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Effect of Photodynamic Therapy on the Pushout Bond Strength of Resin-Based and Calcium Silicate-Based Endodontic Sealers

Saeede Zadsirjan[1], Mohammad Asnaashari[2], Atoosa Yazdani[3], Soolmaz Heidari[4], Tina Estarami[3]*

[1]Department of Endodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[2]Laser Application in Medical Sciences Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[3]Private Practice, Tehran, Iran
[4]Department of Operative Dentistry, Dental Caries Prevention Research Center, Qazvin University of Medical Sciences, Qazvin, Iran

***Correspondence to**
Tina Estarami,
Email: Tina.estrmi@gmail.com

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Abstract
Introduction: This study aimed to assess the effect of photodynamic therapy (PDT) on the pushout bond strength (PBS) of resin-based and calcium silicate-based endodontic sealers.
Methods: Forty single-canal teeth were assigned to four groups. After root canal preparation by the crown-down technique and smear layer removal, groups 1 and 2 served as the control group, and groups 3 and 4 underwent PDT by using a low-level diode laser as the light source and methylene blue as the photosensitizer (MB). The root canals in groups 1 and 3 were filled with AH26 sealer while the root canals in groups 2 and 4 were filled with Endoseal TCS. The samples were sectioned at 4, 8, and 12 mm from the apex tip (1mm thick slices). The PBS test was performed, and the mode of failure was determined in the coronal, middle, and apical thirds. The data were analyzed by the Kruskal-Wallis, Friedman, and Dunn tests.
Results: No significant difference was noted in the PBS of resin-based and calcium silicate-based sealers in the apical, middle, or coronal thirds in the application of PDT ($P>0.05$). The PBS of AH26 was significantly higher than that of Endoseal TCS ($P<0.05$). Cohesive failure was the dominant mode of failure in the AH26 groups, while mixed failure was the dominant failure mode in the Endoseal TCS groups.
Conclusion: PDT had no significant effect on the PBS of resin-based and calcium silicate-based sealers.
Keywords: Calcium silicate; Lasers; Epoxy-resin based root canal sealer; Bond strength

Introduction
Chemomechanical preparation and sealing the root canal system with a three-dimensional method are the main steps in the root canal treatment of teeth.[1] However, the currently used cleaning and shaping methods are not successful in the complete elimination of bacteria and debris from the apical region. In addition to the complex and narrow structure of the apical region, difficult access of chemical irrigating solutions to the apical third is another reason for the difficult elimination of bacteria and debris from this region.[2]

The newly developed adjunctive antibacterial treatments can aid in the elimination of microorganisms as an adjunct to the commonly practiced chemomechanical methods, and they may enable more effective disinfection of infected root canals. Different laser techniques have been proposed for root canal disinfection with greater efficacy for the elimination of bacteria lodged in deeper parts of dentin compared with the conventional chemomechanical methods.[3]

Light-based disinfection methods use a specific wavelength of light to activate a photosensitizer (PS) in the presence of oxygen. The root canal system can be completely devoid of bacteria with the aid of this method, which has shown remarkable effectiveness.[4] In photodynamic therapy (PDT), reactive oxygen species produced by the PS decrease the microbial load of the canal.[5-8] However, the PS residues in the root canal system can cause a smear layer, which causes microbial microleakage and poor adhesion of root filling material to root dentin. Thus, a final rinse would be required to eliminate the smear layer.[9,10] Evidence shows that the bond strength and sealer penetration are affected by the type of sealer, method of disinfection, and type of treatment of root canal walls.[11-13]

Upon the activation of methylene blue (MB), free oxygen is released, which may affect the attachment, polymerization, and mechanical properties of the sealer adjacent to dentin and can directly decrease the success rate and durability of endodontic treatment.[14]

Evidence shows that the bond strength of sealer to dentin is influenced by the physical and chemical properties

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of sealer, reaction with dentin, method of root canal disinfection, and elimination of the smear layer.[15-20] Resin sealers can optimally seal the canal and prevent bacterial leakage due to the bonding property of resins. AH26 sealer is an epoxy resin-based sealer, which is commonly used due to optimal chemomechanical properties and high adaptation to root canal walls.[21,22] Tricalcium silicate-based sealers are hydrophilic and possess bioactive properties as do the MTA-based sealers.[23]

At present, Endoseal TCS sealer is a novel alternative to Endoseal MTA. Studies on the chemomechanical properties of Endoseal TCS sealer are scarce.[24] The number of studies on the bond strength of sealers following PDT with MB is limited. Thus, this study aimed to assess the effect of PDT with MB on the pushout bond strength (PBS) of AH26 and Endoseal TCS sealers to root dentin.

Materials and Methods

Specimen Preparation

Forty extracted human maxillary central incisors were used in this study. The teeth were single-rooted and single-canal and had straight roots. Teeth with calcifications, internal/external root resorption, fracture, cracks, extensive root caries, or evidence of trauma were excluded. The minimum root length was 15 mm. The teeth were decoronated by a thin sectioning machine (Hamco Machines Inc., Rochester, NY, USA) in such a way that 15 mm of root length remained. The working length was considered 1 mm shorter than the root length as determined by observing the tip of a #15 K-file at the apex. The root canals were instrumented with the SP1 Gold rotary system (China) to F3 by the crown-down technique. The sequence of files used was as follows: Orifice shaper, S1, S2, F1, F2, and F3. After using each file, the root canal was rinsed with 1 mL of 5.25% sodium hypochlorite solution (Nik Darman, Iran). After root canal instrumentation, each canal was rinsed with 1 mL of distilled water. Next, 3 mL of 17% EDTA (Canasol, Nik Darman, Iran) was injected into the canal at a speed of 1 mL/minute for smear layer removal. To eliminate EDTA, the root canals were rinsed with 1 mL of distilled water followed by 1 mL of 5.25% sodium hypochlorite, and a final rinse with 5 mL of distilled water was performed. The root canals were then dried with #40 paper points. Subsequently, the root canals were divided into two groups, control and PDT (n = 20).

Photodynamic Therapy

In the PDT group, the root canals were filled with 100 µg/mL MB (NovaTebPars blue plus + M) (which is sensitive to 630-660 nm wavelength) in such a way that the solution leaked out from the orifice. Next, MB was agitated and activated in the canal by using a #15 K-file for 1 minute. Finally, it was left in the canal for 3 minutes as instructed by the manufacturer. The low-level diode laser (Klas-DX, Konf Tech, Taiwan) with 150 mW power, 660 nm wavelength, and 9 J energy (as instructed by Konf Tech for root canal treatment) was then used. The 3D diffuser tip (NovaTebPars) was inserted into the canal in such a way that it reached two-thirds of the working length.[25] The laser was then irradiated into the canal for 60 seconds. The operator moved the laser handpiece apicocoronally, buccolingually, and mesiodistally to enable better light diffusion. After the completion of PDT, the cleaning of all the root canals involved the use of 10 mL of distilled water by an insulin syringe to eliminate MB. To dry the canals, paper points were utilized.

Root Canal Obturation

The teeth in the test and control groups were assigned to 2 subgroups, and they were filled with gutta-percha and AH26 (Dentsply DeTrey, USA) or Endoseal TCS (Maruchi, South Korea) sealer.

- Group 1: The root canals did not undergo PDT, and they were filled with AH26 sealer.
- Group 2: The root canals did not undergo PDT, and they were filled with Endoseal TCS sealer
- Group 3: The root canals underwent PDT and were filled with AH26 sealer.
- Group 4: The root canals underwent PDT and were filled with Endoseal TCS sealer.

The sealers were used as instructed by the manufacturers; 0.05 mL of sealer was injected into each canal, and a #40/4% gutta-percha point was used by the single cone technique. To ensure the absence of voids in the canals, they were radiographed buccolingually using RVG. The coronal seal in all the teeth was obtained by using temporary restorative material (Cavit; Cavisol, Golchai, Iran). The roots were then incubated at 37 °C and 100% humidity for 2 days.

Pushout Bond Strength

The roots were marked at 4, 8, and 12 mm from the apex tip, and they were separately mounted in auto-polymerizing methacrylate resin. Sections were made at the marked areas with 1 mm approximate thickness by a cutting machine (Mecatome T210, Presi, France). A load was applied by a universal testing machine (Zwick Roell, Germany). Cylindrical stainless-steel pistons were selected based on different root canal diameters in apical, middle, and coronal sections, in such a way that the piston tip only touched the filling material in the root canal. Finally, a piston with a 0.75 mm tip diameter was selected for the coronal and middle sections, and a piston with a 0.35 mm tip diameter was selected for the apical sections. Each section was fixed on an acrylic cylinder in such a manner that the apical surface of the section faced the piston tip. A load was applied to the sealer-root canal dentin interface at a speed of 0.5 mm/minute perpendicular to the canal cross-section until the root canal filling was debonded from the root dentin. The debonding force was measured by the software of the universal testing machine (Zwick Roell, Germany).[26-28]

The PBS was calculated using the following formula:

$$Bond\ Strength\,(MPa) = \frac{Debonding\ force\,(N)}{Bonded\ surface\ area\,(mm^2)}$$

To calculate the bonded surface area, the following formula was used:

Bonded surface area: $\pi\,(r1 + r2)\,h$

The apical and coronal diameters of the sections were measured under a stereomicroscope (SMZ-800, Nikon, Japan) using MIP4 software, and the height of each section was measured by a caliper.

Finally, both sides of sections were inspected under a stereomicroscope (SMZ-800, Nikon, Japan) at × 20 magnification. Each segment was assigned to one of these collectives regarding the mode of failure:

- Adhesive: Failure at the sealer-dentin interface with no sealer left on the walls of the root canal.
- Cohesive: Failure within the sealer. The root canal walls were completely covered with sealer.
- Mixed: A combination of adhesive and cohesive failures. The sealer was present on some parts of the root canal wall, while some other parts were free from the sealer.

Statistical Analysis

The normal distribution of the data was evaluated by the Kolmogorov-Smirnov test, which showed non-normal data distribution. Thus, the non-parametric Kruskal-Wallis test was used for data analysis. Pairwise comparisons were carried out by the Dunn test. The Friedman test was applied to analyze the difference in the PBS of different root canal sections. The mode of failure was descriptively reported in percentage.

Results

Table 1 shows the median of the PBS of the study groups in different sections. In the coronal, middle, and apical sections, the difference in PBS was significant among the four groups ($P < 0.05$). In the coronal, middle, and apical sections, no significant difference was noted in PBS in the use of PDT. In all groups, the PBS of AH26 was significantly higher than that of Endoseal TCS ($P < 0.05$). In the middle third, no significant difference was found in the PBS of groups 2 and 3. In all groups, except for group 4, a significant difference existed in PBS among the coronal, middle, and apical thirds ($P < 0.05$) in such a way that the PBS in the apical third was significantly lower than that in the middle third (Figure 1).

Figure 2 shows the frequency distribution of modes of failure in the groups. In groups 1 and 3, cohesive failure was dominant, while mixed failure was dominant in groups 2 and 4.

Table 1. PBS of the Groups in Different Sections (MPa)

Group	Section		
	Coronal	Middle	Apical
AH26	9.11 $^{a\,AB}$	9.32 $^{a\,A}$	4.11 $^{a\,B}$
PDT + AH26	4.88 $^{a\,A}$	5.86 $^{ac\,A}$	2.55 $^{a\,B}$
Endoseal TCS	0.59 $^{b\,AB}$	3.36 $^{bc\,A}$	0.41 $^{b\,B}$
PDT + Endoseal TCS	0.51 $^{b\,A}$	0.39 $^{b\,A}$	0.44 $^{b\,A}$

The values indicate the median PBS.
Lowercase letters indicate comparison of PBS among different groups in the same section (columns) and uppercase letters indicate comparison of PBS among different sections within the same group (rows).
At least one similar letter indicates the absence of a significant difference between the two groups while dissimilar letters indicate the presence of a significant difference between the two groups.
$P \leq 0.05$ was considered statistically significant.

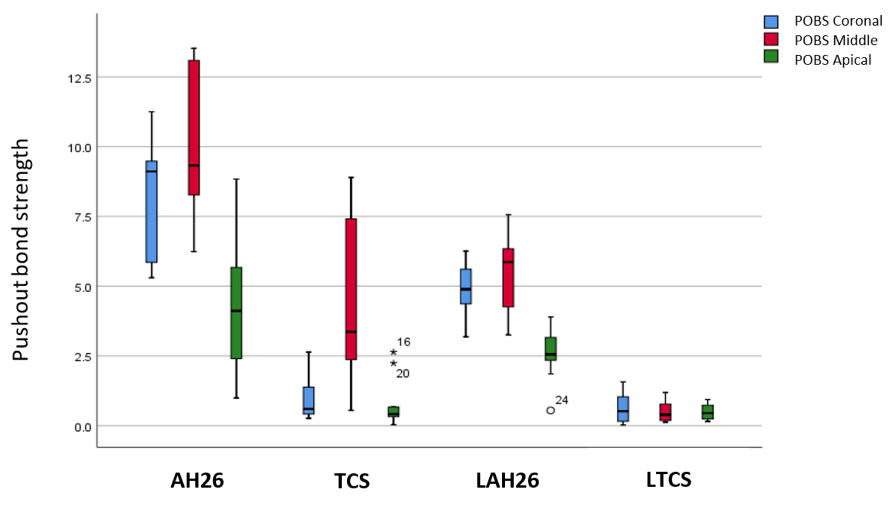

Figure 1. Box Plot of the PBS Values of the Groups

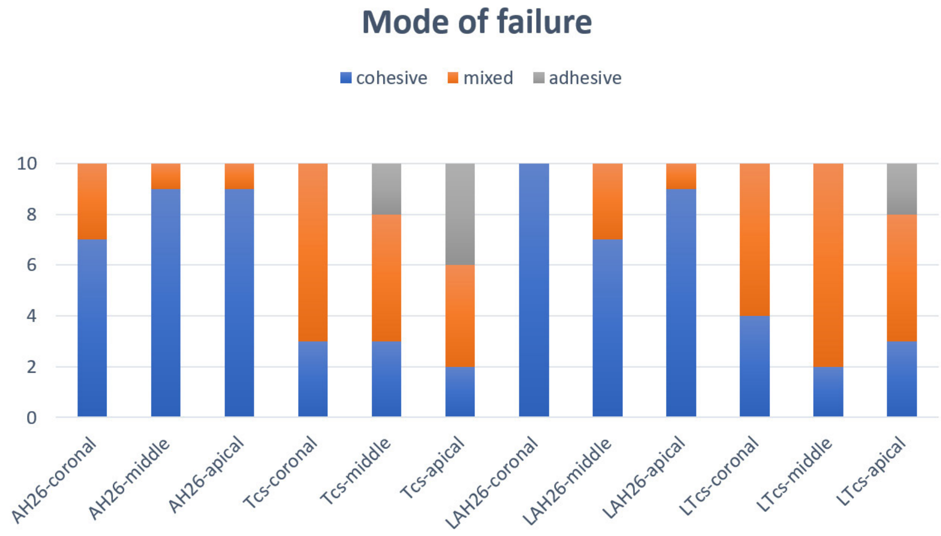

Figure 2. Frequency Distribution of Modes of Failure in the Groups

Discussion

PDT is an adjunct to the chemomechanical preparation of the root canal system, which eliminates microorganisms by the production of reactive oxygen species.[5-8] The residues of PS used in PDT may adversely affect the bonding of sealer to root dentin, decrease the bond strength, and lead to microbial leakage.[10] Not many studies have assessed how PDT affects the bond strength of sealers, and the studies that have been done have yielded different results.[4,28,29]

The PBS test, which induces parallel fractures at the dentin-sealer interface and is superior to other tests for the measurement of bond strength, was used in the present study. Generation of non-uniform stress is a limitation of the bond strength test; however, the present study overcame this limitation by using specimens with 1 mm thickness.[4] Reproducibility, easy interpretation, and recording even small values are among the advantages of this test.[26] There is no other suitable test for the measurement of bond strength. The microtensile test is another commonly used test, which causes a high rate of premature bond failures during the sectioning of specimens. Thus, it was not used in the present study.[30]

In the present study, MB was used as the PS. Phenothiazine salts (such as MB and toluidine blue) are the most commonly used PSs for PDT. Also, MB is activated with 600 to 700 nm laser wavelengths, which correspond to the wavelength of the light source used in the present study.[31]

Among different light sources such as lasers, LED lamps, and halogen lamps, diode lasers are cheaper, easy to handle, and portable.[32] The Konftech laser is a low-level diode laser for which the manufacturer has predefined a specific default setting in terms of power, wavelength, and irradiation time for maximum antimicrobial efficacy in root canal therapy in such a manner that the clinician can use it according to the protocol. Thus, it was selected for the present study. High-power lasers damage the teeth and their surrounding structures due to heat generation and can cause ankylosis, melt dentin, and cementum, and they also lead to root resorption and peri-radicular necrosis.[33] Thus, they are not suitable for this purpose.

In the present study, PDT had no significant effect on the PBS of calcium silicate and resin-based sealers, which matched the results of Banci et al[27] and Hashem et al,[34] who concluded that the bond strength of MTA-Fillapex sealer was not significantly affected by PDT. Ok et al[4,35] in 2013 and 2014 and Hashem et al[34] in 2020 reported that the bond strength of AH plus sealer was not significantly affected by light-activated disinfectants. Almadi,[36] in 2022, reported that PDT had no significant impact on the bond strength of endodontic sealers.

However, the present results were different from the findings of Menezes et al[28] who concluded that PDT decreased the bond strength of MTA Fillapex and AH Plus sealer compared with the control group. They did not eliminate the PS from the root, and they immediately obturated the canal; resultantly, the PS remained in the canal. MB is a hydrophilic substance which absorbs water. Thus, it can decrease the bond strength if remained in the root canal system.[37] Yavari et al, in 2017, concluded that the bond strength of MTA-Fillapex and AH Plus in the PDT group was significantly higher than that in the no-PDT control group.[29] They used toluidine blue as the PS, which might have increased the bond strength, explaining the difference between their results and the present findings.[38]

Root canal preparation parameters (root canal diameter and taper), technique of obturation (cold lateral compaction or warm vertical condensation), tooth type, tooth location, specimen thickness, and crosshead speed during load application can also be responsible for variations in the reported bond strength values.[39] Despite the fact that the bond strength test is extensively used, lack of a standard protocol can cause variations in the results.[40]

The present findings revealed that the PBS of AH26 sealer in all sections was significantly higher than that of Endoseal TCS irrespective of the conduction of PDT. Covalence bonds formed between the epoxy resin ring and collagen amine groups in epoxy resin-based sealers may create stronger bonds to dentin.[41] Moreover, the acidic pH of AH26 may have a self-etching effect on dentin and increase the bond of sealer to dentin.[42] On the other hand, the lower bond strength of calcium silicate sealers can be due to the calcium and hydroxyl ions released from them, which form apatite. Apatite is displaced following contact with dentin collagen and forms mineral masses on the dentin surface. Finally, plaque-like structures form at the interface of the root canal wall and calcium silicate, which results in a weak bond.[43] This finding was consistent with the results of Çakici et al[44] in 2020, Yavari et al[29] in 2017, Hashem et al[34] in 2020, Ok et al[35] in 2013, Almadi[36] in 2022, and Souza et al[45] in 2018; they concluded that the bond strength of AH Plus was higher than that of MTA-Fillapex irrespective of conduction of PDT.

In the present study, the bond strength in the apical third was lower than that in the middle and coronal thirds in all groups, except for the PDT + Endoseal TCS group, in which the difference among the sections was not significant. Lower bond strength in the apical region may be due to more difficult access to the apical third and lower flow of sealer in this region.[46]

In the present study, the dominant mode of failure was cohesive in all sections in the AH26 groups irrespective of the conduction of PDT, while the dominant mode of failure was mixed in all sections in the Endoseal TCS groups irrespective of the conduction of PDT; adhesive failure was also seen. Consistent with the present findings, Banci et al,[27] in 2020, demonstrated that mixed failure was dominant in the use of MTA Fillapex in both PDT and control groups. Yavari et al,[29] in 2017, reported that cohesive failure was dominant in the use of AH Plus, and mixed failure was dominant in the use of MTA Fillapex in both PDT and control groups.

It is obvious that the higher bond strength of sealers is associated with a higher frequency of cohesive failures, while lower bond strength values are correlated with mixed and adhesive failures.[47]

In the clinical setting, the optimal bond strength of sealer to dentinal walls is imperative to withstand mechanical stresses generated by the occlusal forces or restorative procedures such as post-space preparation; however, it has not yet been confirmed that better adhesion of root filling material to the canal walls results in a higher clinical success rate.[48]

Drawing a conclusion regarding the effects of PDT on the bond strength of sealers with different bases would require further investigations. Moreover, due to different root canal preparation protocols and use of different tests, dental materials, and light sources, as well as a limited number of studies in this regard, comparison of studies and interpretation of results are difficult and not highly accurate. Further complementary studies are needed to draw a more definite conclusion.

Conclusion

Among the four study groups, no significant difference was found in the PBS of AH26 and Endoseal TCS sealers in the use of PDT. However, the generalization of this result to the clinical setting requires further investigations on a larger sample size. In all groups, AH26 yielded a higher PBS than Endoseal TCS. The dominant mode of failure in all sections was cohesive in the use of AH26 resin-based sealer and mixed in the use of Endoseal TCS calcium silicate-based sealer, irrespective of the conduction of PDT.

Authors' Contribution

Conceptualization: Soolmaz Heidari.
Data curation: Saeede Zadsirjan.
Formal analysis: Tina Estarami, Atoosa Yazdani.
Funding acquisition: Tina Estarami.
Investigation: Tina Estarami, Atoosa Yazdani.
Methodology: Saeede Zadsirjan, Tina Estarami.
Project administration: Saeede Zadsirjan.
Resources: Tina Estarami.
Software: Tina Estarami.
Supervision: Saeede Zadsirjan, Mohammad Asnaashari.
Validation: Mohammad Asnaashari.
Visualization: Soolmaz Heidari, Saeede Zadsirjan.
Writing–original draft: Tina Estarami.
Writing–review & editing: Tina Estarami, Saeede Zadsirjan.

Competing Interests

None.

Ethical Approval

The study was approved by the ethics committee of the School of Dentistry of Shahid Beheshti University of Medical Sciences (IR.SBMU.DRC.REC.1400.046).

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