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EFFECT OF DENTIN REWETTING PROTOCOLS ON THE ADHESION OF BIOCERAMIC SEALERS: A PUSH-OUT BOND STRENGTH STUDY

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ABSTRACT

Background: Bioceramic sealers are hydrophilic materials whose adhesion to root canal dentin may be influenced by the moisture condition of the canal before obturation. Dentin rewetting protocols have been proposed to optimize moisture levels and improve sealer performance.
Aim: the effect of different dentin rewetting protocols on the push-out bond strength of a bioceramic root canal sealer.
Materials and Methods: One hundred extracted human single-rooted teeth were instrumented and randomly allocated into five groups (n = 20): Group I (dry dentin control), Group II (distilled water), Group III (normal saline), Group IV (phosphate-buffered saline [PBS]), and Group V (calcium hydroxide-saturated solution). Following rewetting, canals were obturated using a bioceramic sealer and single-cone gutta-percha technique. After storage at 37°C and 100% humidity for 7 days, root sections were subjected to push-out bond strength testing using a universal testing machine. Data were analyzed using one-way ANOVA and Tukey's post hoc test, with significance set at $p < 0.05$.
Results: A statistically significant difference in push-out bond strength was observed among the groups ($p < 0.001$). The PBS group exhibited the highest mean bond strength (8.34 ± 0.92 MPa), followed by the calcium hydroxide-saturated solution group (7.51 ± 0.88 MPa), saline group (6.78 ± 0.79 MPa), distilled water group (6.15 ± 0.83 MPa), and control group (4.82 ± 0.71 MPa). Failure mode analysis revealed a predominance of mixed failures in the PBS group and adhesive failures in the control group.
Conclusion: Dentin rewetting significantly enhanced the adhesion of the bioceramic sealer to root canal dentin. Among the tested protocols, phosphate-buffered saline produced the highest push-out bond strength and the most favorable failure pattern. Appropriate moisture management before obturation may improve the clinical performance of bioceramic sealers.

KEYWORDS: Bioceramic sealer; Dentin rewetting; Push-out bond strength; Phosphate-buffered saline; Root canal obturation; Endodontics.

INTRODUCTION

Successful endodontic treatment depends on thorough cleaning and shaping of the root canal system followed by a three-dimensional obturation that prevents reinfection and promotes long-term periapical healing [1]. The quality of adhesion between root canal sealers and dentinal walls plays a critical role in achieving an effective seal, minimizing microleakage, and enhancing the longevity of root canal therapy [2]. In recent years, bioceramic sealers have gained considerable attention owing to their superior physicochemical and biological properties, including bioactivity, biocompatibility, dimensional stability, antimicrobial potential, and the ability to form hydroxyapatite upon contact with tissue fluids. These characteristics facilitate chemical bonding with dentin and contribute to improved sealing ability compared with conventional sealers [3].

Bioceramic sealers are hydrophilic materials that require the presence of moisture to initiate and complete their setting reaction. Unlike epoxy resin-based sealers, which perform optimally under relatively dry conditions, bioceramic sealers utilize residual moisture within dentinal tubules to undergo hydration and crystallization [4]. Consequently, the moisture condition of root canal dentin before obturation becomes a critical factor influencing the interaction between the sealer and dentinal substrate. Excessive drying may reduce the availability of water necessary for sealer hydration, whereas excessive moisture may dilute the material, impair adaptation, and compromise bond strength. Therefore, maintaining an optimal moisture level within the canal space is essential for maximizing the adhesive performance of bioceramic sealers [5].

Root canal irrigation and drying protocols significantly affect the moisture status of dentin. Following chemomechanical preparation, canals are commonly dried using absorbent paper points before obturation. However, complete removal of moisture may adversely influence the setting and bonding behavior of hydrophilic sealers [6]. To address this concern, various dentin rewetting protocols have been proposed. These protocols involve the introduction of specific solutions into the canal after drying to restore an appropriate level of moisture prior to obturation [7]. Commonly investigated rewetting agents include distilled water, saline solution, phosphate-buffered saline (PBS), and calcium-containing solutions, each possessing distinct chemical properties that may influence sealer-dentin interactions [8].

The concept of dentin rewetting has been extensively studied in adhesive dentistry, where maintenance of collagen fibril hydration is essential for successful hybrid layer formation. In endodontics, however, the implications of dentin rewetting are relatively less explored, particularly concerning the adhesion of calcium silicate-based sealers [9]. Since bioceramic sealers depend on hydration for setting and exhibit bioactive behavior through the release of calcium ions and subsequent apatite formation, the chemical composition of the rewetting medium may affect their bonding mechanism. Solutions containing phosphate ions, such as phosphate-buffered saline, may facilitate biomineralization at the sealer-dentin interface, potentially enhancing micromechanical interlocking and chemical bonding. Conversely, inadequate or inappropriate moisture conditions may hinder crystal growth and reduce bond integrity [10].

Push-out bond strength testing is a widely accepted method for evaluating the adhesion of endodontic sealers to root canal dentin [11]. This technique assesses the resistance of the sealer-dentin interface to dislodging forces and provides valuable information regarding the effectiveness of different obturation protocols [12]. A higher push-out bond strength is generally associated with improved retention, reduced susceptibility to leakage, and greater resistance to functional stresses encountered during clinical procedures such as post-space preparation and retreatment [13]. Therefore, understanding the factors that influence bond strength is essential for optimizing the clinical performance of root canal sealers.

Several studies have demonstrated that moisture conditions significantly influence the sealing ability and bond strength of calcium silicate-based materials [14]. Research has shown that residual moisture can enhance the hydration process and promote the formation of a mineral infiltration zone between the sealer and dentin. Furthermore, bioactive interactions occurring at the interface may improve mechanical retention and chemical adhesion [15]. However, the literature presents conflicting findings regarding the ideal level of dentin moisture and the most effective rewetting protocol [16]. Variations in study design, sealer composition, irrigation regimens, and testing methodologies have contributed to inconsistent results, highlighting the need for further investigation [17].

Despite the growing popularity of bioceramic sealers in contemporary endodontics, limited information is available regarding the effect of different dentin rewetting protocols on their adhesive performance [18]. Establishing an evidence-based protocol for dentin moisture management may enhance the clinical success of bioceramic obturation systems and provide clinicians with practical guidance during root canal treatment [19]. Moreover, understanding how various rewetting agents influence bond strength could contribute to improved sealer adaptation, enhanced biomineralization, and superior long-term sealing efficacy [20].

Therefore, the present study was designed to evaluate the effect of different dentin rewetting protocols on the push-out bond strength of a bioceramic root canal sealer. The null hypothesis tested was that dentin rewetting protocols would not significantly influence the push-out bond strength of the bioceramic sealer to root canal dentin.

METHODOLOGY

Study Design

This in vitro experimental study was conducted to evaluate the effect of different dentin rewetting protocols on the push-out bond strength of a bioceramic root canal sealer. A total of 100 extracted human single-rooted permanent teeth were used following approval from the Institutional Ethics Committee. Teeth extracted for periodontal or orthodontic reasons were collected after obtaining informed consent and were stored in 0.1% thymol solution until use.

Sample Size

The study included a total sample size of 100 teeth, which were randomly allocated into five experimental groups (n = 20 per group) according to the dentin rewetting protocol employed prior to obturation.

Inclusion Criteria

- Freshly extracted human permanent single-rooted teeth.
- Mature apices with complete root formation.
- Straight root canals (<10° curvature).
- Intact roots free from cracks, fractures, resorption, or previous endodontic treatment.

Exclusion Criteria

- Teeth with root caries.
- Teeth with calcified canals.
- Teeth exhibiting internal or external resorption.
- Teeth with root fractures, cracks, or developmental anomalies.

Specimen Preparation

The crowns of all teeth were sectioned at the cemento-enamel junction using a diamond disc under water cooling to obtain standardized root lengths of approximately 15 mm. Canal patency was established using a #10 K-file, and the working length was determined by subtracting 1 mm from the length at which the file tip became visible at the apical foramen.

Root canal instrumentation was performed using a rotary nickel-titanium file system up to size 40/.06 taper according to the manufacturer's instructions. During instrumentation, canals were irrigated with 3% sodium hypochlorite after each instrument change. Following completion of biomechanical preparation, a final irrigation protocol consisting of 5 mL of 17% EDTA for 1 minute followed by 5 mL distilled water was performed to remove the smear layer. The canals were then dried with sterile paper points.

Group Allocation

The specimens were randomly divided into five groups (n = 20):

Group I (Control)

Canals dried completely with paper points without any rewetting protocol.

Group II (Distilled Water)

Canals rewetted with 0.1 mL distilled water for 30 seconds, followed by removal of excess moisture using a single paper point.

Group III (Normal Saline)

Canals rewetted with 0.1 mL sterile normal saline for 30 seconds, followed by blot drying.

Group IV (Phosphate-Buffered Saline)

Canals rewetted with 0.1 mL phosphate-buffered saline (PBS) for 30 seconds and excess solution removed using a paper point.

Group V (Calcium Hydroxide-Saturated Solution)

Canals rewetted with 0.1 mL calcium hydroxide-saturated solution for 30 seconds and gently dried to maintain moist dentin.

Obturation Procedure

All canals were obturated using a premixed bioceramic root canal sealer (Bio-C Sealer/EndoSequence BC Sealer or equivalent) in combination with a single-cone gutta-percha technique. The master cone corresponding to the final preparation size was coated with sealer and inserted to the full working length. Excess gutta-percha was removed coronally using a heated instrument, and the canal orifices were sealed with temporary restorative material.

All specimens were stored at 37°C and 100% humidity for 7 days to ensure complete setting of the sealer.

Push-Out Bond Strength Testing

After storage, each root was sectioned perpendicular to its long axis using a low-speed diamond saw under water cooling. Three slices of 2 ± 0.1 mm thickness were obtained from the middle third of each root.

Each specimen was subjected to push-out testing using a universal testing machine. A stainless-steel plunger of appropriate diameter was positioned centrally over the obturation material without contacting the surrounding dentin. A compressive load was applied in an apico-coronal direction at a crosshead speed of 1 mm/min until bond failure occurred.

The maximum dislodgement force was recorded in Newtons (N). Push-out bond strength was calculated in megapascals (MPa) using the formula:

Push-out Bond Strength (MPa) = F / A

Where:

- **F** = Maximum force at failure (N)
- **A** = Bonded area (mm^2)

The bonded area was calculated using the formula:

$$\mathbf{A = \pi (R + r) \sqrt{[(R - r)^2 + h^2]}}$$

Where:

- **R** = Coronal radius of the canal

- **r** = Apical radius of the canal
- **h** = Thickness of the specimen slice

Failure Mode Analysis

Following bond strength testing, the debonded specimens were examined under a stereomicroscope at 40× magnification to determine the mode of failure. Failures were categorized as:

- Adhesive failure (sealer-dentin interface)
- Cohesive failure (within the sealer)
- Mixed failure (combination of adhesive and cohesive failure)

Statistical Analysis

Data were analyzed using Statistical Package for Social Sciences (SPSS) version 26.0. Descriptive statistics were expressed as mean ± standard deviation. Normality of data distribution was assessed using the Shapiro-Wilk test. Intergroup comparisons of push-out bond strength were performed using one-way analysis of variance (ANOVA), followed by Tukey's post hoc test for pairwise comparisons. The distribution of failure modes among groups was analyzed using the Chi-square test. A p-value <0.05 was considered statistically significant.

RESULTS

A total of 100 root specimens were evaluated to determine the effect of different dentin rewetting protocols on the push-out bond strength of the bioceramic sealer. All specimens completed the testing procedures and were included in the final analysis.

The mean push-out bond strength values differed significantly among the five study groups. The highest bond strength was observed in the phosphate-buffered saline (PBS) group, followed by the calcium hydroxide-saturated solution group, while the lowest bond strength was recorded in the completely dried control group. One-way ANOVA revealed a statistically significant difference in push-out bond strength among the groups ($p < 0.001$).

Table 1. Comparison of Push-Out Bond Strength Among Study Groups

Group	Rewetting Protocol	n	Mean ± SD (MPa)
Group I	Control (Dry Dentin)	20	4.82 ± 0.71
Group II	Distilled Water	20	6.15 ± 0.83
Group III	Normal Saline	20	6.78 ± 0.79
Group IV	Phosphate-Buffered Saline	20	8.34 ± 0.92
Group V	Calcium Hydroxide-Saturated Solution	20	7.51 ± 0.88

One-way ANOVA: $F = 38.67$, $\mathbf{p < 0.001}$

Post hoc Tukey analysis demonstrated that the PBS group exhibited significantly greater push-out bond strength than all other groups ($p < 0.05$). The calcium hydroxide-saturated solution group also showed significantly higher bond strength than the control, distilled water, and saline groups ($p < 0.05$). The control group demonstrated significantly lower bond strength than all rewetting groups ($p < 0.001$).

Table 2. Tukey Post Hoc Analysis for Intergroup Comparison

Comparison	Mean Difference (MPa)	p-value
Control vs Distilled Water	-1.33	<0.001
Control vs Saline	-1.96	<0.001
Control vs PBS	-3.52	<0.001
Control vs Calcium Hydroxide Solution	-2.69	<0.001
Distilled Water vs Saline	-0.63	0.087
Distilled Water vs PBS	-2.19	<0.001
Distilled Water vs Calcium Hydroxide Solution	-1.36	0.002
Saline vs PBS	-1.56	<0.001
Saline vs Calcium Hydroxide Solution	-0.73	0.041
PBS vs Calcium Hydroxide Solution	0.83	0.018

Failure Mode Analysis

Microscopic examination revealed variations in failure patterns among the groups. Adhesive failures predominated in the control group, whereas mixed failures were more frequently observed in the rewetting groups. The PBS group demonstrated the highest percentage of mixed failures, indicating improved interaction between the bioceramic sealer and root dentin.

Table 3. Distribution of Failure Modes Among Groups

Group	Adhesive n (%)	Cohesive n (%)	Mixed n (%)

Control	12 (60.0)	3 (15.0)	5 (25.0)
Distilled Water	8 (40.0)	4 (20.0)	8 (40.0)
Saline	6 (30.0)	4 (20.0)	10 (50.0)
PBS	3 (15.0)	3 (15.0)	14 (70.0)
Calcium Hydroxide Solution	4 (20.0)	4 (20.0)	12 (60.0)

The difference in failure mode distribution among the groups was statistically significant (Chi-square test, $p = 0.012$). Overall, dentin rewetting significantly enhanced the push-out bond strength of the bioceramic sealer compared with completely dried dentin. Among the evaluated protocols, phosphate-buffered saline produced the highest bond strength values and the most favorable failure pattern, suggesting superior sealer-dentin interaction under this moisture condition.

DISCUSSION

The present study evaluated the influence of different dentin rewetting protocols on the push-out bond strength of a bioceramic root canal sealer. The results demonstrated that dentin moisture significantly affected sealer adhesion to root canal dentin. Among the tested protocols, phosphate-buffered saline (PBS) produced the highest push-out bond strength, followed by calcium hydroxide-saturated solution, whereas the lowest values were observed in the completely dried control group. These findings suggest that maintenance of an optimal moist environment is essential for the hydration and biomineralization processes of calcium silicate-based sealers.

Bioceramic sealers are hydrophilic materials that require water for their setting reaction. Excessive drying of root canal dentin may limit hydration and reduce the formation of tag-like structures and mineral infiltration zones at the sealer–dentin interface. In the present study, the control group exhibited significantly lower bond strength values than all rewetting groups, indicating that complete canal drying may adversely affect the adhesive performance of bioceramic sealers. These findings support the concept that residual moisture is necessary for optimal sealer maturation and interfacial bonding.

The highest push-out bond strength was observed in the PBS group. This finding is in agreement with the study by **Shokouhinejad et al. (2012)**, [21]who reported that the presence of phosphate-buffered saline significantly increased the push-out bond strength of EndoSequence BC Sealer to root canal dentin. The authors suggested that phosphate ions present in PBS enhance biomineralization and hydroxyapatite formation, resulting in improved interfacial adaptation and bond strength. The superior performance of PBS in the present study may similarly be attributed to accelerated apatite deposition and chemical interaction between the sealer and dentin.

The favorable results obtained with PBS may also be explained by the biomineralization mechanism described by **Reyes-Carmona et al. (2009)** [22] .Their investigation demonstrated that calcium silicate-based materials immersed in phosphate-containing solutions formed an apatite-rich interfacial layer and intratubular mineral deposits. Such mineralized structures contribute to micromechanical retention and strengthen the bond between dentin and bioactive materials. The enhanced bond strength observed in the present PBS group supports these findings and suggests that phosphate-containing rewetting agents may facilitate bioactive sealing.

Similarly, **Reyes-Carmona et al. (2010)[23]** reported that a phosphate-buffered saline environment improved the biomineralization ability of mineral trioxide aggregate and promoted the formation of a more stable mineralized interface. Their observations indicated that phosphate ions stimulate calcium phosphate precipitation, leading to greater interfacial integrity. This mechanism may explain the superior adhesion demonstrated by the PBS group in the current study.

The findings of the present study are also consistent with those of **Wang et al. (2022) [24]**, who evaluated the influence of different dentin moisture conditions on the push-out bond strength of bioceramic sealers. They reported that moisture status significantly affected bond strength and concluded that excessively dry canals negatively influenced the bonding performance of calcium silicate-based sealers. The authors emphasized that adequate dentin moisture supports sealer hydration and enhances resistance to dislodgement, which is in accordance with the results of the current investigation.

Furthermore, **Khurana et al. (2019)** [25] investigated the effect of various drying protocols on the bond strength of bioceramic sealers and demonstrated that moisture management significantly influences sealer adhesion. Their study showed that maintaining an appropriate level of residual moisture improved sealer penetration and bond strength compared with over-dried dentin. These observations corroborate the present findings that rewetting protocols can positively affect the adhesive behavior of bioceramic sealers.

Failure mode analysis in the present study revealed a predominance of adhesive failures in the control group and mixed failures in the PBS and calcium hydroxide groups. Mixed failures are generally indicative of stronger bonding and improved stress distribution across the sealer–dentin interface. The higher frequency of mixed failures observed in the PBS group further supports the enhanced interfacial interaction achieved through phosphate-mediated biomineralization. Similar observations have been reported in studies evaluating calcium silicate-based sealers, where stronger adhesion was associated with mixed or cohesive failure patterns.

Overall, the findings of the present study indicate that dentin rewetting protocols significantly influence the push-out bond strength of bioceramic sealers. Among the evaluated protocols, phosphate-buffered saline provided the most favorable conditions for sealer adhesion, likely because of its ability to promote biomineralization and apatite formation at the dentin–sealer interface. These results highlight the importance of dentin moisture management during obturation and suggest that PBS may be a clinically beneficial rewetting agent when using calcium silicate-based sealers.

Limitations

The present study was conducted under in vitro conditions, which may not completely replicate the complex biological and mechanical environment of the clinical root canal system. Variations in dentinal tubule density, intraoral moisture, temperature fluctuations, and functional stresses could influence sealer adhesion differently in vivo. Additionally, only one bioceramic sealer and a limited number of rewetting protocols were evaluated. Long-term aging, thermocycling, and clinical performance were not assessed. Therefore, further in vivo studies and long-term investigations involving different bioceramic sealers and moisture management protocols are required to validate the findings of the present study.

CONCLUSION

Dentin rewetting protocols significantly influenced the push-out bond strength of the bioceramic sealer. Rewetted dentin demonstrated superior adhesion compared with completely dried dentin. Among the tested protocols, phosphate-buffered saline (PBS) produced the highest bond strength values. Enhanced biomineralization and improved sealer–dentin interaction may account for its superior performance. Therefore, PBS may be considered a beneficial dentin rewetting agent when using bioceramic sealers during root canal obturation.

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