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Effect of Different Irrigation Activation Techniques on the Bond Strength of a Resin-Based Root Canal Sealer: An In Vitro Study

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Abstract

Objective

Irrigant activation is used to improve canal cleaning before obturation, but it remains unclear which activation technique best supports the adhesion of the sealer to root dentin, a property that contributes to the retention and seal of the root filling. This in vitro study aimed to compare the effect of three activation techniques, namely manual dynamic activation (MDA), passive ultrasonic irrigation (PUI), and negative apical pressure (NAP), on the push-out bond strength of AH Plus (Dentsply DeTrey GmbH, Konstanz, Germany) sealer to root dentin, and to determine whether this effect differed among the coronal, middle, and apical thirds of the root.

Methods

Thirty extracted mandibular premolars, each with a single root and a single canal, were used in this comparative in vitro study. After shaping with ProTaper F3 (Dentsply Sirona, Ballaigues, Switzerland), the roots were randomly assigned to three groups of 10 according to the final activation method: MDA, PUI, or NAP delivered with the EndoVac system (Discus Dental, Culver City, CA). Obturation was performed with AH Plus and gutta-percha (META BIOMED, Chungcheongbuk-do, Republic of Korea) by warm vertical compaction, and every root was cut into coronal, middle, and apical slices, giving 90 sections in total. Push-out testing was used to obtain bond strength (MPa), defined as the failure load divided by the area of the bonded interface. A linear mixed model, including activation method, root third, and their interaction as fixed terms and the root as a random term, was fitted, and pairwise contrasts were adjusted with the Bonferroni method ($\alpha = 0.05$).

Results

Bond strength depended significantly on the activation method, the root third, and the interaction between them ($p < 0.001$). The highest coronal (6.71 ± 0.07 MPa) and middle (4.94 ± 0.13 MPa) values were recorded with PUI, whereas NAP gave the highest apical value (2.43 ± 0.08 MPa). MDA yielded the lowest values at every level (5.04 ± 0.09, 3.63 ± 0.08, and 1.25 ± 0.08 MPa, respectively). Within each third, every pairwise comparison between methods reached significance ($p < 0.001$), and in all groups, bond strength fell significantly from the coronal to the apical level ($p < 0.001$).

Conclusions

Under the conditions of this laboratory study, the choice of activation method significantly influenced the bond of AH Plus to radicular dentin, and its effect differed between root levels. PUI performed best in the coronal and middle thirds, while NAP performed best apically.

Categories: Dentistry
Keywords: ah plus, irrigation activation, manual dynamic activation, negative apical pressure, passive ultrasonic irrigation, push-out bond strength

Introduction

Root canal treatment seeks to eradicate infection and obtain a three-dimensional, fluid-tight seal of the canal system [1]. Because of the complex internal anatomy, instrumentation alone cannot achieve this goal, and irrigation is therefore indispensable for flushing out debris and lowering the bacterial load in regions that files cannot reach [2,3]. Conventional syringe irrigation, however, distributes the solution poorly throughout the canal system, a shortcoming that prompted the introduction of several irrigant activation techniques [4,5].

Activation relies on mechanical or physical means to increase the flow of the irrigant inside the canal, and

the available systems work through different mechanisms [6], including manual dynamic, sonic, ultrasonic, negative pressure, and laser activation [7,8]. Of these, manual dynamic activation (MDA) is the least complex and least expensive; a well-fitting gutta-percha cone (META BIOMED, Chungcheongbuk-do, Republic of Korea) is moved up and down within the canal in short, repeated strokes [8]. Passive ultrasonic irrigation (PUI) improves cleaning by generating acoustic microstreaming in the solution [9]. Negative apical pressure (NAP) systems counteract the vapor lock effect using suction through a fine cannula to pull the irrigant toward the apex, instead of trying to force it through the trapped gas [10]. Activation is valuable because it removes the smear layer and opens the dentinal tubules, which promotes sealer penetration and adaptation, improves the quality of the seal, and lowers the risk of microleakage and reinfection [11].

Once the canal has been shaped, it is filled, and the adhesion of the sealer to dentin is governed by the sealer's physical and chemical characteristics [12]. AH Plus (Dentsply DeTrey GmbH, Konstanz, Germany), a widely used epoxy resin sealer, is supplied as two pastes, one epoxide-based and one amine-based, that are mixed before use [1]. It remains dimensionally stable after setting and can bond chemically to collagen in dentin [13,14], and its good flow lets it enter the dentinal tubules and form resin tags that add micromechanical retention and improve the seal [14,15]. The push-out test is a common and dependable way to quantify this adhesion, as it records how much force is needed to dislodge the sealer from the canal wall [16].

Many investigations have examined the influence of irrigant activation on the adhesion of various sealers to root dentin [13,17-23]. The findings are inconsistent regarding which technique is superior, and the effect has been reported to depend on the root level tested [18,21,23], the type of sealer, and the filling technique [13,17,19]. In oval canals, activation by itself is of limited benefit [19]. The present study therefore compared three activation techniques that had not been tested together in one investigation, namely MDA, PUI, and NAP, in terms of their effect on the push-out bond strength of AH Plus at the coronal, middle, and apical levels. The null hypothesis stated that the activation technique would have no influence on the push-out bond strength of AH Plus at any root level.

Materials And Methods

Ethical approval and settings

The study was carried out in vitro at Damascus University (Faculty of Dentistry, Department of Endodontics and Operative Dentistry), Damascus, Syria, between December 2021 and December 2023. Approval was granted by the institution's Local Research Ethics Committee (approval number 300, dated October 11, 2021).

Sample size calculation

G*Power 3.1.9 (Heinrich Heine University, Düsseldorf, Germany) was used to determine the sample size. For a one-way ANOVA comparing three groups, with α set at 0.05 and power at 95%, a Cohen's f of 0.76 was entered as the expected effect size; this value was derived from the group means and standard deviations of push-out bond strength published by Prasad et al. [21], the only earlier study in which PUI and NAP were compared with this test. Although those authors used a mineral trioxide aggregate (MTA)-based sealer, no equivalent data for AH Plus were available. The calculation indicated a total of 30 premolars (10 per group). Each root yielded three sections, which were handled as repeated measurements of that root in the analysis. As every root contributed three correlated observations, a calculation made for a between-group one-way ANOVA gives a conservative estimate for this repeated-measures design.

Sample collection

Thirty freshly extracted human mandibular premolars with one root and one canal were obtained from the Department of Oral and Maxillofacial Surgery at the same faculty. Clinical and radiographic examination confirmed that each tooth met the inclusion criteria: a fully formed apex, an apical constriction corresponding to ISO (International Organization for Standardization) size 20, a root length of 17-21 mm, and a canal curvature of no more than 15°. Teeth showing previous endodontic treatment, root caries, fractures, calcified or constricted canals, or internal or external resorption were not included. Teeth were kept in storage until the full sample had been collected.

Specimen cleaning and storage

The teeth were cleaned with pumice and rotary brushes, after which hand scalers were used to remove any remaining soft tissue and periodontal ligament. They were then disinfected by immersion in 2.5% sodium hypochlorite for one hour and kept in sterile saline at 4°C until use.

Root canal preparation

Crowns were cut with a diamond disc under abundant water spray so that all roots measured 17 mm. A size 10 K-file was advanced until its tip appeared at the apical foramen, and the working length was set 1 mm shorter than this measurement. Canals were shaped with ProTaper® files (Dentsply Maillefer, Ballaigues,

Switzerland) in the order S1, S2, F1, F2, and F3. After each instrument, 2 mL of 5.25% sodium hypochlorite was delivered with a 30-gauge side-vented needle (DiaDent, Chungcheongbuk-do, Republic of Korea).

Grouping and final irrigation protocol

Once shaping was completed, a computer-generated sequence (Random.org; Randomness and Integrity Services Ltd., Dublin, Ireland) was used to assign the teeth to the three activation groups (n = 10 each). Every specimen received the same final irrigation sequence, adapted from Nielsen and Baumgartner [24]: 5 mL of 5.25% sodium hypochlorite delivered over 30 seconds and activated for 60 seconds, then 5 mL of 17% ethylenediaminetetraacetic acid (EDTA) delivered over 30 seconds and activated for 60 seconds, and lastly another 5 mL of 5.25% sodium hypochlorite delivered over 30 seconds and activated for 60 seconds. Between solutions, the canal was rinsed with 5 mL of sterile saline.

Group 1: MDA

A 30/.06 gutta-percha cone (META BIOMED, Chungcheongbuk-do, Republic of Korea) was inserted to the working length and moved in short, quick push-pull strokes for 60 seconds to activate the irrigant.

Group 2: PUI

Activation was carried out with an ultrasonic device (Guilin Woodpecker Medical Instrument Co., Ltd., Guilin, China) set to its endodontic mode. A 21-mm ultrasonic K-file, size 15 (Woodpecker), was positioned 1 mm from the working length and energized for 60 seconds.

Group 3: NAP

With the EndoVac system (Discus Dental, Culver City, CA), the irrigant was released into the pulp chamber by the master delivery tip. Suction from the high-volume evacuation unit drew the solution down the canal and removed it through the microcannula, placed 1-2 mm from the working length. This process was maintained for 60 seconds during each step of the final irrigation sequence.

Root canal obturation and sectioning

Canals were dried with size 30 paper points and filled with warm vertical compaction using gutta-percha and AH Plus, using a META BIOMED downpack heating unit and backfill injection gun (Chungcheongbuk-do, Republic of Korea). A size 30 master cone corresponding to the final preparation was coated with sealer and seated at the working length. The downpack was done with a 40/.06 heat plugger chosen to fit the canal passively, after which the rest of the canal was backfilled with warm gutta-percha. Access cavities were closed with temporary filling material, and the roots were kept at 37°C and 100% humidity for one week. Using a slow-speed Isomet saw (Buehler, Lake Bluff, IL) with constant water cooling, each root was cut at right angles to its long axis into three slices: a coronal slice 3 mm below the canal orifice, an apical slice 3 mm above the apex, and a middle slice halfway between them. This produced 90 sections, each 1.5 ± 0.1 mm thick.

Push-out bond strength test

Testing was done on an Instron 1195 machine (Instron Corp., Norwood, MA) with the crosshead moving at 1 mm/min. Load was applied from the apical toward the coronal side with stainless-steel plungers measuring 0.8, 0.7, or 0.5 mm, selected according to the canal size of each section and centered on the filling so that they did not touch the dentin. Loading was continued until the filling was dislodged or extruded, and the peak force (N) was recorded.

Bond strength (MPa) was obtained by dividing the peak force (N) by the bonded area (mm^2). Because the canal is tapered, the bonded area was computed as the lateral surface of a truncated cone:

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

where R and r are the coronal and apical radii of the filling measured on the two faces of each section in AutoCAD® 2018 images, and h is the section thickness measured with a digital caliper.

Blinding

Because the activation procedures were visibly different, the operator could not be blinded during treatment. Blinding was, however, applied at the testing stage: after sectioning, a researcher not otherwise involved in the study coded every specimen, so the operator performed the push-out tests without knowing the group allocation.

Statistical analysis

Results are presented as mean ± standard deviation. As three sections came from each root, the observations were not independent, so bond strength was modeled with a linear mixed model estimated by restricted maximum likelihood (REML). Activation technique, root third, and the technique × third interaction were included as fixed effects, and a random intercept for each root accounted for the correlation between sections of the same root. Since residual variance was not equal across thirds, a heterogeneous (diagonal) residual structure by third was used; this structure was preferred to a homogeneous-variance model and to an unstructured covariance model on the basis of the Akaike and Bayesian information criteria (AIC and BIC). A likelihood ratio test was used to evaluate the random root effect, and denominator degrees of freedom were obtained with the Satterthwaite method and rounded to whole numbers for reporting. Given the significant interaction, simple effects were analyzed: techniques were compared within each third, and thirds were compared within each technique, using estimated marginal means with Bonferroni correction. Normality of the residuals and the random effects was checked with the Shapiro-Wilk test. Statistical significance was accepted at $p < 0.05$. All analyses were run in R 4.3.3 (R Foundation for Statistical Computing, Vienna, Austria) using the nlme and emmeans packages.

Results

Table *1* summarizes bond strength by group and root level. The best fit was obtained with a random intercept per root and a separate residual variance per third (AIC = −129.7; homogeneous-variance model, −121.8; unstructured model, −128.2). A likelihood ratio test confirmed a significant random root effect ($p = 0.002$). Significant main effects were found for activation technique ($F(2, 32) = 820.54$) and root third ($F(2, 25) = 66{,}493.68$), together with a significant technique × third interaction ($F(4, 25) = 690.14$; all $p < 0.001$), meaning that the influence of the technique differed by root level. PUI gave the highest values in the coronal and middle thirds, followed by NAP and then MDA; in the apical third, the order was NAP, PUI, and MDA. Every pairwise comparison between techniques within a given third was significant after Bonferroni correction ($p < 0.001$). For each technique, values declined significantly at every step, from coronal to middle and from middle to apical (all Bonferroni-adjusted $p < 0.001$). Neither the residuals nor the random effects departed from normality (Shapiro-Wilk $p = 0.82$ and $p = 0.31$, respectively).

Technique	Coronal third	Middle third	Apical third
MDA	5.04 ± 0.09^{cA}	3.63 ± 0.08^{cB}	1.25 ± 0.08^{cC}
PUI	6.71 ± 0.07^{aA}	4.94 ± 0.13^{aB}	1.71 ± 0.05^{bC}
NAP	6.25 ± 0.08^{bA}	4.26 ± 0.10^{bB}	2.43 ± 0.08^{aC}
F (df)	1330.62 (2, 34)	330.50 (2, 33)	721.30 (2, 27)
p-value	<0.001	<0.001	<0.001

TABLE 1: Push-out bond strength (MPa, mean ± SD) of AH Plus sealer according to the irrigation activation technique and root third (n = 10 roots per group)

Within each column, values with different lowercase letters differ significantly between techniques; within each row, values with different uppercase letters differ significantly between root thirds (linear mixed model, Bonferroni-corrected comparisons, $p < 0.05$). F values refer to the technique effect within each third; degrees of freedom (Satterthwaite) are rounded to whole numbers.

MDA: Manual dynamic activation; PUI: Passive ultrasonic irrigation; NAP: Negative apical pressure (EndoVac system).

Discussion

Gutta-percha is the most common core-filling material; however, as it does not bond to dentin, a sealer is needed to fill the gaps and complete the seal [1]. Sealers also contribute to micromechanical retention and frictional resistance, which help the filling resist mechanical loading [22], owing to their chemical adhesion to dentin and their penetration into the tubules [14,20]. The push-out test is a widely accepted, standardized means of assessing sealer adhesion because it directly measures the force needed to displace the root filling [25]. In this study, MDA, PUI, and NAP were compared with respect to the push-out bond strength of AH Plus. As far as could be determined, PUI and NAP have previously been compared in just one study, by Prasad et al. [21], who also tested the CanalBrush (COLTENE, Altstätten, Switzerland) and used an MTA-based sealer. However, the three techniques have not been compared together with AH Plus. In view of the present findings, the null hypothesis was rejected.

In the coronal and middle thirds, the greatest bond strength was obtained with PUI. This is likely due to

cavitation and acoustic microstreaming, which intensify irrigant movement and create shear forces that strip the smear layer from the canal walls [9]. As a result, more tubules are opened, allowing AH Plus to infiltrate them and form resin tags that increase micromechanical retention. Moreover, the canal is broader at these levels, both naturally and after tapered shaping, so the ultrasonic file can oscillate without restriction [18]. A similar advantage of PUI over manual, laser, sonic, and conventional irrigation in the coronal and middle regions has been reported previously [13,17,22,23]. As in the study by Prasad et al. [21], PUI exceeded NAP in the coronal and middle thirds; the difference reached significance in this study but not in their work. In contrast, Pawar et al. [19] observed no effect of either PUI or sonic activation on bond strength, possibly because only oval canals were included, in which activation cannot make up for the shortcomings of instrumentation.

At the apical level, NAP gave the best results, whereas MDA gave the weakest. By bringing fresh solution to the working length and removing it continuously, NAP can overcome vapor lock and clean the smear layer more effectively where access is most difficult. PUI is less efficient apically, as the narrow canal limits file oscillation and increases contact with the walls, which dampens acoustic streaming. Prasad et al. [21] likewise found higher, though not significantly different, apical values for NAP. On the other hand, two investigations reported significantly greater apical bond strength for MDA than for PUI [6,23], a difference that may stem from the ultrasonic devices, tips, and power settings used, as well as from differences in irrigation and filling protocols.

The decrease in bond strength from the coronal to the apical region observed in every group may be explained by the lower number and smaller size of dentinal tubules in the apical region and by the greater difficulty of removing the smear layer there. Two earlier studies reported the same pattern [21,23], whereas others found higher values apically [13,17] and attributed this to the rounder shape of the apical canal and to the thicker sealer layer in the coronal region when single-cone filling is used. In the present study, warm vertical compaction may have reduced such differences in sealer thickness between levels, although this was not measured.

Several limitations should be acknowledged. Only one tooth type and one sealer were tested under laboratory conditions. No control group with non-activated (conventional needle) irrigation was included because the aim was to compare activation methods with each other and because non-activated irrigation may not represent current clinical practice, especially in teeth with periapical lesions, for which activation is advised. For this reason, the findings show how the techniques perform relative to one another but do not show whether any of them improves bond strength over non-activated irrigation. Failure modes and sealer penetration were not assessed, so the mechanisms proposed here remain speculative. In addition, as the EndoVac system delivers and aspirates the irrigant continuously, the amount of fresh solution reaching the apical third may not have been the same as in the other groups, which could have favored NAP apically. Finally, the variability within groups (coefficients of variation of about 1%-6%) was smaller than is usually reported for push-out testing. This may reflect the strict standardization of specimens and procedures, including a single operator, uniform root length and section thickness, and plunger sizes matched to each section, and it explains the large test statistics. The size of the differences between groups may therefore not be reproduced under less controlled conditions, and the results should be confirmed by further studies.

Conclusions

This laboratory study examined how three irrigant activation methods affect the push-out bond strength of AH Plus to root dentin at the coronal, middle, and apical levels. Within the limitations of this study, the activation method had a significant influence on bond strength, and both the magnitude and ranking of this influence varied with root level. PUI gave the strongest bond in the coronal and middle thirds, NAP gave the strongest bond in the apical third, and MDA gave the weakest bond at all three levels. In every group, bond strength declined progressively from the coronal to the apical third. Thus, no single technique was superior at all root levels. Since these results were obtained in vitro using single-rooted mandibular premolars, one sealer, and one filling technique, and without a non-activated control group, they reflect only the relative performance of the tested methods under these conditions and should not be extrapolated directly to clinical outcomes.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Yasser Alsayed Tolibah, Aya M. Al-sabbagh, Hassan Achour, Mohamad J. Othman, Rawan H. Alakash

Acquisition, analysis, or interpretation of data: Yasser Alsayed Tolibah, Aya M. Al-sabbagh, Hassan Achour, Mohamad J. Othman, Rawan H. Alakash

Drafting of the manuscript: Yasser Alsayed Tolibah, Aya M. Al-sabbagh, Mohamad J. Othman, Rawan H. Alakash

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Supervision: Hassan Achour

Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. The Local Research Ethics Committee of the Faculty of Dentistry issued approval (approval number: 300; approval date: October 11, 2021). **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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