Does Hybridization of Intraradicular Dentin Really Improve Fiber Post Retention in Endodontically Treated Teeth?

Chiara Pirani,* Stefano Chersoni,* Federico Foschi,*,† Gabriela Piana,* Robert J. Loushine,‡ Franklin R. Tay,§ and Carlo Prati*†

Abstract
This study tested the hypothesis that hybridization of intraradicular dentin eliminates interfacial gaps, thereby improving the coronal seal and retention of teeth restored with fiber posts. Post spaces were bonded with two types of fiber posts, using the corresponding etch-and-rinse adhesives and dual-cured resin cements. Longitudinal sections of the interfaces were examined for dentin hybridization in the coronal- and middle-thirds of the root canals. Resin replicas of these sections were evaluated for interfacial gap formation. Although intraradicular dentin hybridization was not compromised irrespective of whether the adhesives were light-cured before cementation, the universal occurrence of interfacial gaps along the hybrid layer surface or the post-cement interface reflects the challenge in bonding to post spaces with low compliance and high C-factors. The clinical success associated with bonded fiber posts is probably due predominantly to frictional retention.

Key Words
Hybrid layer, resin tag, adhesion, fiber posts, SEM.

Materials and Methods
Endodontic Procedures
Forty extracted single-rooted human incisors were employed in this study. Straight line access was achieved through the crown of each tooth under an operating microscope (Karl Kaps, Wetzlar, Frankfurt, Germany), using a tapered diamond bur in a high-speed handpiece with water cooling. Canal patency was established using a size 10 Flex-o-file (Dentsply Maillefer, Tulsa, OK). Instrumentation was performed with a crown-down technique, using ProTaper nickel-titanium rotary instruments (Dentsply Maillefer). All canals were prepared to ISO size 30, 0.09 taper and 1-mm short of the apex. They were irrigated in between instrumentation with the alternate use of 5% NaOCl and 17% EDTA for 1 min each before obturation with Thermafil (Dentsply TulsaDental, Tulsa, OK) according to the manufacturer’s instructions. AH Plus endodontic sealer (Dentsply DeTrey, Konstanz, Germany) was introduced using a paper point, followed by a size 30 Thermafil obturator. A heated instrument was used to remove the excess Thermafil carrier at the level of the cementoenamel junction. Each root-filled tooth was temporized with a noneugenol provisional dressing (Coltosol F, Colténe AG, Altstätten, Switzerland) and immersed in water at 37°C.

Fiber posts are considered as alternatives to cast or prefabricated metal posts in restoring endodontically treated teeth (1–5). These fiber-reinforced, epoxy resin-based posts are used with methacrylate-based dentin adhesives and resin cements. Together, they are being marketed as technologically advanced restorative materials. Conceptually, hybridization of intraradicular dentin that results from the application of dentin adhesives should eliminate interfacial gaps that are indicative of a breach of coronal seal or compromised retention (6–8). Thus, it is reasonable for clinicians who are using these materials to demand better performances from fiber post-retained restorations, over those that are luted with nonbonding dental cements (9, 10).

Microtensile bond strength studies on bonding of composites/fiber posts to intact post spaces (i.e., without presectioning to facilitate laboratory bonding) yielded disappointing results (11, 12) that were contrary to their acclaimed clinical success (13, 14). A recent push-out test study further highlighted that retention of bonded fiber posts was contributed predominantly by friction (15). To date, techniques for bonding to intraradicular dentin are based upon the knowledge acquired from bonding to crown dentin. However, the bonding characteristics of root-treated dentin may differ in terms of the optimal moisture content required for application of some etch-and-rinse adhesives (16, 17), the ability to achieve a reasonable degree of conversion when light-cured adhesives are polymerized from the top of the post spaces (18, 19), and the potential for relief of polymerization shrinkage stresses during the setting of resin cements (20, 21). Depending on the time when bonding is performed, exposure of root-treated dentin to sodium hypochlorite (NaOCl) (22), eugenol-containing sealers (23), and heat generated from warm compaction techniques (24) may or may not influence the hybridization quality of intraradicular dentin. Thus, there is a need to evaluate whether compromised bonding within post spaces, as indicated by the occurrence of interfacial gaps, is caused by the ineffectiveness of dentin adhesives to adequately hybridize root-treated dentin.
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Basic Research—Technology

TABLE 1. Comparison of (A) the hybrid layer thickness in root-treated intraradicular dentin in the four experimental groups (measured directly from specimens) and (B) the maximum interfacial gap width measured along the dentin-cement and post interface of resin replicas obtained from the four experimental groups. A. Hybrid layer thickness

<table>
<thead>
<tr>
<th>Group designation</th>
<th>Fiber post/adhesive/resin cement</th>
<th>Adhesive polymerization mode</th>
<th>Hybrid layer thickness (µm) at 5–10 mm (middle-third) from apex (mm)*</th>
<th>Hybrid layer thickness (µm) at 10–15 mm (coronal-third) from apex (mm)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tech 2000/Single Bond/Relinx ARC</td>
<td>Not-cured</td>
<td>6.5 ± 2.3&lt;sup&gt;A&lt;/sup&gt;</td>
<td>6.3 ± 2.2&lt;sup&gt;A&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>Tech 2000/Single Bond/Relinx ARC</td>
<td>Light-cured</td>
<td>6.5 ± 1.3&lt;sup&gt;A&lt;/sup&gt;</td>
<td>7.2 ± 2.3&lt;sup&gt;A&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>EndoPost/All-Bond 2/Duo-Link</td>
<td>Auto-cured</td>
<td>4.3 ± 1.2&lt;sup&gt;B&lt;/sup&gt;</td>
<td>5.7 ± 1.6&lt;sup&gt;B&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>EndoPost/All-Bond 2/Duo-Link</td>
<td>Light-cured</td>
<td>5.8 ± 2.3&lt;sup&gt;B&lt;/sup&gt;</td>
<td>6.4 ± 1.3&lt;sup&gt;B&lt;/sup&gt;</td>
</tr>
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</table>

*For each fiber post/adhesive/resin cement, a two-way ANOVA was employed to examine the influence of adhesive polymerization mode and location of fiber post on hybrid layer thickness. Subgroups with the same superscripts are not statistically significant (p > 0.05).

B. Maximum interfacial gap width

<table>
<thead>
<tr>
<th>Group designation</th>
<th>Fiber post/adhesive/resin cement</th>
<th>Adhesive polymerization mode</th>
<th>Gap width (µm) at 5–10 mm (middle-third) from apex (mm)*</th>
<th>Gap width (µm) at 10–15 mm (coronal-third) from apex (mm)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tech 2000/Single Bond/Relinx ARC</td>
<td>Not-cured</td>
<td>5.5 ± 5.7&lt;sup&gt;A&lt;/sup&gt;</td>
<td>4.2 ± 5.0&lt;sup&gt;A&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>Tech 2000/Single Bond/Relinx ARC</td>
<td>Light-cured</td>
<td>8.1 ± 3.9&lt;sup&gt;B&lt;/sup&gt;</td>
<td>1.4 ± 3.1&lt;sup&gt;B&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>EndoPost/All-Bond 2/Duo-Link</td>
<td>Auto-cured</td>
<td>5.5 ± 3.7&lt;sup&gt;C&lt;/sup&gt;</td>
<td>5.6 ± 12.0&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>EndoPost/All-Bond 2/Duo-Link</td>
<td>Light-cured</td>
<td>3.1 ± 1.6&lt;sup&gt;C&lt;/sup&gt;</td>
<td>0.3 ± 0.6&lt;sup&gt;D&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*For each fiber post/adhesive/resin cement, data were converted into ranks. A two-way ANOVA was employed to examine the influence of adhesive polymerization mode and location of fiber post on maximum interfacial gap width, followed by the use of Tukey multiple comparison tests. Subgroups with the same superscripts are not statistically significant (p > 0.05).

Bonding of Fiber Posts

The Thermafil was removed using Gates Glidden drills from the coronal- and middle-thirds of each root, leaving behind at least 5 mm of intact gutta-percha. Standardized 15-mm long post spaces were prepared with size #2 post-hole drills supplied by the manufacturers. Preparation was performed under the operating microscope to ensure that the post space was free of cutting debris. The specimens were randomly divided into four groups (n = 10) based on the types of post/adhesive/resin cement employed, and whether the corresponding dentin adhesive was light-cured before the placement of the fiber post.

In groups 1 and 2, the fiber post Tech 2000 (Issani, Rome, Italy) was employed with Single Bond (3M ESPE, St. Paul, MN) adhesive and RelyX ARC (3M ESPE) resin cement. For both groups, the post spaces were etched with 35% phosphoric acid for 15 s, rinsed with water for 10 s, and dried with four paper point insertions. The adhesive was applied with a microbrush to the post space and on the post. In group 1, the adhesive was not light-cured before resin cement insertion. In group 2, the adhesive was light-cured for 20 s (Visilux Command II, 3M ESPE) by placing the light source on top of the post-space. For both groups, additional light-curing was performed for 60 s after bonding of the fiber post with the resin cement.

In groups 3 and 4, EndoPost (RTD, St. Egie`ve, France) was placed with All-Bond 2 (Bisco Inc., Schaumburg, IL) adhesive and Duo-Link resin cement. The mixed primer was applied in 5 to 6 coats with Pre-Bond from the All-Bond 2 kit to render the resin dual-curable. For Tech 2000/Single Bond/RelyX ARC (groups 1 and 2) and EndoPost/All-Bond 2/Duo-Link (groups 3 and 4), the thickness (Table 1<sub>B</sub>) of the hybrid layers were independent of the adhesive polymerization mode, gap width (µm) at 5–10 mm (middle-third) from apex (mm)*

Scanning Electron Microscopy

After water storage at 37°C for 1 wk, each specimen was sectioned longitudinally into two halves using a water-cooled diamond saw (REMET, Fossombrone, Italy). The sections were polished with 120 to 4000 grit silicon carbide papers under water irrigation, and subsequently treated with 5% NaOCl to dissolve the collagen fibrils that were not enveloped by resin. Impressions of these interfaces were taken using a low viscosity polyvinyl siloxane (Affinis LightBody; Goléne, Alstätten, Switzerland). Epoxy resin replicas were fabricated from these impressions for interfacial gap evaluation.

The specimens were fixed in 4% glutaraldehyde in 0.2 M sodium cacodylate buffer for 4 h, rinsed in cacodylate buffer, dehydrated in an ascending ethanol series (40%–100%), critical point dried, gold-sputter and examined with a scanning electron microscope (JSM-5200, JEOL, Tokyo, Japan).

Each section was evaluated at the middle (5–10 mm measured from root apex) and the coronal-third (10–15 mm) of the root for the quality of hybrid layer and its thickness. For each adhesive, a two-way ANOVA was performed to evaluate the influence of polymerization mode (uncured/auto-cured versus light-cured) and location (middle-third versus coronal-third) on the thickness of the hybrid layer. Statistical significance was set in advance at α = 0.05.

The resin replicas were also gold-sputtered and examined along the same sites for the occurrence of interfacial gaps. For each adhesive, a two-way ANOVA and Tukey tests were employed to evaluate the influence of polymerization mode and location on the maximum gap width, with α = 0.05.

Results

For Tech 2000/Single Bond/Relinx ARC (groups 1 and 2) and EndoPost/All-Bond 2/Duo-Link (groups 3 and 4), the thickness (Table 1<sub>A</sub>) of the hybrid layers were independent of the adhesive polymerization modes and the location of the intraradicular dentin (p > 0.05). Hybrid layers formed by Single Bond (Fig. 1A) and All-Bond 2 (Fig. 1B) after laboratory NaOCl challenge did not demonstrate features that were indicative of inferior quality, such as incomplete resin infiltration.

For both systems, gap widths were significantly influenced only by the location of the intraradicular dentin (Table 1B). However, interfacial gaps could be universally observed in all sections. An example of a gap at the cement-dentin interface is depicted in Fig. 2A. When gaps were absent from the cement-dentin interface, delamination of the fiber post from the resin cement could frequently be identified (Fig. 2B).
When a light-cured dentin adhesive is employed for bonding to root canals, the depth of the post space usually exceeds the depth of cure of most light-curing units (19). A pragmatic but earnest question is whether light-curing from the top of a post space, which may be 10 to 15 mm away from the most vulnerable site that requires a coronal seal (i.e., the severed end of the gutta-percha), is sufficient to optimally polymerize a light-cured adhesive. It is important to determine whether such a technique results in a better degree of conversion than what may be attained via diffusion of free radicals from the adjacent dual-cured resin cement (25). Although the use of light-transmitting posts may improve the polymerization of adhesives and resin composites in deep post spaces (26), such a concept was challenged in a recent study (27).

Clinicians are often confronted with advertisements that portray excellent micrographs of hybrid layers and profuse resin tag formation in root canal dentin. Although resin tag penetration was also examined initially, the authors felt that the method of investigation was not robust enough to permit a cause-effect correlation, and have refrained from including such data in this work. Nevertheless, the present study demonstrated that hybridization of intraradicular dentin, even in the absence of deterioration after laboratory challenge, is merely a phenomenological manifestation of resin infiltration following smear layer dissolution and partial demineralization of the root dentin (28). As such, it has no bearing on the integrity of the coronal seal or resistance to dislocation of fiber post-retained restorations.

This work was performed in the absence of eugenol-containing endodontic sealers. A recent study also demonstrated that heat generated from warm compaction techniques did not result in disappearance of collagen cross-banding in intraradicular dentin (29). However, as the fiber posts were bonded 24 h after endodontic treatment, the residual oxidizing effect of NaOCl on resin polymerization could not be neglected. Even under the circumstances when this residual oxidizing effect is managed with reducing agents (30), the most relevant issue related to the occurrence of interfacial gaps is the problem of low compliance that one encounters in endodontics.

In pulpal inflammation, the minimal capacity for pulpal tissues to expand accounts for the augmentation in pulpal hydrostatic pressure associated with vasodilatation and increase in vascular permeability.

**Discussion**

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(31). Likewise, in bonded root canals, the low compliance of the hard tissue cage renders it impossible to contract to accommodate resin polymerization shrinkage (32). It is not possible to rely on layering techniques to reduce polymerization shrinkage in post spaces. Relief of the shrinkage stresses thus generated is further hampered by the high cavity-configuration factors encountered in these long narrow channels, the nonfitting nature of circular prefabricated posts in irregular post spaces such as those with canal fins, and the light-curing that is initiated from the top of the post space (21, 33). As a result, interfacial gaps appeared either along the cement-dentin interface or the cement-post interface. It has also been assumed that epoxy resin-based posts bond to methacrylate-based adhesive resins. However, as the two materials differ completely in resin chemistry, adhesion must rely on the silanization of the glass fibers within the post, if indeed glass-fiber posts are utilized.

This work makes no attempt to deter clinicians from using fiber posts, or to challenge the excellent clinical track record of these systems. Rather, the concurrent identification of subclinical interfacial gaps and hybridization of intraradicular dentin should alert clinicians that the clinical success associated with fiber posts may have little to do with the actual benefits derived from dentin bonding, and may simply be the result of resistance to dislocation contributed by frictional retention (16). Thus, it would be desirable to examine ways to improve the adhesion of fiber posts to root canals, such as refining them with resin composites to minimize the cement space (32–34), and etching of fiber posts with hydrogen peroxide to increase micromechanical retention (35). While the former technique has been brought to fruition with the commercialization of the “anatomic fiber post system” (RTD, St. Égée, France), we are currently investigating the combination of the two techniques to enhance the adhesion of fiber posts in clinically relevant, intact post spaces.

Acknowledgments
This study was based on a dissertation to be submitted by Dr. Chiara Pirani in partial fulfillment of the requirements of the degree of Doctor of Philosophy in the University of Bologna, Italy. The fiber posts examined in this study were generously sponsored by Isasan, Italy and RTD, France. The work was supported by 60% UNIBO 2002 and 2003, Italy, and by RGC CERG grant 10204604/07840/08004/324/01, Faculty of Dentistry, University of Hong Kong. The authors are grateful to Anna Prati and Anna Tay for secretarial support.

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