Abstract. – OBJECTIVE: The present lab-based investigation aimed at evaluating the canal disinfectants using photodynamic therapy (PDT) using different photosensitizers, conventional NaOCl, a mixture of doxycycline, citric acid, and a detergent (MTAD) and their impact on the bond strength of glass fiber post to radicular dentin.

MATERIALS AND METHODS: Forty extracted human premolars were gathered and disinfected. The decoration was performed up to the cementoenamel junction. Using the crown down technique cleaning of the canal was done following rinse with distilled water. All canals were dried with paper points and obturated with gutta-percha. Post space was prepared using peso reamers and samples were randomly allocated into four groups following different disinfection regimes: Group 1 – Methylene blue photosensitizer (MBP) + MTAD; Group 2 – RBP (Rose Bengal photosensitizer) + MTAD; Group 3 – CP (curcumin photosensitizer) + MTAD and Group 4 – 2.25% NaOCl + MTAD (control). Following disinfection, the canals were dried and the post was placed and cemented within the canal. Samples were dissected at coronal, middle, and apical thirds and placed in a universal testing machine for push-out bond strength (PBS). Debonded surfaces were evaluated for failure modes. PBS was examined using a one-way analysis of variance (ANOVA). The means of PBS were compared using Tukey multiple comparison tests with a significance threshold of \( p<0.05 \).

RESULTS: Group 3 canals disinfected with CP and MTAD had the highest PBS at two levels: cervical (9.57±1.21 MPa), middle (6.37±0.79 MPa), and group 2 canal space disinfected by RBP and MTAD had the maximum PBS in apical portion (5.35±0.42 MPa). No significant difference at all root levels between group 2 (RBP + MTAD) and group 3 \(( p>0.05 \). Canal irrigation with group 1 (MBP + MTAD) and group 4 control (2.25% NaOCl + MTAD) exhibited comparable PBS at all three levels of the root.

CONCLUSIONS: CP, MTAD, RBP and MTAD for canal disinfection and bonding of glass fiber post to radicular dentin demonstrated comparable bond values at all three root levels and can be recommended in clinical settings after further investigations.

Key Words: Photosensitizers, Curcumin, Methylene blue, Rose Bengal, Canal disinfection, Push out bond strength.

Introduction

A positive endodontic outcome is achieved by chemo-mechanical preparation of the diseased root canal with antimicrobial agents (irrigants and medicaments), followed by obturation and coronal repair. The Chemo mechanical debride-ment method of the canals may reduce the bacte-
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rial count but does not completely cleanse the can-
als leading to recurrent endodontic infection. Apart
from chemical cleansing and debridement of en-
dodontically treated teeth to have a good
prognosis, an impermeable seal in the coronal
area is essential. Sometimes, when there is an
excessive coronal structure loss glass fiber-rein-
forced composite posts (FRCP) are an alternate
treatment for repairing teeth. The fiber posts have
the benefits of being esthetically favorable, cor-
rosion-resistant, and simple to operate/remove if
necessary. The strength of the bond between the
dentine-cement interface and the post-cement in-
terface is essential for the retention of adhesively
luted fiber-reinforced posts.

Among different chemical cleansers, sodium hypochlorite (NaOCl) is the most common can-
al disinfectant which debrides the canals for
pursuing endodontic treatment and securing the
viability of a tooth. It is inexpensive and is
diluted in the range of 0.5% to 5.25%. However,
its use interferes with the polymerization of resin
cement, jeopardizing the post-dentine bond, and
has an unpleasant odor and taste.

An alternative biocompatible cleansing solu-
tion has been introduced, combining a tetracy-
ccline isomer, an acid (citric acid), and a detergent
(MTAD). It functions as a disinfectant in the root
canal procedure and helps in the eradication of
the smear layer with negligible erosion of dentin-
al tubules. Being a calcium chelator, it delivers
a long-lasting antimicrobial effect and optimizes
adhesion capacity. Two studies conducted by
Torabinejad et al. and Mortazavi et al. revealed
that a blend of 1.3% NaOCl as an endodontic irri-
gant with MTAD as ultimate cleanser was further
effective against E. faecalis than 5.25% NaOCl
with 17% EDTA.

Besides the standard treatment, photodynam-
ic therapy (PDT) is an advanced and revolu-
tionary endodontic disinfectant alternative. This
procedure is non-invasive, reproducible, easy to use, and has no cytotoxic effects. It improves
the treatment outcome by its effective bacterici
dal property. It shows its effect by a combina-
tion of three components: photosensitizer (PS),
light source, and oxygen – the so-called pho-
todynamic antimicrobial chemotherapy. This
photoactivated disinfection process includes
the activation of photosensitizers by a
particular wavelength of light to yield oxygen
reactive species (singlet oxygen) which, as a result,
produce an impact on the bonding strength of glass fiber post to radicular dentin.

**Materials and Methods**

The current experimental investigation fol-
lowed a checklist for reporting in vitro study
(CRIS) guidelines. The study lasted three
months. Forty extracted human premolars were
gathered. Inclusion criteria: possess a non-cari-
ous, non-traumatized, and single straight canal
with a closed full apex, and teeth. An ultrasonic
scaler (Woodpecker Hw-5l Handpiece Optic Scal-
er, England, UK) was used to remove attached
periodontal ligaments and calculus. All specimens
were kept in a 0.5% thymol solution for 48 hours
at a temperature of 4°C. To ensure a straight lin-
er canal path, periapical radiographs were cap-
tured from both the mesiodistal and buccolingual
sides for every examined tooth. De-coronation
of specimens up to the cementoenamel junction
was performed employing a diamond bur (Kith
Dent Supply, Mumbai, Maharashtra, India) under
refrigeration, conserving 12 mm of root length.
Specimens were implanted perpendicularly in
heat cure acrylic resin (Ortho Plast, Bulandshahr, Uttar Pradesh, India), using a Teflon mold with a 3 mm radius.

The endodontic process was performed on teeth with a K-file #10 (Dentsply NITI-flex K-File, Berlin, Germany) at a length of 1 mm shorter than the working length. The manual filing was used to expand the canals to a size of 25 K file. Mechanically, the canal was prepared using the crown down approach with the Protaper universal NiTi system (Dentsply Maillefer) which comprises shaping files S1, S2, SX, and finishing files F1 and F2. Canals were irrigated with distilled water during the cleaning and shaping process. Following chemical-mechanical preparation, the canals were dried using paper points (Meta Absorbent Paper Points - 4%, Delhi, India) and finally obturated with gutta-percha (Dentsply Gutta Percha Points, Mumbai, India) with AH Plus sealer (Dentsply AH Plus Root Canal Sealer, Delhi, India).

After completion of the endodontic procedure, the space for post-placement was prepared using three-peso reamers numbered 2, 3, and 4 in order. Gutta-percha was removed up to a 10 mm length. The samples were subsequently disinfected with various chemical irrigations and photosensitizers, and divided into 4 different groups (n=10) based on the chemical disinfectant administered.

**Group 1: MBP + MTAD**

MB photosensitizer (Sisco Research Lab. Pvt. Ltd, Maharashtra, India) was used to treat group 1 samples. A 50 mg/l solution of MBP was put in the canal for 180 seconds before irradiation. For equal distribution of the light source, a diode laser (Biolase Epic X Dental Diode Laser, Calcutta, India) with a fiber-optic tip (200 m) was employed at a 90° incidence angle. PS was activated using a wavelength of 638 nm, a frequency of 30 Hz, and a power of 2 W. After aspiration of MBP, the canal space was irrigated with MTAD.

**Group 2: RBP + MTAD**

Specimens in group 2 were treated with RB at a concentration of 5 μM (Innovative, Kalbadevi, Mumbai, Maharashtra, India). RB was activated using a light-emitting diode (LED, Ekon Electronics Kalbadevi, Mumbai, Maharashtra), with a wavelength of 480 nm at a power output of 200 mW and power density of 526 (mW/cm²) with a duration of laser 180 sec. Following RBP, the post space was disinfected by MTAD.

**Group 3: CP + MTAD**

CP photosensitizer was employed to treat the specimens in group 3. A 2.5 mg/ml solution was poured into the canal for 180 seconds before irradiation. The widespread radiation was achieved using a diode laser with a fiber-optic tip. Afterward, the canal was cleansed with MTAD.

**Group 4: 2.25% NaOCl + MTAD [control]**

All specimens in the control group were disinfected with a 2.25% NaOCl solution (Acuro Organics Limited, Mumbai, India), followed by MTAD disinfection for 60 seconds with a 30-gauge needle.

**Post-Placement**

The canals were dried with a paper point after post-space irrigation. The glass fiber post was cleaned in 70% ethanol and air-dried before being cemented in a post-specified area. Following the manufacturer’s directions, the post was cemented with Panavia F 2.0 self-etch dual-cure cement (Kuraray Dental, Tokyo, Japan) and a light-emitting diode unit (Woodpecker Dental Curing Light, Bangalore, India) was used for the polymerization of the cement. For around 24 hours, samples were kept at 37°C in a 100% humid environment.

Vertically anchored specimens in acrylic blocks were dissected horizontally at the coronal, middle, and apical thirds using a diamond bur (Kith Dent Supply, Mumbai, Maharashtra) under copious irrigation. From each group, 30 sections were obtained in total (10 each coronal, middle and apical). To assess the bond strength of FRCP to radicular dentin, all slices were placed on a metallic mold of a universal testing machine (Universal Testing Machine-Dual Load Cells - 5kn, 30 kn-For Tensile Shear Adhesion Test, EIE Instruments Private Limited).

The fracture mode of the post following debonding was determined using a stereomicroscope at 40× magnification. The force necessary to debond the fiber post from the radicular dentin (MPa) is deliberated in Mega Pascal (MPa).

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\text{Debond stress} = \frac{N}{\text{mm}^2}
\]

Where N represents the maximum failure load and mm² represents the post-segment bonding area.
Table I. Means and Standard deviations (SD) of Push-out bond strength (MPa) values among experimental groups at cervical, middle, and apical levels of root.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Cervical</th>
<th>Middle</th>
<th>Apical</th>
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<tbody>
<tr>
<td>Group 1: MBP + MTAD</td>
<td>6.33 ± 0.19&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>5.61 ± 0.12&lt;sup&gt;b,A&lt;/sup&gt;</td>
<td>3.35 ± 0.81&lt;sup&gt;b,B&lt;/sup&gt;</td>
</tr>
<tr>
<td>Group 2: RBP + MTAD</td>
<td>9.47 ± 0.21&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>6.21 ± 1.07&lt;sup&gt;b,A&lt;/sup&gt;</td>
<td>5.35 ± 0.42&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Group 3: CP + MTAD</td>
<td>9.57 ± 1.21&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>6.37 ± 0.79&lt;sup&gt;b,A&lt;/sup&gt;</td>
<td>5.01 ± 0.37&lt;sup&gt;b,B&lt;/sup&gt;</td>
</tr>
<tr>
<td>Group 4: 2.25% NaOCl + MTAD (control)</td>
<td>6.13 ± 1.26&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>5.01 ± 0.36&lt;sup&gt;a,A&lt;/sup&gt;</td>
<td>3.42 ± 0.39&lt;sup&gt;b&lt;/sup&gt;</td>
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Sodium hypochlorite (NaOCl); Mixture of Doxycycline, citric acid, and a detergent (MTAD); Methylene blue Photosensitizer (MBP); Rose Bengal Photosensitizer (RBP); Curcumin Photosensitizer (CP). Different superscript lower-case alphabets denote statistically significant difference within the same column (<i>p</i>&lt;0.05). Data with different upper-case alphabets denotes significant difference within each row (<i>p</i>&lt;0.05).

Statistical Analysis
The percentages of adhesive, cohesive, and admixed failure patterns were identified. The means and standard deviations of PBS were examined using a one-way analysis of variance (ANOVA). The means of PBS were compared using Tukey multiple comparisons t-tests with a <i>p</i>-value significance < 0.05.

Results
The homogeneity of data was assessed by the Shapiro Wilks test. Table I shows the values of PBS at all three levels: cervical, middle, and apical. Group 3 canals disinfected with CP and MTAD had the highest PBS at two levels: cervical (9.57±1.21 MPa), middle (6.37±0.79 MPa), and group 2 canal space disinfected by RBP and MTAD had the maximum PBS in apical portion (5.35±0.42 MPa).

Intergroup comparison displayed that there is no significant difference in glass fiber post space disinfection at all root levels between group 2 (RBP + MTAD) cervical (9.47±0.21 MPa), middle (6.21±1.07 MPa), and apical (5.35±0.42 MPa) and group 3 (CP + MTAD) cervical (9.57±1.21 MPa), middle (6.37±0.79 MPa) and apical (5.01±0.37 MPa) (<i>p</i>&gt;0.05). Whereas, canal irrigation with group 1 (MBP + MTAD) cervical (6.33±0.19 MPa), middle (5.61±0.12 MPa) and apical (3.35±0.81 MPa), and group 4 control (2.25% NaOCl +MTAD) cervical (6.13±1.26 MPa), middle (5.01±0.36 MPa) and apical (3.42±0.39 MPa) exhibited comparable PBS at all three levels of root (<i>p</i>&gt;0.05) (Table I, Figure 1).
Different superscript lower-case alphabets denote statistically significant differences within the same column ($p<0.05$).

Data with different upper-case alphabets denote significant differences within each row ($p<0.05$).

The intragroup comparison demonstrated that group 3 (CP + MTAD) showed the highest bond strength value at two levels, cervical (9.57±1.21 MPa) and middle (6.37±0.79 MPa). Correspondingly, the lowest push-out bond strength was shown by group 4 (2.25% NaOCl + MTAD) cervical (6.13±1.26 MPa) and middle (5.01±0.36 MPa), but in the apical area group 2 had the highest (5.35±0.42 MPa) and group 1 showed the lowest (3.35±0.81 MPa) push out bond strength. All groups had statistically decreased bond strength in the apical third compared to cervical and middle thirds ($p<0.05$).

Figure 2 presents the results of the fracture analysis according to failure type. Admixed, adhesive between cement and post, and cohesive (within resin cement) failure types were identified. Adhesive failure was the most common type of failure in groups 1, 2, and 4. However, group 3 had a high percentage of admixed failure types in all three root segments.

**Discussion**

The present *in vitro* study was based on the hypothesis that antimicrobial efficacy and bond strength of FRCP to radicular dentin after disinfecting root canals with PDT photosensitizers and MTAD will display better results compared to conventional disinfecting technique (2.25% NaOCl and MTAD). The outcome of the current study revealed that better antibacterial characteristics and improved bond strength of FRCP to root dentin were found in samples treated with CP, RBP, and MTAD at all levels (cervical, middle, and apical). As a result, the hypothesis was partially approved. PBS was used to assess the strength between GFP and radicular dentin. The test was useful because it mimicked oral circumstances and transferred stress uniformly throughout the long axis of the radicular dentin. PBS had a higher sensitivity, easy positioning of samples, and a lower failure rate. When compared to other testing methods, PBS showed the benefit of measuring several test samples from a single root structure and comparing them to other researched groups.

Specimens in group 4 control treated with 2.25% NaOCl + MTAD at cervical (6.13±1.26 MPa), middle (5.01±0.36 MPa), and apical (3.42±0.39 MPa) exhibited comparable PBS at all three levels of root to samples in group 1 (MBP + MTAD) cervical (6.33±0.19 MPa), middle (5.61±0.12 MPa) and apical (3.35±0.81 MPa). This outcome can be explained in a variety of ways. The antibacterial effect of NaOCl is due to chlorine (Cl) and oxygen (O$_2$) in NaOCl. NaOCl alone as a canal irrigant reduces bond strength due to its oxidative nature. The released

![Figure 2](image-url)
oxygen interferes with resin cement polymerization, decreasing bond strength. Also, collagen degradation happens, which fails links between carbon atoms and dentinal collagen. The use of MTAD over other irrigation solutions may be advantageous because it appears to be successful in eliminating both organic and inorganic debris, and have an antimicrobial impact. The effect of MTAD on the bonding strength of fiber post to radicular dentin has never been investigated, according to the authors’ knowledge. NaOCl when used as a first rinse and MTAD as a final rinse, a chemical reaction occurs, resulting in the production of a brown solution in the root canal. It has been hypothesized that this is caused by doxycycline absorption in MTAD which hinders the bonding of fiber post to dentin, compromising bond values. Moreover, low bond scores were noted at all three levels of root structure when radicular dentin was disinfected by MBP. MBP is both cationic and hydrophilic. Poor MBP absorption by Calcium and Phosphate ions in dentin may have influenced the findings of our study and led to the present conclusion which is also consistent with the findings of previous research.

Canal disinfected by RBP and CP activated by PDT showed increased bond strength at all three levels, cervical, middle, and apical thirds compared to specimens disinfected by MBP and NaOCl. In the authors’ opinion, irradiation with a higher concentration of curcumin PS, along with blue LED light activation, caused significant changes in the dentin substrate, promoting the generation of hydrogen peroxide (H₂O₂) that can bind to dentinal components like calcium (Ca++) in hydroxyapatite crystals. Curcumin is an anionic compound with a hydrophobic polyphenol component, which means it absorbs less water, improving the resin interface and hence escalating bond values. A recent study has demonstrated that curcumin enhanced the bond strength of glass-fiber posts luted to dentin, improving the quality of the adhesive interface. However, it has been anticipated that, due to the anionocity of the material, calcium would precipitate in the apical third decreasing the interaction between the luting agent and the root dentin surface, hence reducing PBS values. Similar outcomes were revealed by the previous investigational study of Al Ahdal et al.

Failure modes include admixed, adhesive (cement and post), and cohesive (inside resin cement). The most common type of failure in all of the analyzed groups was an adhesive failure in groups 1, 2, and 4. In all three root segments, group 3 had a high percentage of admixed failure types. The reported inconsistency in the number of dentinal tubules along distinct regions of root dentin is responsible for heterogenous failure tendency.

**Limitations**

The results of the current investigation should be clinically taken with caution as dentinal structure, tubular fluids, odontoblastic projections, smear layer, dentin nature, and bonding agents may influence an outcome. The effects of different concentrations of NaOCl and MTAD, and PDT photosensitizers on radicular dentin need to be investigated further. Scanning electron microscopy (SEM) along with atomic force microscopy (AFM) of debonded samples needs additional examination. This should be supported by clinical trials, as well as in vivo research, to implement the findings of the present study.

**Conclusions**

CP and MTAD and RBP and MTAD for canal disinfection and bonding of glass fiber post to radicular dentin demonstrated comparable bond values at all three root levels and can be recommended in clinical settings after further investigations.

**Conflict of Interest**

The Authors declare that they have no conflict of interests.

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**Authors’ Contribution**

Conceptualization, M.S.; Methodology, A.B, and R.J.A.; Software, M.S. and R.J.A.; Validation, Z.Q., R.J.A., and A.B.; Formal analysis, R.J.A.; Investigation, A.M.A, Z.Q, R.J.A; Resources, A.B.; data curation, R.J.A.; writing – original draft preparation, Z.Q., and R.J.A.; writing – review and editing, M.N.; visualization, F.N.; supervision, R.J.A., Z.Q. and M.N.; project administration, M.N.; funding acquisition, F.N. All authors have read and agreed to the published version of the manuscript.
References


