Effects of Different Root Canal Obturation Techniques on the Bond Strength of Fiber Post to Intraradicular Dentine

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Objective: To evaluate the bond strength of fiber posts to intraradicular dentine pretreated with two root canal obturation techniques and three postspace irrigation solutions.

Methods: A total of 96 human premolars were collected and treated with complete or partial root canal obturation techniques. The roots were further divided into three subgroups (n = 16) based on postspace irrigation solutions: 2.5% NaOCl, 37% phosphoric acid etching, and distilled water. The fiber posts were bonded with self-adhesive resin cement, and the roots were sectioned into three slices (cervical, middle, and apical regions) after 5,000 thermocycles. The push-out bond strengths were determined and subjected to analysis of variance (α = 0.05). A stereomicroscope was used to observe the failure modes of the specimens.

Results: The irrigation solution, root canal obturation technique, and root region had significant effects on bond strength (P < 0.001). The completely obturated root canals showed significantly lower bond strength than the partially obturated root canals. The 2.5% NaOCl treatment produced the highest bond strength among the three irrigation solutions. Among the root regions, the cervical part showed significantly greater bond strength than the middle and apical parts. The most common failure mode was mixed failure.

Conclusion: The partial root canal obturation technique provided better bond strength of the fiber post to intraradicular dentine. Irrigation with 2.5% NaOCl solution and phosphoric acid etching before cementation improved the push-out bond strength of the fiber posts to intraradicular dentine.

Key words: root canal obturation technique, post space irrigation, bond strength, dentine


A n intraradicular post is often required to restore an endodontically treated tooth, especially when it contains extensive coronal structural defects resulting from dental caries or trauma1,2. The use of a fiber post has been widely accepted in dentistry due to its suitable elastic modulus, ease of use, and high success rate3-7.

Establishment of reliable bonding at the root-cement-post interface is critical to the long-term success of both the fiber post and definitive restoration8,9. Given that the most common failure mode of fiber posts is post debonding at the dentine-resin cement interface, extensive efforts have been directed toward improving the adhesion of resin cements to intraradicular dentine10,11, and pretreating the dentine with laser was a common method used by researchers. Strefezza et al12 reported that the diode laser irradiation can enhance the bond strength between post and dentine. Pelozo et al13 reported that dentine pretreatments with erbium:yttrium aluminium garnet (Er:YAG) laser improved bond strength of cement-post-dentine interfaces. Many variables that affect the bond strength of resin cements to the post and intraradicular dentine have been proposed, including postspace preparation14, postspace irrigation15,16, anatomical and morphological characteristics of the dentine substrate17,18, limited light penetration into the apical region of the root canal19,20, and poten-
tial incompatibility between the adhesive system and
resin cement\textsuperscript{21}.

During postspace preparation, a smear layer con-
sisting of gutta-percha remnants, the root canal seal-
ant, and inorganic components are created by drilling
motions\textsuperscript{22,23}. Moreover, the gutta-percha remnants may
be plasticised by the friction heat generated from post-
space preparation\textsuperscript{23}. The presence of a smear layer can
occlude dentinal tubules, hinder the penetration of the
adhesive resin cement, and results in low bond strength
at the dentine-resin cement interface\textsuperscript{24}. Removal of the
smear layer has been shown to improve the fluid-tight
sealant of the root canal system and the bond strength
of the resin cement to the intraradicular dentine, and
can be achieved by using irrigation solutions, such
as sodium hypochlorite (NaOCl), hydrogen perox-
ide, and ethylenediamine tetraacetic acid (EDTA)\textsuperscript{25-30}.
Although conflicting results have been reported\textsuperscript{28,31,32},
systematic reviews concluded that self-adhesive resin
cement (SARC) is a less technique-sensitive protocol
and exhibits better performance than conventional resin
cements\textsuperscript{33,34}. However, only a few studies have evalu-
ated the bond strength of SARC to intraradicular dentine
pretreated with different irrigation solutions\textsuperscript{35-37}. Scanning electron microscopy indicated that phos-
phoric acid application can reduce the thickness of the
smear layer, although this is less effective than EDTA
and/or NaOCl application\textsuperscript{38}. Kul et al\textsuperscript{37} evaluated dif-
ferent postspace irrigation treatments on the push-out
bond strength of SARC (RelyX U200) to fiber posts
and intraradicular dentine. The results showed that
postspace irrigation using EDTA in combination with
NaOCl improves the adhesion between fiber posts and
SARC. In contrast, Moura et al\textsuperscript{39} reported that the push-
out bond strength values of SARC were not affected by
NaOCl and/or EDTA irrigation.

Apart from the above-mentioned variables, the
effects of the root canal obturation procedure seem
to be underestimated in the literature. Thermoplastic
root canal obturation is a well-established technique
for endodontically treated teeth, enabling obturation
of the root canal at any level\textsuperscript{40}. The partial root canal
obturation technique seals only the apical third of the
root and leaves the middle and cervical thirds free of
gutta-percha and root canal sealant. Postspace prepar-
ation of a partially obturated root canal may result in
a thinner smear layer than a completely obturated root
canal, affecting the bond strength of the fiber post to
the intraradicular dentine. However, limited information is
available in the literature.

Therefore, the present study aimed to evaluate the
effects of different root canal obturation techniques on
the bond strength of fiber posts to intraradicular dentine
pretreated with three postspace irrigation methods. The
null hypotheses were proposed as follows: 1) different
root canal obturation techniques do not affect the push-
out bond strength of the fiber post to intraradicular
dentine; 2) different postspace irrigation methods do
not alter the push-out bond strength of fiber posts to intraradicular dentine; and 3) different regions of the intraradicular dentine exhibit similar push-out bond strength values.

**Materials and methods**

**Tooth collection**

The research protocol was reviewed and approved by the Research Ethics Committee of the School and Hospital of Stomatology, Fujian Medical University (no. FMUSS-21749). The study design is depicted in Figure 1. A total of 96 human premolars of similar sizes and shapes with a fully formed apex were selected for the present study. The teeth were recently extracted for orthodontic reasons from patients who provided an informed consent. The inclusion criteria were: a single root canal (as verified radiographically); absence of caries, root cracks, internal resorption, and previous endodontic treatment; and a root length greater than 16 mm. External debris was removed with a periodontal curette. Each tooth was sectioned below the cemento-enamel junction using a low-speed diamond blade saw (Isomet, Buehler, IL, USA) under constant and copious water cooling. The roots were cut to a uniform length of 16 mm from the apical end. The working length was determined by subtracting 1 mm from the length of an inserted no. 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) with its tip visualised at the apical foramen. The roots were stored at 4°C in 100% humidity until use.

**Root canal obturation**

All the roots were instrumented and finished using Profile .06 (Dentsply DeTrey, Konstanz, Germany). The canals were irrigated with 3 ml of 2.5% NaOCl solution between each file size. The root canals were dried with absorbent paper after the final irrigation, and obturated using warm vertical compaction with an Elements Obturation Unit (Sybron Endo, Orange, USA). A .06 tapered master gutta-percha point (Dentsply DeTrey) was selected and assessed for apical tug-back. The master point was covered with AH Plus resin-based sealant (Dentsply DeTrey) and placed into the root canal. A heat plugger was activated and utilised to sear off the master point until 5 mm from the apical terminus. Half of the filled roots were assigned to group P (partial root canal obturation), and the other half of the roots were filled completely using a backfilling technique and assigned to group C (complete root canal obturation). All procedures were performed by a trained endodontic specialist. After root canal obturation, the endodontic accesses were sealed using glass ionomer cement (Ketac-Fil, 3M ESPE, St. Paul, MN, USA). The roots were then stored at 37°C for seven days in 100% humidity.

**Specimen preparation**

After storage, the sealant was removed, and root canals were prepared for a post with a length of 10 mm using the rotary drill burs of a glass fiber post system (RelyX Fiber Post, 3M ESPE, St. Paul, MN, USA) to match the corresponding RelyX fiber post (2# Fiber Post, 3M ESPE). The diameter of the fiber post was 0.80 mm in the apical and 1.60 mm in the coronal. New drills were used for every five roots. The postspace was viewed with a stereomicroscope (x100, MM400, Nikon, Tokyo, Japan) to completely remove the root canal filling. The samples were then randomly divided into three subgroups (n = 16) according to the postspace irrigation solutions used: subgroup NaOCl, 5 ml of 2.5% NaOCl followed by 10 ml of distilled water for 30 seconds; subgroup PA, 37% phosphoric acid (Ivoclar Vivadent AG, Schaan, Liechtenstein) for 10 seconds followed by 10 ml of distilled water for 20 seconds; and subgroup DW, 10 ml of distilled water for 30 seconds.

After respective postspace preparation, the postspace was dried with absorbent paper points (Dayading Medical, Shenyang, China). The post was tried in the prepared postspace and then cut with a low-speed diamond blade saw to the selected length. After the try-in procedure, the posts were cleaned with ethanol (Spark Medical, Fuzhou, China). SARC (RelyX Unicem, 3M ESPE, St. Paul, MN, USA) was applied to the root canal with an elongation tip according to the manufacturer's instructions. The fiber posts were immediately inserted into the prepared postspaces with finger pressure. A LED-light-curing unit (Elipar S10, 3M ESPE, St. Paul, MN, USA) was used to illuminate the cement and post through the cervical portion of the root for 40 seconds at a light intensity of 1,200 mW/cm². During the curing procedure, the light curing tip was kept close to the surface of the tooth. The power of the LED-light-curing unit was assessed with a radiometer (Bluephase II, Ivoclar Vivadent AG, Schaan, Liechtenstein) before use.

**Push-out test**

All specimens were stored at 37°C in 100% humidity for 24 hours before thermocycling. Thermocycling was performed for 5,000 cycles at bath temperatures of 5°C
and 55°C using a thermal cycling machine (TC-501F, Weier, Tianjin, China). The dwell time was 30 seconds in each bath, and the transfer time was 10 seconds. This procedure corresponds to a 5-year period of oral temperature conditions. After thermocycling, each specimen was sectioned perpendicular to its long axis into 2-mm-thick slices with a low-speed diamond blade saw. The slice from the top with a thickness of 1 mm was discarded to prevent misinterpretation of push-out bond strength values due to the influence of residual resin cement on the root surface. Ultimately, three slices were obtained from each specimen, representing the coronal, middle, and apical regions of the specimen. Due to the tapered design of the fiber posts, the post diameters were measured on both the coronal and apical surfaces of all slices using a digital caliper (Mitutoyo, Kawasaki, Japan). A piston with a cylindrical tip (0.6 mm diameter) was attached to a universal testing machine (AGS-X, Shimadzu, Kyoto, Japan) and positioned at the apical surface of the section. The piston was pointed directly on the centre of the post. A load was applied at a speed of 0.5 mm/minute until the post was extruded. The maximum failure load (Newtons) was recorded and converted into Megapascals (MPa) by dividing the load that produced failure by the post interface area (A). The post interface area was calculated with the following equation:

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

where \( \pi = 3.14 \), \( R = \) coronal post radius (mm), \( r = \) apical post radius (mm), and \( h = \) thickness of the slice (mm).

After the push-out test, a stereomicroscope was used to observe the failure modes of all slices. The failure modes were classified into three types: 1) adhesive failure, the fracture occurring between the dentine and the resin cement; 2) cohesive failure, the fracture occurring between the resin cement and the post; and 3) mixed failure.

**Statistical analysis**

The data were analysed using SPSS software, version 20.0 for Windows (SPSS, Chicago, IL, USA) at \( \alpha = 0.05 \). The assumption of normality was confirmed using the Kolmogorov-Smirnov test and the equality of variances was confirmed with the Levene test. The push-out bond strength values were analysed with three-way analysis of variance (ANOVA) and the Tukey Honestly Significant Difference (HSD) post hoc test. The frequencies of different failure modes among the groups were evaluated.

**Results**

The three-way ANOVA revealed that the postspace irrigation solution, root region, and root canal obturation technique significantly affected the push-out bond strength values \( (P < 0.001) \). Significant interactions were found between the root canal obturation technique and the root region, and between the root region and the postspace irrigation treatment (Table 1).

The mean and standard deviation of push-out bond strength are presented in Table 2. Significant differences in push-out bond strength values were found among the postspace irrigation treatments \( (P < 0.001) \). The NaOCl irrigation exhibited the best push-out bond strength value among the three postspace irrigation treatments,
whereas distilled water irrigation produced the lowest push-out bond strength values. Group P (partial root canal obturation technique) resulted in significantly greater push-out bond strength values than group C (complete root canal obturation technique) ($P = 0.049$). Significant differences in push-out bond strength were found among different root regions ($P < 0.001$). The cervical region showed the best push-out bond strength, followed by the middle region and the apical region.

The frequencies of the different failure modes are shown in Figure 2. The mixed failure was the most common failure mode, followed by adhesive failure between the dentine and resin cement and the cohesive failure in the resin cement.

### Discussion

The present study aimed to compare the bond strength of fiber post to intraradicular dentine pretreated with two root canal obturation techniques and three postspace irrigation treatments. Based on the current findings, the null hypotheses were rejected: different root canal obturation techniques did not affect the push-out bond strength of fiber posts to intraradicular dentine; different irrigation methods did not alter the push-out bond strength of fiber posts to intraradicular dentine; and different regions of the intraradicular dentine exhibited similar push-out bond strength values.

During the preparation of the post space, drills create a smear layer rich in gutta-percha, root canal sealant, and inorganic components, which compromises the bond strength of fiber posts to intraradicular dentine$^{16,37}$. Removal of the smear layer is therefore essential to the bonding of fiber posts to the intraradicular dentine$^{24}$. The bonding mechanism of SARC is based on the chemical bond between an acid monomer and a hydroxyapatite through the formation of calcium phosphates$^{46}$. The existing smear layer and debris along the post space canal walls would hinder this process and lead to further reduction in the bond strength. The lower

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>P</th>
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<tbody>
<tr>
<td>Post space treatment</td>
<td>96.024</td>
<td>2</td>
<td>48.012</td>
<td>115.558</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Root region</td>
<td>761.864</td>
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<td>380.932</td>
<td>916.849</td>
<td>&lt; 0.001</td>
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<tr>
<td>Root canal obturation technique</td>
<td>22.667</td>
<td>1</td>
<td>22.687</td>
<td>54.604</td>
<td>&lt; 0.001</td>
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<tr>
<td>Post space treatment x Root region</td>
<td>5.074</td>
<td>4</td>
<td>1.268</td>
<td>3.053</td>
<td>0.018</td>
</tr>
<tr>
<td>Post space treatment x Root canal obturation technique</td>
<td>0.543</td>
<td>2</td>
<td>0.272</td>
<td>0.654</td>
<td>0.521</td>
</tr>
<tr>
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<td>5.088</td>
<td>2</td>
<td>2.544</td>
<td>6.123</td>
<td>0.003</td>
</tr>
<tr>
<td>Post space treatment x Root region x Root canal obturation technique</td>
<td>0.285</td>
<td>2</td>
<td>0.071</td>
<td>0.171</td>
<td>0.953</td>
</tr>
<tr>
<td>Error</td>
<td>77.279</td>
<td>186</td>
<td>0.415</td>
<td>-</td>
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<table>
<thead>
<tr>
<th>Root region</th>
<th>Group C (complete root canal obturation)</th>
<th>Group P (partial root canal obturation)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>NaOCl</td>
<td>Phosphoric acid</td>
</tr>
<tr>
<td>Cervical</td>
<td>9.59 ± 0.87$^{a,A}$</td>
<td>8.99 ± 0.71$^{a,A}$</td>
</tr>
<tr>
<td>Middle</td>
<td>6.79 ± 0.51$^{b,A}$</td>
<td>6.31 ± 0.82$^{b,A}$</td>
</tr>
<tr>
<td>Apical</td>
<td>4.91 ± 0.74$^{c,A}$</td>
<td>4.35 ± 0.67$^{c,A}$</td>
</tr>
</tbody>
</table>

Note: Values marked with same superscript lower case letter were not significantly different within the same column. Values marked with the same superscript upper case letter were not significantly different within the same group and root region ($P \geq 0.05$).
push-out bond strength of group C (complete root canal obturation) indicated that the rotary post drill failed to sufficiently remove the smear layer. Therefore, partial obturation of the root canal system can improve the bonding strength of the fiber post. In addition, partial obturation techniques can also reduce the clinical treatment time. Thus, partial obturation techniques can be applied to root canal treatments in the teeth that require fiber posts for restoration. SARC cannot establish sufficient chemical interactions and micromechanical retention when a thick smear layer is present\textsuperscript{37,46}. Although the manufacturer 3M ESPE (St. Paul, MN, USA) recommends NaOCl irrigation, previous studies have shown the effects of various postspace irrigation procedures on the bond strength of SARC\textsuperscript{30,36,37}. Bitter et al\textsuperscript{36} concluded that the use of NaOCl irrigation together with EDTA increased the SARC bond strength. Similarly, in the present study, the NaOCl irrigation group showed the best push-out bond strength among the irrigation treatment groups. The phosphoric acid exhibited lower effectiveness, possibly due to insufficient dissolution of the smear layer with the use of SARC\textsuperscript{37,46}. However, in the present study, the completely obturated roots exhibited significantly lower push-out bond strength than the partially obturated roots, even after NaOCl irrigation. The present findings may indicate that NaOCl irrigation alone is incapable of providing sufficient dissolution of the smear layer\textsuperscript{29}, especially when the root canal is completely obturated.

Our findings also showed that the push-out bond strength of fiber posts to the intraradicular dentine varied in different root regions. Significantly higher push-out bond strength was observed in coronal dentine than in the middle and apical sections, which is consistent with reports from previous studies\textsuperscript{47,48}. The most likely explanation could be the limited light energy received in the apical region due to greater distance from the light source\textsuperscript{49}. Moreover, the greater push-out bond strength in the coronal and middle regions than in the apical region, can be partially explained by differences in the density and distribution of dentinal tubules along the canal walls, which decrease from the cervical area to the apical area\textsuperscript{50}.

Failure mode implies the quality of cementation\textsuperscript{51}. The most common fracture mode in this study was the mixed failure between cement and root canal, which is consistent with reports from previous studies\textsuperscript{37,52}. Moreover, the specimens subjected to 2.5% NaOCl irrigation had the fewest adhesive failures, which correlated well with the findings for the push-out bond strength. In contrast, some studies have reported that the failures observed after the push-out test were predominantly adhesive failures followed by mixed and cohesive failures\textsuperscript{36}. This discrepancy may be explained by the different resin cement systems used.

The limitations of the present study were that no topographical observations were conducted at the resindentine interface. This study revealed that the partial root canal obturation technique is recommended when a fiber post is required in further treatment. However, due to the limitations of in vitro studies, future clinical studies are required to confirm the present findings.

Conclusions

Within the limitations of present study, the following conclusions can be drawn:

- The partial root canal obturation technique provided better bond strength of the fiber post to the intraradicular dentine than the complete root canal obturation technique;
- Irrigation with 2.5% NaOCl solution and phosphoric acid etching before post cementation improved the push-out bond strength of fiber posts to intraradicular dentine.

Conflicts of interest

The authors reported no conflicts of interest related to this study.

Author contribution

Dr Chang Yuan ZHANG performed the fiber post bonding procedure and wrote the manuscript; Dr Hao YU collected the teeth, prepared the specimens, performed the push-out tests and the statistical analysis; Dr Qi LIN performed root canal treatment of all the specimens; Prof. Yohsuke TAINA reviewed the manuscript; Prof. Hui CHENG designed the study.

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References


