Operative Dentistry, 2008, **33-1**, 92-101

Microleakge in Overflared Root Canals Restored with Different Fiber Reinforced Dowels

S Erkut • K Gulsahi • P Imirzahoglu
A Caglar • VM Karbhari • I Ozmen

Clinical Relevance

Based on the *in vitro* results of this study, restoration of a tooth with an overflared root canal, using individually shaped polyethylene reinforced dowels, may help to reduce microleakage.

SUMMARY

This study evaluated microleakage in overflared root canals restored with four different types of adhesively-luted fiber-reinforced dowels: DT Light Post (LP), Glassix (GL), Ribbond (RB) and StickTech Post (ST). Forty non-carious, single-rooted mandibular human premolars with straight root canals were prepared using a step-back technique and obturated with gutta-percha using lateral condensation. The restored roots were randomly divided into four groups (n=10). The root canals were overprepared, creating an overflared dowel space, and each dowel was adhesively luted using a total-etched adhesive (Single Bond) and dual-polymerizing luting agent (RelyX ARC). All specimens were thermal cycled 1000 times between 5°C and 55°C and stored in 2% methylene-blue solution for one week. The teeth were cut horizontally into three consecutive sections: apical (A), middle (M) and coronal (C). Each section was digitally photographed from the occlusal direction under a stereomicroscope. The images were transferred to a PC and stored in TIFF format. For each image, dye penetration was estimated as the ratio of methylene-blue–infiltrated surface divided by total dentin surfaces. The data were compared and statistically analyzed using the Kruskal-Wallis test (*p*<.05). The Mann-Whitney U test was used to compute multiple pairwise comparisons to determine differences between the

---

*Selim Erkut, DDS, PhD, assistant professor, Department of Prosthetic Dentistry, Faculty of Dentistry, Department of Prosthodontics, Ankara, Turkey

Kamran Gulsahi, DDS, PhD, postdoctoral fellow, Department of Prosthetic Dentistry, Faculty of Dentistry, Süleyman Demirel University, Isparta, Turkey

Pervin Imirzahoglu, DDS, PhD, associate professor, Department of Prosthetic Dentistry, Faculty of Dentistry, Baskent University, Ankara, Turkey

Alper Caglar, DDS, PhD, postdoctoral fellow, Department of Prosthetic Dentistry, Faculty of Dentistry, Baskent University, Ankara, Turkey

Vistasp M Karbhari, PhD, professor, Materials Science & Engineering Program and Department of Structural Engineering, University of California San Diego, La Jolla, CA, USA

Ilknur Ozmen, MSc, assistant professor, Department of Statistics & Computer Science, Baskent University, Ankara, Turkey

*Reprint request: 11 sokak no 27 Bahçelievler 06490, Ankara, Turkey; e-mail: selim@baskent.edu.tr

DOI: 10.2341/07-47

experimental groups (*p*=.083). Dentin-luting agent fiber-reinforced dowel (FRD) interfaces were evaluated under a scanning electron microscope. Scanning electron microscopy (SEM) showed detachment of the luting resin from the dentin surface in varying degrees in all specimens evaluated. All groups showed considerable leakage at the sections evaluated. Significant differences were demonstrated between LP-RB for the apical and middle sections and between GL-RB, LP-RB and ST-RB for the coronal sections (*p*<.0083). Among the FRDs evaluated, the individually shaped polyethylene-reinforced dowel (Ribbond) showed the least overall leakage.

INTRODUCTION

Restoration of an endodontically-treated tooth with extensive coronal destruction requires a dowel-and-core restoration to retain full and final crown restoration. Fiber-reinforced dowels (FRDs) that can be bonded to intraradicular dentin[1-6] using adhesive systems are preferred by many clinicians, as they are easier and faster to fabricate and less expensive than custom-cast dowel and cores.

Favorable stress distribution of FRDs along the root that prevents catastrophic root fractures[7] has been attributed to their modulus of elasticity being similar to dentin.[8-9] Acceptable long-term performance of bonded FRDs has also been validated clinically.[10-12] The fracture resistance of a dowel and core-restored tooth is proportional to the residual dentin tissue,[13-15] as decreased root dentin thickness will weaken the tooth/dowel complex.[16-18] Although a decrease in microleakage in teeth restored with bonded FRDs compared with teeth restored with non-dentin bonding luting agents has been reported, leakage along the dowel space remains a concern.[19-23]

Appropriate dowel dimensions are crucial when enlarging the canal space, as too great an enlargement will weaken the remaining tooth structure. It has been reported that the dowel diameter should be no more than one-third of the root diameter at the cemento-enamel junction[24] and a minimal dentin thickness of 1 mm around the dowel should be provided.[25] However, in some situations, the remaining residual root structure is dramatically reduced, and the dowel space is overflared as a consequence of post removal, internal resorption and endodontic therapy.[26-28] Decreased thickness of the coronal walls may also make it difficult to achieve a "ferrule effect." Therefore, in an overflared canal where prefabricated dowels are used, inevitably, there will be relatively large excess space (mostly at the coronal portion) between the prefabricated dowel and the root dentin that must be compensated for with the luting agent. In such situations, increased resin thickness may lead to detachment of the luting resin from the dentin, which later may lead to microleakage along the dowel space, as shrinkage of the polymer is strongly related to the volume of the restoration.[29] From a materials' perspective, this can lead to not only gaps but also to microcracks within the luting resin layer, which can lead to both microleakage and to microcrack coalescence over the lifetime of the restoration, ultimately leading to premature failure.

According to the application procedures, fiber-reinforced dowels can be categorized as pre-shaped and individually shaped dowels. The adaptation of pre-shaped dowels to the root canal is provided by preparing the canal with drills that correspond to dowel size. However, individually shaped dowels are formed according to the existing dowel space. In overflared root canals, the application of individually shaped dowels that are formed inside the dowel space may provide a closer adaptation of the fibers against the tooth substrate, decreasing luting-agent thickness and increasing filler content of the restoration. In addition, the closer the conformance of the fibrous reinforcement is to the original structure, the better the stress transfer, and the lower the occurrence of residual stresses from shrinkage of the luting resin agent.[30-31]

Although in different clinical reports[26-28,32] and research articles[33-36] preservation of the remaining tooth structure and restoration of a severely weakened endodontically-treated tooth have been evaluated, based on the knowledge of the authors of this study, no study has evaluated microleakage in overflared root canals restored with different fiber reinforced dowels.

Therefore, this study was designed to evaluate microleakage in overflared root canals restored with different fiber reinforced dowels. The null hypothesis tested was that, compared with prefabricated dowels in overflared root canals, the use of individually shaped dowels was more effective in reducing microleakage. For this purpose, the microleakage of four different adhesively luted fiber-reinforced dowel systems was measured. Scanning electron microscopy (SEM) photomicrographs were used to evaluate the interfacial regions around the different dowels.

METHODS AND MATERIALS

Two different types of pre-shaped and individually shaped dowels were used for this study. For pre-shaped dowels, glass fiber (Glassix, Haral Nordin sa, Chailly, Switzerland) or quartz fiber reinforced dowels (DT Light Post, BISCO, Schaumburg, IL, USA) were used. For individually shaped dowels, polyethylene woven fiber ribbon (Ribbond, Ribbond Inc, Seattle, WA, USA) or semi-interpenetrating polymer network (IPN) E-glass fiber dowels (everStick Post, Stick Tech, Turku, Finland) were selected.

Forty extracted non-carious, single-rooted mandibular human premolars with straight root canals of per-

Table 1: *Batch Numbers, Material Description and Manufacturers of the Materials Used in the Study*

Material	**Material Description**	**Manufacturer**	**Lot #**
Single Bond	Bonding agent	3M ESPE, St Paul, MN, USA	4KG
Smartseal	One component unfilled resin (fissure sealant)	Detax, Ettlingen, Germany	030201
RelyX ARC	Resin-based luting agent	3M ESPE, St Paul, MN, USA	EPFR
Glassix (GL)	Prefabricated glass fiber reinforced dowel	Haral Nordin sa, Chailly, Switzerland	03538/547 05155/000
DT Light Post (LP)	Prefabricated-quartz fiber reinforced dowel	BISCO Inc, Schaumburg, IL, USA	300007004
everStick Post (ST)	Individually shaped resin-impregnated non-polymerized glass fiber reinforced dowel	Stick Tech Ltd, Turku, Finland	5023
Ribbond (RB)	Individually shaped polyethylene fiber reinforced dowel	Ribbond Inc, Seattle, WA, USA	9550 (THM) T106 (Triaxial)

manent dentition, having an average length of 23 ± 1 mm, were used in this study. The teeth were stored in sterile saline solution at 4°C and used within one month of extraction. The coronal part of each tooth was sectioned at the cemento-enamel junction using a low-speed diamond-coated disk (NTI Kahla GmbH, Im Camisch, Germany) to obtain roots approximately 16-17 mm long. The pulp tissue was removed with a barbed broach (Dentsply, Maillefer, Ballagiues, Switzerland). The teeth were then instrumented 1 mm short of the apex with a step-back technique, using stainless-steel K files (Zipperer, Munich, Germany) with 5.25% sodium hypochlorite irrigation. The prepared teeth were obturated using a lateral condensation technique, gutta-percha (Diadent, Chongju, Korea) and resin-based sealer (AH-26, De Trey, Zurich, Switzerland). After completion of the endodontic treatment, the root canal walls were initially enlarged with Peeso reamers (Dendia, Vienna, Austria) from size 3 through size 5. Then, an overflared dowel space was created by circumferentially using a diamond bur (D 20, Intensiv SA, Grancia, Switzerland) under copious amounts of water for cooling, leaving approximately 1 mm of dentin between the prepared root canal and the root surface at the cervical region and a depth of 10 mm from the cervical surface. The specimens were then randomly divided into four groups of 10 teeth each. Before luting, the fiber dowel canals were rinsed with 5.25% NaOCl for one minute, rinsed with distilled water and dried with paper points. The resin-based luting agents, bonding agent, resins and FRDs, and their chemical compositions are listed in Table 1.

All the dowels were luted using an adhesive system (Single Bond, 3M ESPE, St Paul, MN, USA) and dual polymerizing adhesive luting resin (RelyX ARC, 3M ESPE). Prior to restoration with the selected dowel, occlusal dentin and dowel spaces were etched with 35% orthophosphoric acid (Scotchbond etchant, 3M ESPE) for 15 seconds. Each canal was then irrigated with 20 mL of water (using an irrigation needle to remove the etchant) and dried with paper points. Two consecutive coats of Single Bond Adhesive were applied in the canals using a disposable fiber applicator (Microbrush X, Grafton, WI, USA) to provide more uniform hybridization of the dentin.[37] The dowel space was then air dried for five seconds, and paper points were used to remove any excess bonding agent. The canal was then light polymerized for 20 seconds from the occlusal direction using a halogen polymerization light (Hi-Lux, Benlioglu, Ankara, Turkey).

For the everStick Post group (ST), the dowels were individually adapted into the dowel space. To achieve this, one main post (1.5 mm diameter) was placed into the prepared length of the canal and the remaining dowel space was supported with additional dowels (0.9 mm in diameter). The adapted dowels were polymerized inside the canal using a halogen light of 500 mW/mm^2 intensity (Hi-Lux, Benlioglu, Ankara, Turkey) for 20 seconds, leaving approximately 4 mm of fiber dowel extending above the coronal root surface. Then, using a pair of pliers, the dowel was removed and polymerized outside for 40 seconds, at which point adaptation of the dowel was checked. The dowels were coated with a resin composite (Single Bond, 3M ESPE), and the resin was allowed to act for three minutes while being protected from light. Excess resin was then evaporated from the dowel surface with oil-free air and light and polymerization was again conducted for 20 seconds. Luting resin (RelyX ARC) was dispensed onto a mixing pad, mixed for 10 seconds and applied into the dowel space using a periodontal probe. The dowel was coated with a thin layer of mixed luting resin and seated using finger pressure. Excess luting resin was cleaned and polymerized from the occlusal direction for 30 seconds. A coronal core portion was made with a hybrid light polymerizing composite (Z250, 3M ESPE). Three increments of the composite were applied to the core, each requiring 20 seconds of polymerization to complete the coronal core. Using a diamond bur (308, Intensiv SA) under copious amounts of water for cooling, a core 5 mm high was prepared with a 1 mm chamfer finish at the cemento-enamel junction. The same core build-up procedure was used in each group.

For the Ribbond group (RB), the luting resin was applied into the dowel space as described in the ST group. Preparation of the dowel was performed following a technique previously described by Eskitascioglu and others:[38] two pieces of Ribbond (2 mm wide and 24 mm long) were wetted with unfilled resin (Smartseal, Detax, Ettlingen, Germany); excess resin was removed with a metal spatula, and the Ribbond material was placed horizontally in a mesiodistal direction over the coronal dowel space and condensed into the apical region with the aid of an endodontic plugger (Ribbond Condenser No 1, Ribbond Inc, Seattle, WA, USA). Another length of resin-wetted Ribbond material was then placed across the previous one in a buccolingual direction and condensed in the same manner. Condensation of the ribbons was continued until a maximum amount of dowel adaptor had been acquired, leaving approximately 4 mm of the emerging ends of the ribbons at the coronal portion of the tooth. Excess resin was removed, and the assembly was polymerized from the occlusal direction for 30 seconds. The same core buildup and preparation procedures were used as in the previous group.

Glassix No 3 dowels (GL) were coated with a thin layer of bonding agent (Single Bond, 3M) and polymerized for 20 seconds using a light-polymerizing unit. The dowels then were coated with a thin layer of luting resin and seated by finger pressure into the conditioned space and luting resin was placed into the dowel spaces. Excess luting resin was cleaned and polymerized for 30 seconds using the same dental curing light; 4 mm of the dowel head extended above the coronal and core buildup and preparations were done.

For the quartz fiber dowel group (LP), bonding agent (Single Bond, 3M ESPE) was applied to the surface of the dowel and light polymerized. The dowels were then coated with a thin layer of luting resin (RelyX ARC, 3M ESPE) and inserted with finger pressure into the conditioned and luting-resin-coated dowel space. After removal of any excess luting resin, the resin was polymerized for 30 seconds, 4 mm of the dowel head was left above the coronal and the same core buildup and preparation procedures were used as in previous groups.

After placing the FRDs, the specimens underwent 1000 thermal cycles between 5°C-55°C (dwell time, 20 seconds). The specimens were stored in tap water for one week at 37°C before being treated with a dye penetration test. The specimens were dried with absorbent paper tissues and air and were coated with clear nail varnish to prevent the dye from penetrating into the tooth. Areas 1 mm from the coronal were left uncoated. One tooth from each group was randomly selected and used for examination by scanning electron microscopy. The specimens were subsequently immersed in freshly prepared 2% methylene-blue solution in separate containers for one week. The specimens were then rinsed under running tap water, and any visual dye remnants on the surface were cleaned with a brush and pumice stone. The cleaned specimens were then embedded in epoxy resin (Araldite M, Agar Scientific Limited, Essex, UK). After polymerization of the resin, the specimens were cut horizontally into three consecutive sections using a slow-speed, water-cooled rotary diamond blade (Isomet, Buehler Ltd, Lake Bluff, IL, USA). The first section was made 0.5 mm apical from the preparation margins and labeled the *coronal section* (C). The second section was made 0.5 mm coronal to the gutta percha seal and labeled the *apical section* (A) and the third section was made by sectioning the longest remaining root segment horizontally from the middle and labeled the *middle section* (M) (Figure 1). Digital images from the side of the occlusion of each section were captured under magnification (40x) using a digital camera (GCX35E, JVC, Yokohama, Japan) attached to a stereomicroscope (Leica MZ 12, Leica Microsystems, Glattbrugg, Switzerland), giving a total of three images per specimen and 30 images per group. The images were then transferred to a personal computer and stored in a TIFF format. For each image, the extent of dye penetration was estimated to be the ratio of methylene-blue–infiltrated surface divided by total dentin surfaces (Figure 2). The methylene-blue–infiltrated surface for each specimen was measured and data were collected using AutoCAD 2000 software (Autodesk Inc, San Rafael, CA, USA). Non-parametric data were statistically analyzed by the Kruskal-Wallis test ($p<.05$). The Mann-Whitney U test was used to compute multiple pairwise comparisons of the data to determine significant differences between groups. The Mann-Whitney U test was used for the six pairwise comparisons (GL-LP, GL-RB, GL-ST, LP-RB, LP-ST and RB-

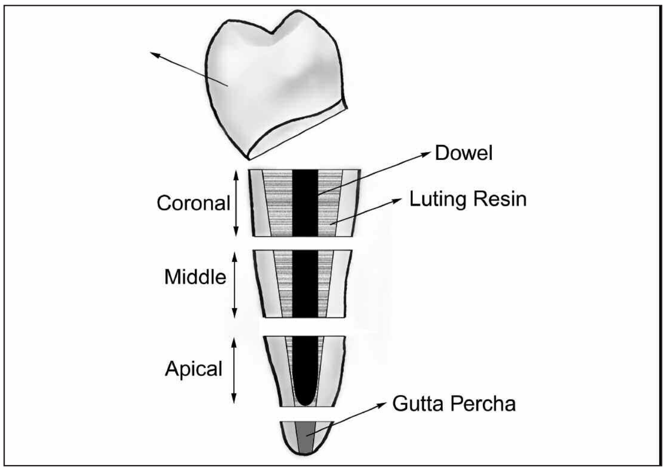

Figure 1: *Preparation of coronal, middle and apical sections for microleakage evaluation.*

Table 2: *The Ratio of the Cross-sectional Area of Dye-infiltrated Dentin to the Total Dentin Area*

	Sectional Areas								
	Apical			**Middle**			**Coronal**		
Groups	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
Glassix	0.2566	0.2153	0.2880	0.4941	0.4795	0.3570	0.9194	1.0000	0.1116
DT Light Post	0.2501	0.1769	0.2437	0.5190	0.4830	0.2022	0.8312	0.8400	0.1620
Ribbond	0.0204	0.0000	0.0271	0.1431	0.1139	0.1550	0.5110	0.5345	0.1144
everStick Post	0.1408	0.0000	0.2391	0.4832	0.3747	0.3568	0.8451	0.8565	0.1540

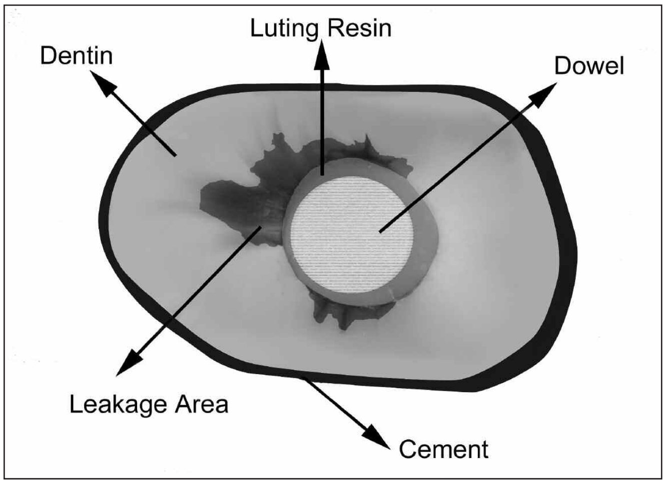

Figure 2: *Schematic drawing of a horizontal section for microleakage evaluation.*

Table 3: *Results of the Kruskal-Wallis Test*

Sectional Areas	***p*-value**
Apical	.022
Middle	.021
Coronal	.001

ST). In order to evaluate a non-directional alternative hypothesis and ensure that the family-wise type-1 error rate (α_{FW}) does not exceed .05, the value of comparisons per type-1 error rate (α_{PC}) was set equal to 0.0083 (0.05/6).

For SEM evaluation, the specimens were sectioned buccolingually, then horizontally using a low-speed diamond saw blade (Isomet, Buehler Ltd, Lake Bluff, IL, USA) under water cooling. The sections were polished using 600-grit silicone abrasive paper (P 600; Kovax Co, Tokyo, Japan), acid etched in 10% H_3PO_4 acid solution (Sigma-Aldrich Co, Deisenhofen, Germany) for 10 seconds, then rinsed in distilled water for 60 seconds. The specimens were then placed in 5% NaOCl solution (Sigma-Aldrich, Deisenhofen, Germany) and rinsed in distilled water. Each conditioned half was coated with a thin layer of gold using a sputter coater (VG Microtech Polaron SC500, Tokyo, Japan), then photographed using an electron microscope (JEOL, JSM 5600, Peabody, MA, USA).

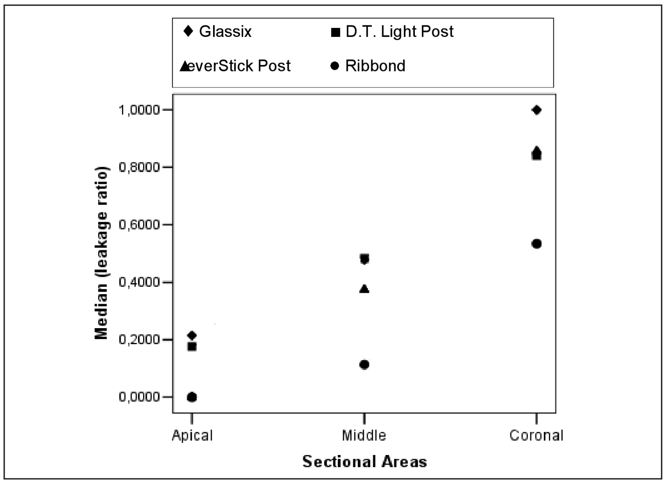

Figure 3: *Ratio of the cross-sectional area of dye-stained area to total dentin area.*

RESULTS

Results of the mean, median and standard deviation for the four experimental groups (GL: Glassix; LP: DT Light Post; RB: Ribbond; ST: everStick Post) and their relationship with each of the three sectional areas are given in Table 2. Results of the Kruskal-Wallis test (Table 3) indicate that there was a significant difference among the experimental groups regarding the sectional areas ($p<.05$). According to the results of the Mann-Whitney U test in Table 4, a significant difference existed between LP–RB for the apical and middle sectional areas and between GL–RB, LP–RB and ST–RB for the coronal sectional area ($p<.0083$).

Figure 3 shows the ratio of dye-stained area to the total dentin area at the apical, middle and coronal sections for each experimental group.

The bonding interfaces were evaluated with a scanning electron microscope. SEM photomicrographs of the study show good penetration of the bonding agent to dentinal tubules and formation of a distinct hybrid layer. A relatively thick layer of luting agent and detachment along the luting resin-dentin surface interface was evident in the SEM photomicrographs of the GL (Figure 4) and LP groups (Figure 5). SEM photomicrographs in the RB and ST groups (Figures 6-10) showed less detachment and better continuity at the

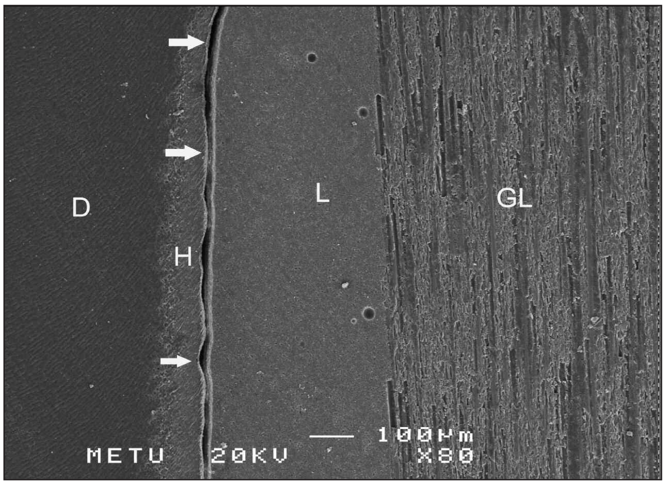

Figure 4: *Scanning electron micrograph from the middle section of the interfacial layers between dentin, resin based luting agent and FRD in group GL. D, dentin; L, luting agent; GL,Glassix (original magnification 80x).*

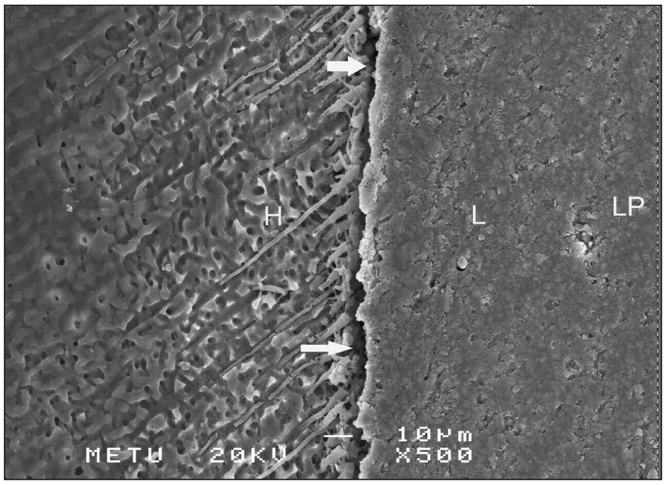

Figure 5: *Scanning electron micrograph from the middle section of the interfacial layers between dentin, luting resin and FRD in group LP. D, dentin; L, luting agent; H, hybrid zone; RT, resin tag; LP, DT Light Post (original magnification 500x).*

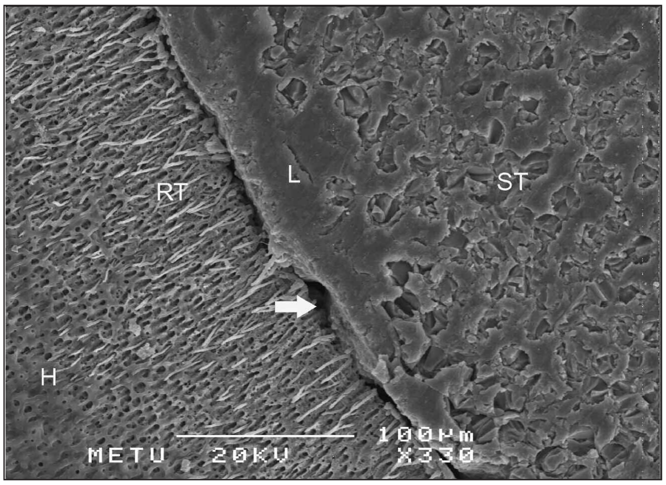

Figure 6: *Scanning electron micrographs from the middle section of the interfacial layers between dentin, resin-based luting agent and FRD in Group ST. D, dentin; L, luting agent; H, hybrid zone; RT, resin tag; ST, everStick Post (original magnification 330x).*

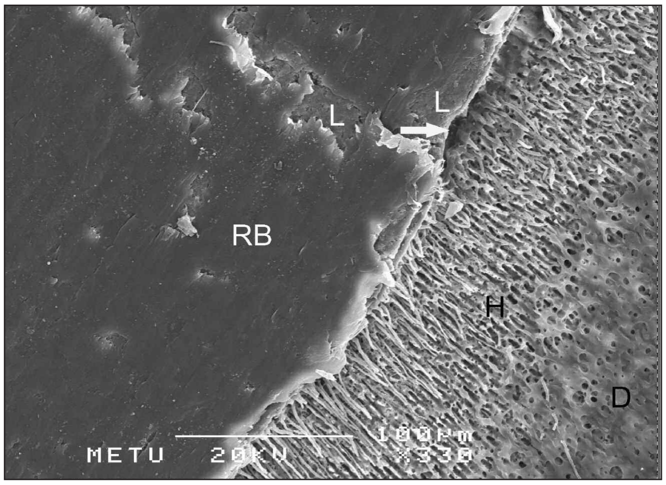

Figure 7: *Scanning electron micrographs from the middle section of the interfacial layers between dentin, resin based luting agent and FRD in the RB group. D, dentin; L, luting agent; H, hybrid zone; RT, resin tag; RB, Ribbond (original magnification 330x).*

Table 4: p-*values (Mann-Whitney U test) of Comparison Among Groups with Regard to Leakage Proportion at the Apical, Middle and Coronal Sectional Areas*

Sectional Areas	**Groups**	**LP**	**RB**	**ST**
Apical	GL	0.965	0.033	0.248
	LP	-	0.001*	0.096
	RB	-	-	0.880
Middle	GL	0.965	0.024	0.965
	LP	-	0.003*	0.691
	RB	-	-	0.024
Coronal	GL	0.219	0.000*	0.309
	LP	-	0.003*	0.894
	RB	-	-	0.002*

**shows statistically significant difference (*p*<.0083).*
GL: Glassix, LP: DT Light Post, RB: Ribbond, ST: everStick Post.

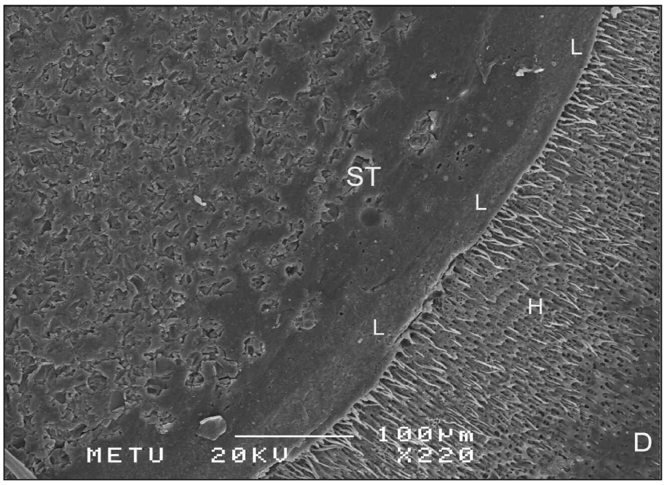

Figure 8: *Scanning electron micrographs from the coronal section of the interfacial layers between dentin, resin-based luting agent and FRD in Group ST. D, dentin; L, luting agent; H, hybrid zone; RT, resin tag; ST, everStick Post (original magnification 220x).*

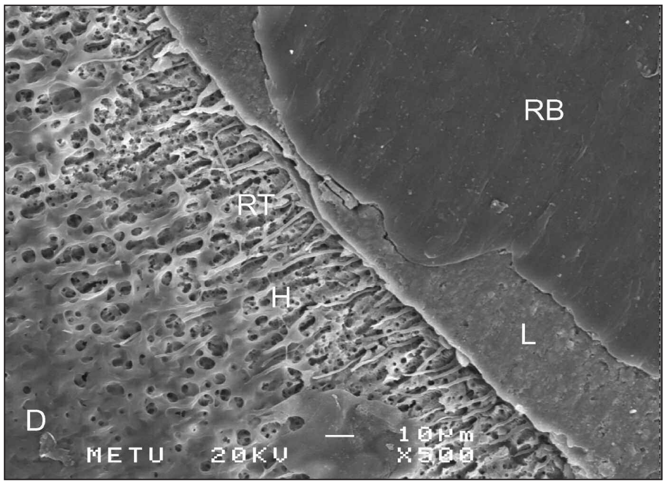

Figure 9: *Scanning electron micrographs from the coronal section of the interfacial layers between dentin, resin based luting agent and FRD in the RB group. D, dentin; L, luting agent; H, hybrid zone; RT, resin tag; RB, Ribbond (original magnification 500x).*

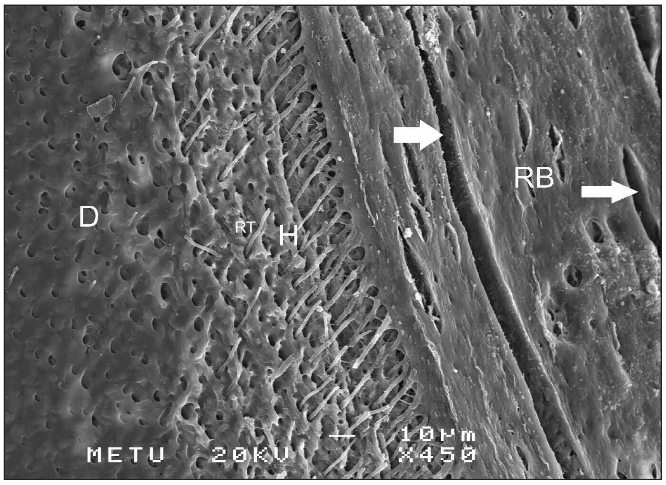

Figure 10: *Scanning electron micrographs from the apical section of the interfacial layers between dentin, resin based luting agent and FRD in the RB group. D, dentin; L, luting agent; H, hybrid zone; RT, resin tag; RB, Ribbond (original magnification 450x).*

luting-resin-dentin interface compared with the GL and LP groups (Figures 4 and 5).

DISCUSSION

In light of the data from this study regarding the microleakage test of the null hypothesis, the authors believe that use of individually shaped dowels decreases microleakage in overflared root canals. Among individually shaped dowels, only the polyethylene reinforced dowel (Ribbond) showed a significant decrease in microleakage at the coronal section compared with the other groups. The significant decrease in microleakage leads to acceptance of the null hypothesis for the RB group.

It has been reported that survival of endodontically-treated teeth significantly depends more on coronal sealing provided by coronal restoration than it does on apical sealing provided by endodontic therapy.[39] In a study by Manocci and others,[12] restorations with fiber posts and composites were found to be more effective than amalgam in preventing root fractures but less effective in preventing secondary caries. Therefore, the extent of microleakage should be taken into consideration while performing adhesively luted FRDs and core restorations in structurally compromised teeth.

Goracci and others[3] stated that greater bonding potential exists for total-etch resin-based luting systems than for self-etched or self-adhesive systems. In another study by Goracci and others,[4] conditioning of the dowel space with dentin–bonding-agent treatment before post placement did not significantly increase dislocation resistance of the fiber posts luted with resin-based luting agents regardless of the bonding system used. Researchers also have related this to the fact that post retention may be related to sliding friction rather than to adhesive bonding.[4] In a more recent study, interfacial gaps between hybridized root dentin–luting resin or luting resin-FRP interfaces were observed after polymerization.[5] Vichi and others[1] have also documented a discontinuous gap between the hybrid layer and luting resin in FRD-restored teeth. SEM micrographs of this study show detachment of luting resin from dentin surfaces (Figures 4-7). In the current study, a very limited area of interfacial gaps between the luting-resin–FRD interfaces was seen in the SEM micrograph of the RB group (Figure 9). Many studies have pointed out that the bond strength between luting resin and the post is stronger than the bond between the post and root dentin.[2-6] This may be related to the fact that bond strength between the luting resin and FRD is greater then the bond strength between FRD and root dentin.

The C factor, first described by Davidson and others,[40] is the ratio of bonded to unbonded surface areas of the cavity. In another study by Bouillaguet and others,[41] these authors reported that, in dowel restorations, the C factor may exceed 200; whereas, it generally varies from one to five in intracoronal restorations. In the same study, the bond strength of root canal dentin was found to be significantly less than that of flat dentin. This is attributed to the fact that the system had a high C factor and that, owing to this, high polymerization shrinkage stress, which caused detachment of the luting resin from the dentin, existed.

It also has been reported that variations in mechanical and structural properties in different regions of dentin could influence dentin bond strength.[42] In an overflared canal, the inner portion of the dentin is reduced and replaced with luting resin and a dowel. In such situations, the bonding interfaces between the luting resin and dentin are moved toward a less-stressful absorbing outer root canal dentin.[17] Therefore, it can be speculated that increased volumetric polymerization shrinkage due to an increased amount of luting resin, high C factor configuration of the dowel cavity41 and unfavorable stress-absorbing capacity of the outer root canal dentin[17] would negatively affect adhesive bonding in overflared root canals.

Usumez and others[21] have reported that resin-supported glass fiber–reinforced prefabricated dowels and polyethylene-reinforced dowels (Ribbond) showed similar leakage. However, in studies by these authors of prefabricated dowels, dowel spaces were prepared with their corresponding drills, which provided for a close agreement between the dowel and its space. In the current study, the dowel spaces were overflared, and a relatively increased amount of luting resin was evident between the dowel and root canal dentin in prefabricated dowels (Figures 4 and 5). However, in individually shaped dowels, increased amounts of luting resin may have caused high volumetric polymerization shrinkage and detachment of luting resin from the root dentin and subsequent microleakage.

In the ST group, where the dowel is also formed *in situ*, increased leakage at the middle and coronal portions was evident compared with the RB group. Although both materials were formed according to dowel space, in the ST group, the polymerized dowel was removed from the canal and luted into the dowel space with a resin-based luting agent. As seen in Figures 6 and 8, there is a relatively thin luting resin layer between the everStick post and the root dentin as in the RB group (Figures 7 through 9). A previous study has shown that polymerization contraction stress in thin resin composite films increases, while the layer thickness of the composite decreases.[43] Therefore, it may be assumed that high contraction stresses in a thin luting-resin layer surrounding an everStick post may be expected during polymerization. This may be why detachment was seen in some parts of the luting resin-dentin interface. In RB (Figures 7 and 9), the dowel also largely filled the cavity, leaving very little area for the non-reinforced luting agent. In the Ribbond group, the resin-infiltrated FRD and the luting resin polymerized together. In this situation, the luting resin-dentin interface may be subjected to less contraction stress during polymerization compared with the other groups. Since the Ribbond is not unidirectional, it has fibers in both the longitudinal and transverse directions, resulting in (a) better conformance to the cavity; (b) more-balanced modulus and coefficients of thermal expansion in the three principle directions (although the properties in the longitudinal direction are greater) and (c) more "give" across the post, since folding and handling provide gaps that may act as local damping areas to relieve polymerization contraction stress (Figure 10). This ability of the Ribbond to fill the gap allows for conformance of the fibers to the cavity walls, decreasing areas of bulk resin that can shrink. Polymerization shrinkage cracks actually occur but are within the Ribbond layers and are mixed with voids (Figure 10). In comparison, Figures 4 and 5 show the gap due to polymerization shrinkage away from the wall. It is noted that the capacity for leakage is formed by the luting resin shrinking towards the post and away from the original tooth structure. In the case of Ribbond, since the "dowel" is formed *in situ* and actually conforms to the cavity wall, shrinkage is minimal and is restricted by distribution of the fibers. A fiber-reinforced composite is anisotropic and, hence, has different moduli and coefficients of thermal expansion in the different directions. Most of the posts are of unidirectional material, that is, the fibers are in the longitudinal direction. In this case, the modulus and coefficient of thermal expansion is much greater in the longitudinal direction than in the radial/transverse direction.

In this study, specimens were not subjected to cyclic loading before microleakage testing. In root canal–treated and dowel-restored teeth, stresses were concentrated at the coronal third of the root, especially at the interfaces of the materials with different moduli of elasticity.[44] This may be considered a limitation of the study, as the microleakage might have increased after cyclic loading.

This *in vitro* study tested four different FRDs that were adhesively luted with a total-etch method. Only one dual-polymerizing resin-based luting agent was used to evaluate microleakage in overflared root canals. Future studies should be directed towards evaluating the effects of new generation self-etching adhesive bonding systems, various types of resin-based luting agents, different polymerization methods (self-polymerizing or dual polymerizing), slow polymerizing resins that may help relieve polymerization shrinking stress due to resin flow[45] and different light sources on microleakage in overflared root canals

CONCLUSIONS

Within the limitations of this study, it is concluded that all FRDs that are adhesively luted to overflared root canals showed considerable leakage at different sections. Detachment of luting resin from the dentin surface was seen in varying degrees in all SEM specimens. Among the FRDs tested, individually shaped polyethylene-reinforced dowels (Ribbond) showed the least amount of overall leakage.

(Received 9 March 2007)

References

1. Vichi A, Grandini S, Davidson CL & Ferrari M (2002) An SEM evaluation of several adhesive systems used for bonding fiber posts under clinical conditions *Dental Materials* **18(7)** 492-502.
2. Boschian Pest L, Cavalli G, Bertani P & Gagliani M (2002) Adhesive post-endodontic restorations with fiber posts: Push-out tests and SEM observations *Dental Materials* **18(8)** 596-602.
3. Goracci C, Sadek FT, Fabianelli A, Tay FR & Ferrari M (2005) Evaluation of the adhesion of fiber posts to intraradicular dentin *Operative Dentistry* **30(5)** 627-635.
4. Goracci C, Fabianelli A, Sadek FT, Papacchini F, Tay FR & Ferrari M (2005) The contribution of friction to the dislocation resistance of bonded fiber posts *Journal of Endodontics* **31(8)** 608-612.
5. Pirani C, Chersoni S, Foschi F, Piana G, Loushine RJ, Tay FR & Prati C (2005) Does hybridization of intraradicular dentin really improve fiber post retention in endodontically treated teeth? *Journal of Endodontics* **31(12)** 891-894.
6. Mak YF, Lai SC, Cheung GS, Chan AW, Tay FR & Pashley DH (2002) Micro-tensile bond testing of resin cements to dentin and an indirect resin composite *Dental Materials* **18(8)** 609-621.
7. Akkayan B & Gülmez T (2002) Resistance to fracture of endodontically treated teeth restored with different post systems *Journal of Prosthetic Dentistry* **87(4)** 431-437.
8. Lanza A, Aversa R, Rengo S, Apicella D & Apicalle A (2005) 3D FEA of cemented steel, glass and carbon posts in a maxillary incisor *Dental Materials* **21(8)** 709-715.
9. Asmussen E, Peutzfeldt A & Sahafi A (2005) Finite element analysis of stresses in endodontically treated, dowel-restored teeth *Journal of Prosthetic Dentistry* **94(4)** 321-329.
10. Fredriksson M, Astback J, Pamenius M & Arvidson K (1998) A retrospective study of 236 patients with teeth restored by carbon fiber-reinforced epoxy resin posts *Journal of Prosthetics Dentistry* **80(2)** 151-157.
11. Monticelli F, Grandini S, Goracci C & Ferrari M (2003) Clinical behavior of translucent-fiber posts: A 2-year prospective study *International Journal of Prosthodontics* **16(6)** 593-596.
12. Mannocci F, Qualtrough AJE, Worthington HV, Watson TF & Pitt Ford TR (2005) Randomized clinical comparison of endodontically treated teeth restored with amalgam or with fiber posts and resin composite: Five-year results *Operative Dentistry* **30(1)** 9-15.
13. Marchi GM, Paulillo LA, Pimenta LA & De Lima FA (2003) Effect of different filling materials in combination with intraradicular posts on the resistance to fracture of weakened roots *Journal of Oral Rehabilitation* **30(6)** 623-629.
14. Assif D & Gorfil C (1994) Biomechanical considerations in restoring endodontically treated teeth *Journal of Prosthetic Dentistry* **71(6)** 565-567.
15. Pereira JR, de Ornelas F, Conti PC & do Valle AL (2006) Effect of crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts *Journal of Prosthetic Dentistry* **95(1)** 50-54.
16. Morgano SM (1996) Restoration of pulpless teeth: Application of traditional principles in present and future context *Journal of Prosthetic Dentistry* **75(4)** 375-380.
17. Kishen A, Kumar GV & Chen NN (2004) Stress-strain response in human dentine: Rethinking fracture predilection in postcore restored teeth *Dental Traumatology* **20(2)** 90-100.
18. Boschian P, Guidotti S, Pietrabissa R & Gagliani M (2006) Stress distribution in a post-restored tooth using the three-dimensional finite element method *Journal of Oral Rehabilitation* **33(9)** 690-670.
19. Bachicha WS, DiFiore PM, Miller DA, Lautenschlager EP & Pashley DH (1998) Microleakage of endodontically treated teeth restored with posts *Journal of Endodontics* **24(11)** 703-708.
20. Fogel HM (1995) Microleakage of posts used to restore endodontically treated teeth *Journal of Endodontics* **21(7)** 376-379.
21. Usumez A, Cobankara FK, Ozturk N, Eskitascioglu G & Belli S (2004) Microleakage of endodontically treated teeth with different dowel systems *Journal of Prosthetic Dentistry* **92(2)** 163-169.
22. Rogic-Barbic M, Segovic S, Pezelj-Ribaric S, Borcic J, Jukic S & Anic I (2006) Microleakage along Glassix glass fibre posts cemented with three different materials assessed using a fluid transport system *International Journal of Endodontics* **39(5)** 363-367.
23. Mannocci F, Qualtrough AJ, Worthington HV, Watson TF & Pitt Ford TR (2005) Randomized clinical comparison of endodontically treated teeth restored with amalgam or with fiber posts and resin composite: Five-year results *Operative Dentistry* **30(1)** 9-15.
24. Shillingburg HT, Hobo S, Whitsett LD, Jacobi R & Brackett S (1997) *Fundamentals of Fixed Prosthodontics* Ed 3 Quintessence Publishing Chicago.
25. Lloyd PM & Palik JF (1993) The philosophies of dowel diameter preparation: A literature review *Journal of Prosthetic Dentistry* **69(1)** 32-36.
26. Lui JL (1992) Cermet reinforcement of a weakened endodontically treated root: A case report *Quintessence International* **23(8)** 533-538.
27. Lui JL (1994) Composite resin reinforcement of flared canals using light-transmitting plastic posts *Quintessence International* **25(5)** 313-319.

28. Mendoza DB, Eakle WS, Kahl EA & Ho R (1997) Root reinforcement with a resin-bonded preformed post *Journal of Prosthetic Dentistry* **78(1)** 10-14.
29. Braga RR, Boaro LC, Kuroe T, Azvedeo CL & Singer JM (2006) Influence of cavity dimensions and their derivatives (volume and "C" factor) on shrinkage stress development and microleakage of composite restorations *Dental Materials* **22(9)** 818-823.
30. Karbhari VM & Strassler H Effect of fiber architecture on flexural characteristics and fracture of fiber reinforced composites *Dental Materials* in press.
31. Karhabri VM & Wang J (2007) Influence of triaxial braid denier on ribbon reinforced dental composites *Dental Materials* **23(8)** 969-976.
32. Erkut S, Eminkahyagil N, Imirzalioglu P & Tunga U (2004) A technique for restoring an overflared root canal in an anterior tooth *Journal of Prosthetic Dentistry* **92(6)** 581-583.
33. Newman MP, Yaman P, Dennison J, Rafter M & Billy E (2003) Fracture resistance of endodontically treated teeth restored with composite posts *Journal of Prosthetic Dentistry* **89(4)** 360-367.
34. Marchi GM, Paulillo LA, Pimenta LA & De Lima FA (2003) Effect of different filling materials in combination with intraradicular posts on the resistance to fracture of weakened roots *Journal of Oral Rehabilitation* **30(6)** 623-629.
35. Yoldas O, Akova T & Uysal H (2005) An experimental analysis of stresses in simulated root canals subjected to various post-core applications *Journal of Oral Rehabilitation* **32(6)** 427-432.
36. Goncalves LA, Vansan LP, Paulino SM & Sousa Neto MD (2006) Fracture resistance of weakened roots restored with transilluminating post and adhesive restorative materials *Journal of Prosthetic Dentistry* **96(5)** 339-344.
37. Ferrari M, Vichi A, Grandini S & Geppi S (2002) Influence of microbrush on efficacy of bonding into root canals *American Journal of Dentistry* **15(4)** 227-231.
38. Eskitascioglu G, Belli S & Kalkan M (2002) Evaluation of 2 post-core systems using two different methods (fracture strength test and a finite element stress analysis) *Journal of Endodontics* **28(9)** 629-633.
39. Ray HA, Trope M (1995) Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration *International Endodontics Journal* **28(1)** 12-18.
40. Davidson CL, de Gee AJ & Feilzer A (1984) The competition between the composite-dentin bond strength and the polymerization contraction stress *Journal of Dental Research* **63(12)** 1396-1399.
41. Bouillaguet S, Troesch S, Wataha JC, Krejci I, Meyer JM & Pashley DH (2003) Microtensile bond strength between adhesive cements and root canal dentin *Dental Materials* **19(3)** 199-205.
42. Yang B, Ludwig K, Adelung R & Kern M (2006) Micro-tensile bond strength of three luting resins to human regional dentin *Dental Materials* **22(1)** 45-56.
43. Alster D, Feilzer AJ, de Gee AJ & Davidson CL (1997) Polymerization contraction stress in thin resin composite layers as a function of layer thickness *Dental Materials* **13(3)** 146-150.
44. Assif D & Gorfil C (1994) Biomechanical considerations in restoring endodontically treated teeth *Journal of Prosthetic Dentistry* **71(6)** 565-567.
45. Tay FR, Loushine RJ, Lambrechts P, Weller RN & Pashley DH (2005) Geometric factors affecting dentin bonding in root canals: A theoretical modeling approach *Journal of Endodontics* **31(8)** 584-589.