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In vitro evaluation of the bond strength of an epoxy resin-based and bioceramic root canal sealers after using different final irrigant agitation techniques

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Purpose: Evaluating the effect of different final irrigation agitation techniques on the bond strength of AH Plus Bioceramic sealer (AHPBS).

Methods: Ninety single-rooted teeth were included in this study. Endodontic access cavities were prepared. The working length (WL) was established. All root canals were enlarged up to Protaper Universal F3. The teeth were then randomly divided into three main groups of 30 teeth according to the final irrigation agitation methods (n = 30). Group 1: Manual dynamic activation (MDA), Group 2: Ultrasonic irrigant agitation (UIA), Group 3: Sonic agitation (SA). The canals were dried using paper points before being obturated. Each group was randomly divided into three subgroups according to the type of root canal sealer (n = 10): AH Plus Jet (AHPJ), AHPBS, and Sure Seal Root (SSR). Push-out bond strength (PBS) tests were performed for all specimens. After the measurement of PBS, the failure types were evaluated with a stereomicroscope (BX60; Olympus, Tokyo, Japan) at 30× magnification. The failure types were classified as adhesive failure, cohesive failure, and mixed failure.

Results: While AHPJ had the highest mean PBS value, SSR had the lowest mean PBS value (AHPJ > AHPBS > SSR, P < 0.05). Coronal and middle thirds were statistically significantly lower than the apical third (P < 0.05), while they had similar mean PBS values (P > 0.05). UIA had a statistically significantly higher mean PBS value compared to MDA (P < 0.05). When failure types were evaluated, cohesive failure was the most frequent type of failure in all groups.

Conclusion: All root canal sealers had the highest PBS value at the apical third, and an epoxy resin-based sealer also had a higher PBS value than a bioceramic-based sealer. The PBS value of all sealers may increase with UIA compared to MDA.

Keywords: AH plus bioceramic sealer; irrigant agitation technique; push-out bond strength.

Introduction

The quality of the root canal filling is one of the most critical factors in the success of root canal treatment. A good root canal filling should prevent coronal leakage, provide an excellent apical seal, and keep any remaining microbes from reproducing in the root canal following chemo-mechanical debridement (1). Chemo-mechanical preparation results in a smear layer (SL) on the cut surface of inorganic

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dentin debris and the organic matrix (2). The SL, containing bacterial biofilms and necrotic pulp tissue, can lead to treatment failure (3). Studies have shown that the penetration of irrigation solution and intracanal medicament into the root canal system increases when the SL is wholly removed. The increased irrigation solution penetration also allows the canal filling materials to adapt successfully to the root canal dentin. Thus, root canal filling may show a higher bond strength because of the complete removal of the SL (4–6). However, Türker et al. (7) showed that the push-out bond strength (PBS) of AH26 and BioRoot root canal sealers was not affected by the presence or absence of an SL.

Using irrigation is a crucial procedure for root canal disinfection and removal of the SL. The SL has been removed by various irrigation solutions from the past to the present (8). Sodium hypochlorite (NaOCl) is commonly used to remove organic components of the SL. At the same time, ethylenediaminetetraacetic acid (EDTA) is employed to remove inorganic components of the SL, so the alternate use of both is recommended (9). Conventional needle irrigation (CNI) fails to deliver these solutions effectively because of the vapor lock effect and complex root canal anatomy (10). Numerous machine-assisted or manual irrigant agitation techniques (IAT), including manual dynamic activation (MDA), ultrasonic irrigant agitation (UIA), and sonic agitation (SA), have been developed to overcome the limitations of CNI (11). Different irrigation techniques can cause structural and chemical changes to the dentin surface. As a result, dentin's permeability and solubility properties can be altered (12). The effect of irrigation agitation systems on the bond strength of root canal filling materials has been the subject of many studies. Some studies have shown that the irrigation agitation systems increased the PBS of the root canal sealer, while another study has presented that these systems did not positively affect the PBS (13–15).

AH Plus Jet (AHPJ) is a gold-standard epoxy resin-based root canal sealer. It has favorable physical and biological properties, low solubility, and good adhesion to root dentin (16). AH Plus Bioceramic Sealer (AHPBS) (Dentsply Sirona, York, PA, USA) was introduced as a premixed tricalcium silicate-based sealer. AHPBS's manufacturer claims lower solubility and film thickness, faster setting time, and higher radiopacity than the Endosequence BC Sealer, another premixed bioceramic sealer (17).

Our study is the first to investigate the effect of different final IATs on the bond strength of AHPBS, a bioceramic root canal sealer. While the impact of different final IATs on the bond strength of AH Plus sealer has been explored, our research aims to fill the gap in knowledge by evaluating the effect on AHPBS.

Materials and Methods

Tooth Selection and Preparation

The manuscript of this laboratory study has been written according to Preferred Reporting Items for Laboratory Studies in Endodontology (PRILE) 2021 guidelines (18). The present research exactly followed the PRILE recommendations (Fig. 1). Ethics approval was received from the university ethics board (2023/484). The sample size for the bond strength test was 81 at 95% power and a significance level of 0.05 using data (effect size = 0.654) obtained from a previous study (13). Thus, 90 single-rooted, single-canal teeth extracted for periodontal and/or orthodontic reasons from people aged 18–60 years with a fully formed apex and no previous root filling, resorption, or calcification were included in this study and stored at 4°C in saline solution. The crowns were separated from the root via sectioning with a diamond disc perpendicular to the long axis

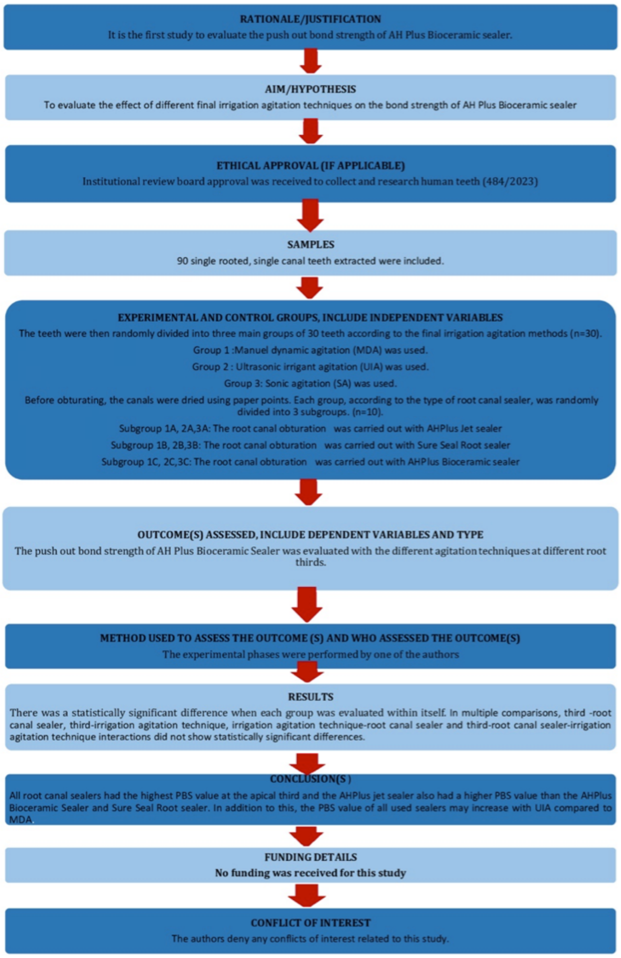

Fig. 1. PRILE 2021 Flowchart.

of the root under water cooling to obtain roots 12 mm in length. Endodontic access cavities were prepared using a diamond bur with a high-speed handpiece under water cooling.

The apical patency of each root canal was then checked using a #15 K file. The root length was measured when its tip appeared at the apical foramen. The working length (WL) was established by subtracting 1 mm from this measurement. All root canals were enlarged up to Protaper Universal F3 (Dentsply Sirona), and the root canal was irrigated with 2 mL 2.5% NaOCl between each file using a side-vented syringe with a 29-gauge (NaviTip; Ultradent, South Jordan, UT). The teeth were then randomly divided into three main groups of 30 according to the final irrigation agitation methods (n = 30).

Group 1 (MDA): First, 5 mL of 17% EDTA was used with a side-vented needle placed 1 mm short of WL for root canal irrigation. A well-fitting gutta-percha cone (size F3, Dentsply Maillefer) was passively inserted into the canal to the WL and moved up and down for 60 seconds over a 2–3 mm range. The above procedure was then repeated for 5 mL 2.5% NaOCl.

Group 2 (UIA): 5 mL of 17% EDTA irrigation was performed with an ultrasonic device (EMS, Le Sentier, Switzerland) and a smooth ultrasonic file with a size of 15 and a taper of 0.02 (ESI instrument). The power was set at 1/6 of the scale for 60 seconds. The device was inserted into the canal 1 mm short of the WL without contact with the walls for free vibration. The above procedure was then repeated for 5 mL 2.5% NaOCl.

Group 3 (SA): Each canal was first irrigated with 5 mL of 17% EDTA. Then, an EndoActivator (EA) device (Dentsply Sirona, Tulsa, USA) with a small tip size of 15/0.02 was inserted into the canal 1 mm short of the WL. The EA was activated at 10,000 rpm for 60 seconds. The above procedure was then repeated for 5 mL 2.5% NaOCl.

Root Canal Obturation

Before obturating, the canals were dried using paper points. Each group, according to the type of root canal sealer, was randomly divided into three subgroups (n = 10).

Subgroup 1A, 2A, 3A: The root canal obturation was carried out using the single cone technique with an AHPJ sealer and F3 gutta-percha cones.

Subgroup 1B, 2B, 3B: The root canal obturation was carried out using the single cone technique with SSR sealer and F3 gutta-percha cones.

Subgroup 1C, 2C, 3C: The root canal obturation was carried out using the single cone technique with AHPBS sealer and F3 gutta-percha cones.

The access cavity whose root canal fillings were completed was restored with temporary material filling. The teeth were stored for seven days in an incubator at 37°C and 100% humidity (19).

Push-Out Bond Strength Test

After the root canal sealer had set, the root surfaces were ground to obtain a smooth surface, and the prepared specimens were embedded in cold acrylic using cylindrical molds measuring 10 mm in diameter and 20 mm in height. From each specimen placed in a low-speed, water-cooled micro-cutting device (Isomet; Buehler, Lake Bluff, IL), horizontal sections of 1 mm thickness were cut at depths of 4, 7, and 10 mm (i.e., apical, middle, and coronal).

After all slices were scanned, the diameters of filling materials for the push-out test were measured using an electronic scale in software (Adobe Photoshop). The diameters of the plungers to be used were then determined. Each sample in subgroups was placed in the universal testing machine (Instron Corp, Canton, MA) using a cylindrical plunger with a tip of 0.7, 0.8, or 0.9 mm in diameter (respectively, apical, middle, and coronal third). Loading was applied at a 1 mm/min crosshead speed from the apical to the coronal direction until bond failure occurred.

The maximum load applied to filling material before failure was recorded in newtons and converted to megapascals (MPa) using the following formula:

Push-out bond strength (MPa) = N / A

where N = maximum load (N) and A = adhesion area of root canal filling (mm^2) (20).

Following the measurement of PBS, the failure types were evaluated with a stereomicroscope (BX60; Olympus, Tokyo, Japan) at 30× magnification. According to a previous study, failure types were divided into three categories: adhesive failure, cohesive failure, and mixed failure (21).

Statistical Analysis

Statistical analysis was carried out using the three-way ANOVA. The Tukey post hoc test was then conducted for multiple comparisons. The significance level was set at $P < 0.05$. SPSS version 20.0 for Windows (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses.

Results

The mean PBS values of each sealer, third, and IAT are respectively shown in Table 1. When the root canal sealers were evaluated within themselves, AHPJ had the highest mean PBS value. SSR had the lowest mean PBS value

Table 1. The mean push-out bond strength according to all groups

	Groups	Mean value (MPa) ± SD	p
Root	AHPJ	11.86 A ± 3.74	
Canal	SSR	8.46 B ± 3.38	
Sealers	AHPBS	10.38 C ± 3.96	P < 0.05
Root	Coronal third	9.87 D ± 3.91	
Canal	Middle third	9.31 D ± 3.57	
Thirds	Apical third	11.52 F ± 4.03	P < 0.05
Irrigant	MDA	9.81 G ± 3.89	
Agitation	UIA	10.89 I ± 4.06	
Techniques	SA	10.00 G. I ± 3.84	P < 0.05

*Different capital letters indicate statistically significant differences. Standard deviation: SD. **Manual dynamic activation (MDA); Ultrasonic Irrigant Agitation (UIA); Sonic agitation (SA). ***AH Plus Jet (AHPJ); AH Plus Bioceramic Sealer (AHPBS); Sure-Seal Root™ (SSR).

Table 2. Multiple comparisons between groups

Groups	F-value	P-value
Thirds * Sealers	0.444	0.777
Thirds * IAT	0.994	0.410
Sealers * IAT	1.797	0.128
Thirds * Sealers * IAT	1.597	0.129

*P < 0.05 indicates a statistically significant difference. **Irrigant Agitation Technique (IAT).

(AHPJ > AHPBS > SSR, P < 0.05).

The thirds were evaluated within themselves. In contrast, coronal and middle thirds had similar mean PBS values (P > 0.05) and were statistically significantly lower than the apical third (P < 0.05). When irrigation agitation techniques were evaluated individually, UIA had a statistically significantly higher mean PBS value compared to MDA (P < 0.05). However, there was no statistically significant difference between the mean PBS values of UIA and SA. Also, there was no statistically significant difference between the mean PBS values of SA and MDA (P > 0.05).

Table 2 presents multiple comparisons between the groups. In multiple comparisons, the interactions of third-root canal sealer, third-irrigation agitation technique, irrigation agitation technique and root canal sealer, and third-root canal sealer-irrigation agitation technique did not show statistically significant differences (P > 0.05).

Table 3 shows the failure types according to the groups. Figure 2 also displays representative pictures of the failure types. Considering the kinds of failure in the coronal third, cohesive failure was the most common failure mode among the other groups, except subgroups 2B and 3B, which exhibited the mixed failure mode.

As for the failure types in the middle third, cohesive failure was the most frequent type of failure among the other groups, except subgroup 2A, which exhibited the adhesive failure mode, and subgroups 3A and 1C, which exhibited the mixed failure mode. Considering the types of fracture in the apical third, cohesive failure was the most common type of failure in all groups, except subgroup 1C, indicating the mixed failure mode.

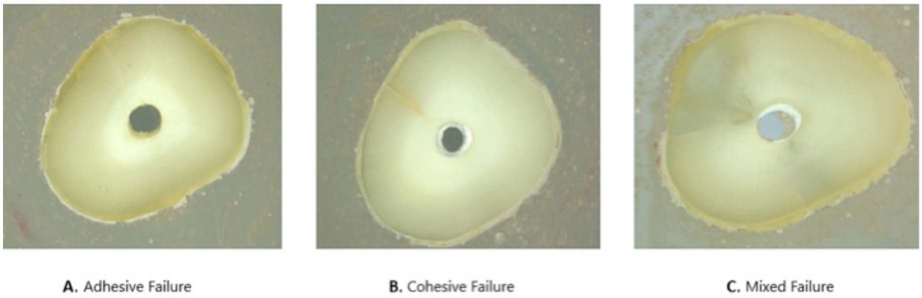

Fig. 2. Representative images of the failure types.

Table 3. Distrubition of the failure types in root canal thirds for different sealers and irrigation agitation methods after push-out test

Sealer	Irrigation Method	Root Canal Third	Adhesive Failure	Cohesive Failure	Mixed Failure
AHPJ	MDA				
		Coronal	0 (0%)	14 (78%)	4 (22%)
		Middle	2 (11%)	10 (56%)	6 (33%)
		Apical	0 (0%)	15 (83%)	3 (17%)
AHPJ	UIA				
		Coronal	3 (17%)	12 (67%)	3 (17%)
		Middle	8 (45%)	4 (22%)	6 (33%)
		Apical	3 (17%)	13 (72%)	2 (11%)
AHPJ	SA				
		Coronal	2 (11%)	10 (56%)	5 (28%)
		Middle	4 (22%)	5 (28%)	9 (50%)
		Apical	3 (17%)	13 (72%)	2 (11%)
AHPBS	MDA				
		Coronal	1 (6%)	10 (56%)	7 (38%)
		Middle	3 (17%)	5 (28%)	10 (56%)
		Apical	0 (0%)	6 (33%)	12 (67%)
AHPBS	UIA				
		Coronal	2 (11%)	13 (72%)	3 (17%)
		Middle	2 (11%)	11 (61%)	5 (28%)
		Apical	4 (22%)	10 (56%)	4 (22%)
AHPBS	SA				
		Coronal	1 (6%)	10 (56%)	7 (38%)
		Middle	3 (17%)	8 (44%)	7 (38%)
		Apical	0 (0%)	16 (89%)	2 (11%)
SSR	MDA				
		Coronal	0 (0%)	11 (61%)	7 (38%)
		Middle	5 (28%)	7 (38%)	6 (33%)
		Apical	3 (17%)	15 (83%)	0 (0%)
SSR	UIA				
		Coronal	2 (11%)	3 (17%)	13 (72%)
		Middle	3 (17%)	10 (56%)	5 (28%)
		Apical	1 (6%)	12 (67%)	5 (28%)
SSR	SA				
		Coronal	3 (17%)	6 (33%)	9 (50%)
		Middle	0 (0%)	12 (67%)	6 (33%)
		Apical	3 (17%)	9 (50%)	6 (33%)

*AH Plus Jet (AHPJ), AH Plus Bioceramic Sealer (AHPBS), Sure-Seal Root™ (SSR), Manual dynamic activation (MDA), Ultrasonic Irrigant Agitation (UIA), Sonic agitation (SA)

Discussion

Successful root canal treatment depends on eliminating debris and pathogenic microorganisms in the canal system. This is followed by a sealed root canal filling that will prevent microorganisms from passing from the oral environment and periapical tissues. Since gutta-percha is generally used as a root canal filling material that does not adhere to the canal wall in obturation, it must be used with a root canal sealer (22).

Root canal sealers are essential in preventing pathogenic microorganisms and their by-products from entering the canal space by creating a hermetic barrier between the canal wall and the root-filling material. The bond strength to dentin is critical to root canal treatment to create a three-dimensional root canal filling (23). Therefore, in the current study, the rational PBS test was used to evaluate the PBS of root canal sealer.

In the current study, when comparing the mean PBS values between root thirds themselves, regardless of the root canal sealers and irrigation agitation techniques used, the apical third had the highest PBS value compared to the coronal and middle third, and there was no statistically significant difference between the coronal and middle third. These results may depend on the shape of the root cross-sections, the root canal filling technique, and the film thickness of the root canal sealer. It is well known that while the root canal cross-section is relatively round at the apical third, it becomes more oval towards the coronal. When the single cone technique is used, the film thickness of the root canal sealer at the middle and coronal third is necessarily higher because of the master apical gutta-percha, which was well-fitting at the apical and the root canal shape, which became oval towards the coronal (14).

In the present study, when comparing the mean PBS values between root canal sealers within themselves, regardless of irrigation agitation techniques used and the root thirds, the AHPJ had the highest PBS value, and the AH-PBS value had a higher PBS value than SSR. While the results of this study are consistent with the results of some studies that evaluated the PBS of sealers (24,25), they contradict the results of some other studies (26,27).

The reason AHPJ had the highest PBS value can be explained by the ability of the epoxide rings of AHPJ to bind to the amino groups of dentin collagen and the cohesion amongst the molecules of epoxy resin-based sealer (24). Nouroloyouni et al. (27) stated that SSR had a higher mean PBS value than AHPJ, which may be because calcium silicate-based sealer (CSBS) undergoes a slight expansion when it is set. These contradictory results may stem from the differences in methodology between studies. The mean PBS value of AHPBS being higher than SSR may result from the fact that AHPBS canal sealer contains dimethyl sulfoxide, which can reduce dentin surface free energy, improving wettability (28) and adhesive penetration (29).

The SL should be removed from the root canal wall because it inhibits the penetration of irrigation solutions, medicines, and sealants into the dentinal tubules. Moon et al. (30), evaluating the effects of irrigation agitation techniques on sealer penetration in their study, showed that the penetration of root canal sealer into the tubules may indicate the removal of the SL and may increase the bonding of the filling material. The most effective method to remove an SL is the utilization of NaOCl (0.5%–5.25%) and EDTA (15%–17%) together (31). Therefore, 17% EDTA with 2.5% NaOCl was used to remove the SL in the present study.

In the current study, when comparing the mean PBS values between irrigation agitation techniques within themselves, regardless of root canal sealers used and the root thirds, the UIA group had higher mean PBS values than the MDA group. UIA causes a high velocity and volume of oscillation and efficient removal of the SL into the root canal. In this way, the root canal sealer may penetrate the dentinal tubules better, and as a result, its mean PBS value can increase.

At the same time, when evaluated in terms of the mean PBS values, there was no statistically significant difference between the UIA group and the SA group and between the SA group and the MDA group. In light of all these results, although UIA promoted greater penetration and the higher PBS of the sealer to root dentine, this relationship is not well established in the literature. Machado et al. (32) showed in their study that the sealer penetration into dentinal tubules is not directly associated with the PBS (32). The reason for the different results in the current study may originate from the differences in the age range of the teeth used in the research and the study's methodology.

When the failure types are evaluated, the current study's results agree with those of other studies (33,34). This can be explained by the fact that increased resistance to dislodgement may reduce the likelihood of disruption of the sealer-dentin interface, increasing the likelihood of failure occurring within the sealer itself (34).

Conclusion

Under the conditions of this study, it can be concluded that all root canal sealers had the highest PBS value at the apical third, and the AHPJ also had a higher PBS value than the AHPBS and SSR sealers. In addition, the PBS value of all used sealers may increase with UIA compared to MDA.

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Informed consent: Written informed consent was obtained from patients who participated in this study.

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