentin tubule penetration and the pushout bond strength of fiber posts. *J Prosthet Dent* 2022;127:295-301.
13. Alcalde MP, Bramante CM, Vivan RR, Amoroso-Silva PA, Andrade FB, Duarte MA. Intradentinal antimicrobial action and filling quality promoted by ultrasonic agitation of epoxy resin-based sealer in endodontic obturation. *J Appl Oral Sci* 2017;25:641-9.
14. Paixão S, Rodrigues C, Grenho L, Fernandes MH. Efficacy of sonic and ultrasonic activation during endodontic treatment: A meta-analysis of *in vitro* studies. *Acta Odontol Scand* 2022;80:588-95.
15. Setzer FC, Kratchman SI. Present status and future directions: Surgical endodontics. *Int Endod J* 2022;55 Suppl 4:1020-58.
16. Silva IA, Só GB, Weissheimer T, Mendes A, Hashizume LN, Só MV, *et al.* Does the ultrasonic activation of calcium silicate-based sealers affect

- their physicochemical properties? *Braz Dent J* 2022;33:20-7.
17. Nesello R, Silva IA, Bem IA, Bischoff K, Souza MA, Só MV, *et al.* Effect of bioceramic root canal sealers on the bond strength of fiber posts cemented with resin cements. *Braz Dent J* 2022;33:91-8.
18. Souza CC, Bueno CE, Kato AS, Limoeiro AG, Fontana CE, Pelegrine RA. Efficacy of passive ultrasonic irrigation, continuous ultrasonic irrigation versus irrigation with reciprocating activation device in penetration into main and simulated lateral canals. *J Conserv Dent* 2019;22:155-9.
19. Talreja T, Tandale A, Kunkulol R, Maniyar V, Krishnakumar K, Dube R, *et al.* Comparative evaluation of penetration of sealers in dentinal tubules using passive ultrasonic irrigation and erbium: Yttrium-aluminum-garnet laser – A confocal laser scanning microscope study. *J Conserv Dent Endod* 2023;26:634-8.
20. Awati AS, Dhaded NS, Mokal S, Doddwad PK. Analysis of the depth of penetration of an epoxy resin-based sealer following a final rinse of irrigants and use of activation systems: An *in vitro* study. *J Conserv Dent Endod* 2024;27:87-94.
21. Rosa RA, Barreto MS, Moraes Rdo A, Broch J, Bier CA, Só MV, *et al.* Influence of endodontic sealer composition and time of fiber post cementation on sealer adhesiveness to bovine root dentin. *Braz Dent J* 2013;24:241-6.
22. Soares FZ, Follak A, da Rosa LS, Montagner AF, Lenzi TL, Rocha RO. Bovine tooth is a substitute for human tooth on bond strength studies: A systematic review and meta-analysis of *in vitro* studies. *Dent Mater* 2016;32:1385-93.
23. Saikaew P, Matsumoto M, Sattabanasuk V, Harnirattisai C, Carvalho RM, Sano H. Ultra-morphological characteristics of dentin surfaces after different preparations and treatments. *Eur J Oral Sci* 2020;128:246-54.
24. Scherrer SS, Cesar PF, Swain MV. Direct comparison of the bond strength results of the different test methods: A critical literature review. *Dent Mater* 2010;26:e78-93.
25. Boutsoukias C, Arias-Moliz MT. Present status and future directions – Irrigants and irrigation methods. *Int Endod J* 2022;55 Suppl 3:588-612.
26. Liu C, Li Q, Yue L, Zou X. Evaluation of sonic, ultrasonic, and laser irrigation activation systems to eliminate bacteria from the dentinal tubules of the root canal system. *J Appl Oral Sci* 2022;30:e20220199.
27. Chandra SS, Shankar P, Indira R. Depth of penetration of four resin sealers into radicular dentinal tubules: A confocal microscopic study. *J Endod* 2012;38:1412-6.
28. Llana C, García-Gallart M, Forner L, Ferrari M. Root canal adaptation and intra-tubular penetration of three fiber-post cementation systems. *J Clin Exp Dent* 2018;10:e1198-204.
29. Cuadros-Sanchez J, Szesz A, Hass V, Patzlaff RT, Reis A, Loguercio AD. Effects of sonic application of adhesive systems on bonding fiber posts to root canals. *J Endod* 2014;40:1201-5.
30. Zarpellon DC, Szesz AL, Loguercio AD, Arrais CA. Effect of sonic application of universal adhesive systems on bond strength of fiber posts to root canal. *J Adhes Dent* 2016;18:493-9.
31. Bagis B, Turkarslan S, Tezvergil-Mutluay A, Uctasli S, Vallittu PK, Lassila LV. Effect of ultrasonic agitation on bond strength of self-etching adhesives to dentin. *J Adhes Dent* 2008;10:441-5.
32. Bagis B, Turkarslan S, Vallittu PK, Lassila LV. Effect of high frequency ultrasonic agitation on the bond strength of self-etching adhesives. *J Adhes Dent* 2009;11:369-74.