Push-out bond strengths of endodontic posts bonded with different resin-based luting cements

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LIONEL HUBER, DMD, MARIA CATTANI-LORENTE, PHD, LIGIA SHAW, DMD, IVO KREJCI, DMD, PHD & SERGE BOUILLAGUET, DMD, PHD

ABSTRACT: Purpose: To compare the push-out bond strengths of endodontic posts bonded with different resin-based luting cements and to verify that bond strengths did not vary with cement thickness. **Methods:** 48 root canals were shaped using 6% NiTi rotary files, obturated with gutta-percha and AH Plus sealer and prepared for post cementation using Panavia F, Parapost cement, SuperBond and Unicem Rely X. All roots were sectioned into 0.7 mm thick slices and digital photographs of each slice were analyzed using Scion Image to measure the surface area of the luting cement. The root slices were stressed to failure at 1 mm/minute using a push-out test. Push-out strength was calculated as the force at failure divided by the bonded surface area. Least squares linear regression analysis was used to assess the effect of cement thickness on bond strength. Fractured specimens were further observed under the SEM. **Results:** Mean push-out bond strengths were: Panavia F (8.8 ± 3.6 MPa), Parapost cement (9.1 ± 4.4 MPa) SuperBond (14.6 ± 2.9 MPa) and Rely X Unicem (12.4 ± 3.3 MPa). The Panavia F and the Parapost cement were not significantly different from each other, but both were significantly lower ($P \leq 0.05$) than SuperBond and Rely X Unicem. Although there were large variations in cement thickness, the cementation of fiber posts with thicker cement layers did not affect the performance of the adhesive luting cements applied to root canal dentin. (*Am J Dent* 2007;20:167-172).

CLINICAL SIGNIFICANCE: Although the thickness of the luting cement observed after post cementation was variable, it did not influence the bonding performances of the resin-based luting cements tested to root canal dentin.

✉: Dr. Serge Bouillaguet, Section of Dental Medicine, 19 rue B. Menn, 1205 Geneva, Switzerland. E-✉: serge.bouillaguet@medecine.unige.ch

Introduction

Endodontically-treated teeth with extensive loss of coronal tooth structure frequently require the placement of a post inside the root canal to help retain the final restoration.[1] Current clinical procedures rely on the use of prefabricated fiber posts adhesively cemented to root canal dentin.[2] Reports[3,4] have shown a significant increase in the retention of prefabricated posts luted with resin-based cements compared to conventional cements. There is also evidence[5] that bonding parallel-sided fiber posts to root dentin reduced the risk of vertical root fracture compared to tapered metallic posts cemented with conventional cements.

Although there is growing interest in using adhesive posts which have the potential for increased retention, esthetics and reinforcement of tooth structure, many factors that may compromise the outcome of such treatment must be considered.[6]

Root anatomy can have significant influence over post placement and cementation inside the root canal. Root curvature, furcations, developmental depressions and root concavities observed at the external surface of the root are all likely to be reproduced inside the root canal. Within the same root, the shape of the canal will also vary between the cervical level and the apical foramen.[7] As a result, severe alteration of the natural shape of the canal is necessary to adapt a post inside the root.

Current endodontic procedures rely on the use of Ni-Ti rotary instruments to clean and shape the root canal system. Research has shown that root preparation with Ni-Ti rotary shaping files results in a very wide tapered and unretentive canal exhibiting a significant divergence from apical to coronal.[8] If a paralled-sided fiber post is to be placed under such conditions, then the coronal part of the canal must be filled with a thick layer of resin-based luting cement.[9] Another approach would be adjusting the shape of the root canal to the shape and dimensions of the endodontic post. However, this operation would result in additional loss of tooth substance which has been shown to compromize the longevity of endodontically treated teeth.[10-12] Therefore, clinicians have to balance the search for a perfect fit of the post inside the root canal with the amount of internal root structure to be removed.

Other research[13,14] has shown that the shrinkage accompanying the polymerization of resin-based luting cements promotes the development of contraction stresses at the adhesive interface which may cause debonding. Photo-initiated polymerization, which occurs more rapidly than chemically initiated reactions, produces more shrinkage stress because of the rapid polymerization rates. Contraction stress also depends on the configuration of the cavity (C-factor) which is known to be unfavorable in the case of the adhesive cementation of endodontic posts.[15-17] Moreover, Alster *et al*[18] showed that the contraction stress produced by the polymerizing resin in a confined space is higher when resin cements are applied in thin layers compared to thicker resin layers. Therefore, root anatomy, polymerization process of luting cements and cement thickness are all factors that may influence the adhesion of endodontic posts to root canal dentin.

In recent years, a number of techniques have been developed to measure the adhesion of endodontic posts to root canal dentin. These methods include the pull-out tests, the microtensile bond strength tests and the push-out tests.[16,19,20] Although the pull-out test is one of the most convenient techniques for evaluating post-cement-dentin bonds, this test is heavily influenced by the presence of flaws and there are many problems with precisely calculating the bonded surface areas.[20] Others[16] have used microtensile bond strength tests, but the preparation of the samples has been shown to break weak post-dentin bonds which increased the risk of premature failures. Recently, Goracci *et al*[19] reported that push-out tests were more appropriate than pull-out tests and microtensile bond strength tests to measure the adhesion of endodontic posts to root canal dentin.

This study compared the push-out bond strengths of endodontic posts bonded with different resin-based luting cements and evaluated whether bond strengths varied with cement thickness.

Materials and Methods

Forty-eight human extracted lower canines and premolars were selected for this study and randomly assigned to four experimental groups. Single rooted lower canines and premolars were used because the shape of these canals vary from ovoid at the cervical level to round at the apical foramen without exhibiting extreme radicular irregularities. This anatomical configuration allowed us to promote the formation of various thicknesses of luting cement throughout the root.

Each tooth was sectioned below the cemento-enamel junction to obtain a 12-mm long root that was prepared for endodontic treatment. During endodontic procedures, the canal space was mechanically enlarged using the Hero[a] endodontic files operated at 300 rpm under a constant irrigation with 3% NaOCl. The final preparation had a 6° taper and a diameter of 0.3 mm at the apex. The canals were then rinsed with distilled water, dried with ethanol and paper points, and obturated with gutta percha cones and AH Plus sealer.[b] The roots were stored 24 hours in a humid atmosphere at 37°C before being prepared for post cementation.

The endodontic posts used in this study were prefabricated posts (EasyPost[b]) made of a combination of an epoxy resin matrix reinforced with silicium fibers enriched with zirconium. Except the tip of the post which is tapered (3 mm long), the posts are parallel-sided and have a 1.3 mm external diameter. A silane coupling agent (ESPE Sil[c]) was applied for 5 minutes to the surface of the post and dried with air.

The canal space of each root was progressively enlarged using low-speed calibrating drills provided by the manufacturer, to create a 9 mm-deep post space. Before post cementation, the root canals were rinsed for 1 minute with 3% NaOCl, rinsed with double distilled water for 2 minutes and dried with paper points. The posts were then luted following manufacturer's instructions.

For the Panavia F[d] luting system, equal amounts of ED Primer liquids A and B were mixed together on the mixing dish, applied with a brush inside the canal and allowed to stand for 60 seconds. Excess liquid was eliminated with a paper point before evaporating the solvent with a gentle air flow. Equal amounts of Panavia F paste A and B were then mixed for 20 seconds on the mixing plate and applied with a brush to the silanated post. The resin cement was rapidly applied inside the canal using a lentulo spiral. The post covered with cement was inserted into the root canal and polymerized by light for 20 seconds (Freelight 2[c]). Oxygen excluding gel was applied on the top of the luting cement covering the top of the root section to avoid the formation of an oxygen-inhibited layer.

For the Parapost Cement (Coltene-Whaledent[e]), equal amounts of Parapost Cement Conditioner A and B were mixed

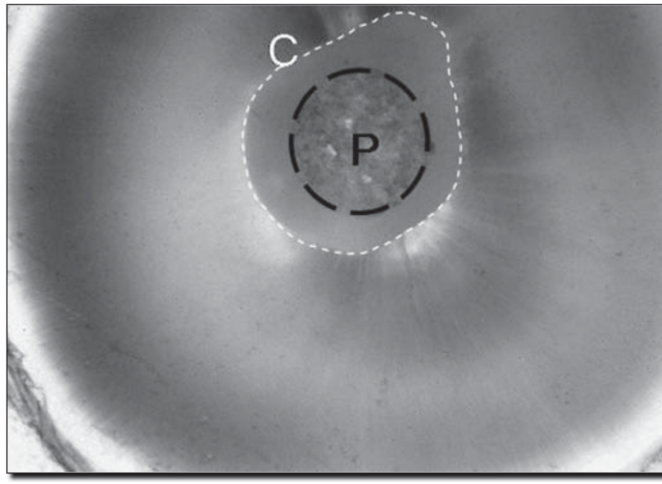

Fig. 1. For each slab, the surface area of the post (P) was measured with Scion Image using the oval selection tool. Because the surface area of the cement (C) was not necessarily circular, the free hand selection tool was used for the measurements.

together on the mixing dish and applied with a brush to the root canal walls. The conditioner was left in place for 30 seconds before removing the excess with paper points. A gentle air blast was used to evaporate solvent. Equal amounts of Parapost Cement base and catalyst were mixed for 30 seconds on the mixing plate until a white homogenous mix was obtained. The posts and the root canal walls were coated with cement before the post was inserted into the post space under slight pressure where it was chemically cured.

According to manufacturer's instructions, the SuperBond adhesive cement[f] was applied to the canal after conditioning the dentin with Dentin Activator (10% citric acid with 3% ferric chloride). This conditioner was applied with a small sponge to the canal for 10 seconds, rinsed with water thoroughly, and dried with paper points. The Superbond resin was prepared by mixing four drops of liquid with one drop of catalyst in a cool mixing well and introduced with a brush inside the canal to wet the dentin walls. Then two scoops SuperBond radiopaque powder were added to a fresh mix of base and catalyst to prepare the luting cement, which was inserted inside the canal using a lentulo spiral. Finally the post was inserted into the post space and held in place for 10 minutes.

For cementation of posts with the RelyX Unicem[c] self-adhesive and self-curing resin cement, the root canal dentin was rinsed for 20 seconds with water and gently dried with a paper point to avoid excessive dehydration of the dentin. The cement was prepared by mixing the caps for 15 seconds and introduced in the canal by use of a lentulo spiral. The post was then covered with cement, inserted in the canal and held in place for 10 minutes where it was chemically cured.

The roots were stored for 1 week in a humid atmosphere at 37°C before being sectioned with a low speed saw (Isomet[g]) perpendicular to the tooth axis. The sections were fixed with sticky wax onto a polishing holder (Model 160[h]) and wet ground (SiC papers 500-4000 grit) down to a thickness of 700 µm using a Struers LaboPol-2 polishing machine.[i] The thickness of each slab was carefully controlled with a digital caliper because this parameter can influence the results of the test. Five slabs were produced per root.

Each slab was then placed under a stereomicroscope (Stemi

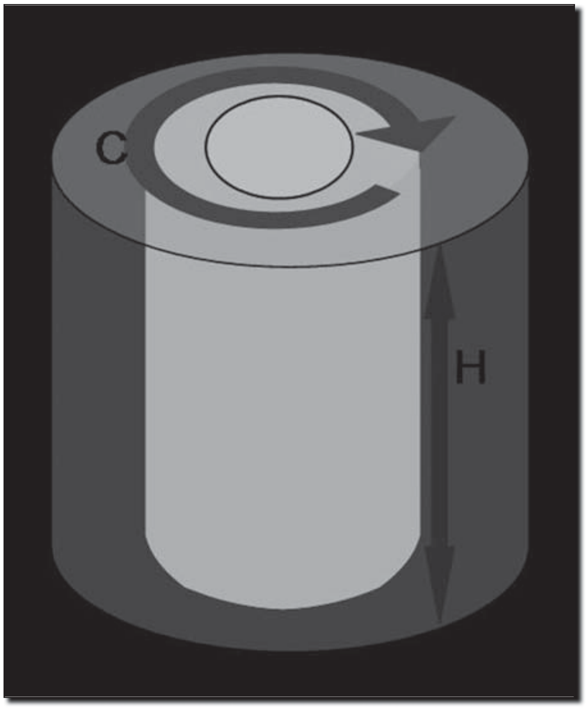

Fig. 2. Diagram illustrating how the bonded surface area was calculated. The circumference of the cement (C) was multiplied by the thickness of the slab.

SV11[j]) and recorded with digital black and white photography. Images were imported into an image processing and analysis program (Scion Image[k]) to measure the surface of the post and the surface area of luting cement (Fig. 1). Briefly, a calibration (pixels/micrometer) was performed by drawing a line using the line tool over a precision ruler that was introduced into the image field prior to digitization. The surface area of the post was manually drawn using the oval selection tool. Because the surface area of the luting cement was not necessarily circular, the freehand selection tool was used to define this region. Image regions defined by the outlining tools were automatically measured by the analysis program and the area of the selection was expressed in square millimeters. The surface area occupied by the luting cement was calculated by substracting the surface of the post from the surface of the bonded area.

For the push-out test, each slab was fixed with sticky wax onto a special aluminum stub presenting a central circular opening with the bonded post centered over this opening. This assembly was placed under a 1.2 mm diameter metallic plunger used to push out the post through the aluminum stub. A 638 nm helium-neon laser beam passing through the circular opening was used to guarantee the exact position of the fiber post under the plunger. Push-out tests were performed at a cross-head speed of 1 mm/minute using a universal testing machine (Vitrodyne V-1000 Universal Tester[l]). The bond strength of each slab was calculated as the quotient of the maximum force at failure and the interface area and expressed in MPa. The bonded surface area was calculated by multiplying the thickness of the slab by the circumference of the cement (Fig. 2).

All specimens used for the push-out test were further observed under the SEM to assess the fracture mode. Specimen preparation for SEM observation followed routine procedure (specimens were fixed in 10% buffered formaldehyde overnight, carried through ascending alcohol concentrations to 100%

Table 1. Mean (± SD) push-out bond strengths (MPa).

Panavia F	8.8 ± (3.6) [a]
Parapost Cement	9.1 ± (4.4) [a]
SuperBond	14.6 ± (2.9) [b]
Rely X Unicem	12.4 ± (3.3) [c]

Same superscript indicates no significant difference.

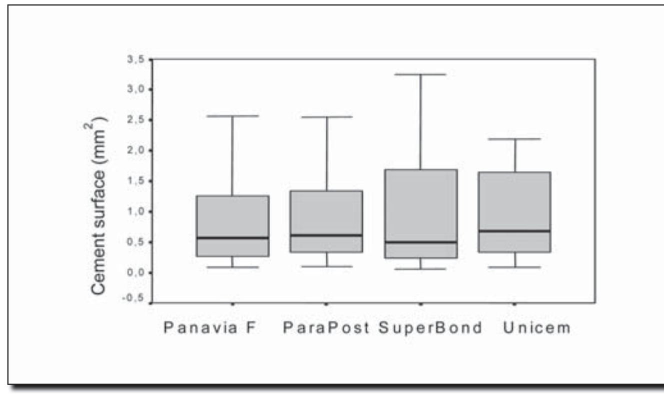

Fig. 3. Cement surfaces measured using the Scion Image analysis program. The box represents the spreading of the data between the first and the third quartiles. The central line represents the mean. The whiskers denote the range of variance.

alcohol and finally critical-point dried. They were sputter-coated with gold and examined in a Phillips XL 20 scanning electron microscope).

Statistical analysis - Because each root yielded five measurements, a mean push-out bond strength was calculated for each root and the means among roots were then compared using ANOVA. Since this test showed no statistically significant differences among the means ($P > 0.05$), the individual specimens within each root were treated as independent measurements ($n = 60$). The push-out bond strengths among different cements were compared using a one-way ANOVA and Tukey multiple comparison intervals ($\alpha = 0.05$). To assess the effect of cement thickness on push-out bond strength, a least squares linear regression analysis was used. The appropriateness of the linear model was assessed using an R^2 value.

Results

Table 1 shows the results of the push-out tests. For the Panavia F and the Parapost cement, mean push-out strengths were 8.8 ± 3.6 MPa and 9.1 ± 4.4 MPa respectively. The Panavia F and the Parapost cement were not significantly different from each other ($P > 0.05$), but both were significantly lower ($P \leq 0.05$) than SuperBond (14.6 ± 2.9 MPa) and Rely X Unicem (12.4 ± 3.3 MPa). These latter two cements were statistically different from each other ($P \leq 0.05$).

The results of the image analysis showed that, for all materials, the mean surface area of luting cement observed around the fiber posts was approximately 0.6 mm^2 (Fig. 3). For most materials, cement surfaces ranged between 0.3 mm^2 and 1.4 mm^2. SuperBond exhibited slightly larger cement surface values. When surface area data was converted into cement thickness values, results indicated that a 0.6 mm^2 surface area corresponded to approximately a 130 µm thick cement layer.

Least squares regression analyses showed that no relationship was found between push-out strengths and cement surface areas (Fig. 4). For Panavia F, a slight trend toward a decrease in

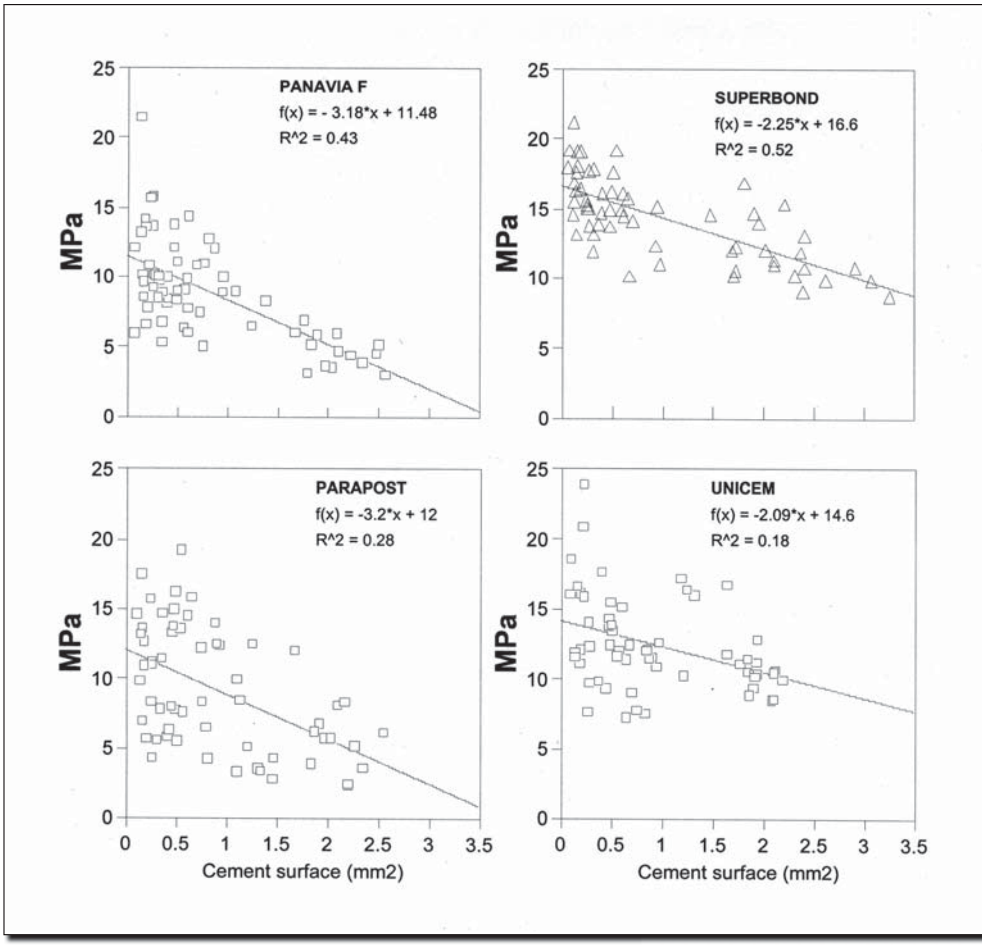

Fig. 4. Push-out bond strength of each test specimen plotted *versus* cement surface area.

Table 2. Type of failure observed in dentin-cement-post specimens by SEM.

Cement	Type of failure: Adhesive[a]	Mixed[b]	Cohesive[c]: In post	In luting cement
Panavia F	47	13	0	0
Parapost Cement	57	3	0	0
SuperBond	20	29	5	1
Rely X Unicem	31	26	0	4

[a] Adhesive fracture means the resin separated from the dentin at the dentin-luting cement interface.
[b] Mixed fractured means the fracture extended from the dentin through the luting cement.
[c] Cohesive fracture means the fracture occurred within the fiber post or the luting cement.

bond strength was observed in the presence of larger cement surface areas (R^2= 0.42). A similar trend was observed for SuperBond (R^2= 0.57). However, no correlation was seen for ParaPost cement (R^2= 0.27) and Rely X Unicem (R^2= 0.18).

Specimens collected after the push-out tests were further observed under the SEM to determine the type of fracture after testing (Table 2). Failures after testing mostly occured between the adhesive layer and dentin (adhesive failure: 65.7%) with some specimens exhibiting mixed fractures (combined fractures located inside the adhesive layer and the luting cement: 31%). A few specimens, however, showed cohesive failures in fiber posts (2%) or in luting cement (2%). Although there were some exceptions, Panavia F and ParaPost cement specimens mostly fractured through the cement/dentin interface without any noticeable difference between thin and thick cement layers (Fig. 5). On the contrary, specimens with thick layers of SuperBond demonstrated a propensity to either fracture into the post or the luting cement. Most specimens of Unicem Rely X applied in thicker cement layers exhibited mixed fractures (Fig. 6).

Discussion

It is generally accepted that bonding endodontic posts to root canal dentin can improve the distribution of forces applied along the root, thereby decreasing the risk of root fracture and contributing to the reinforcement of the remaining tooth structure.[2,23] As reported by Robbins *et al*,[1] a well-adapted, passively cemented fiber post is considered the most retentive with the least stress generated on the canal walls.[2]

The push-out tests were performed on the most coronal section of each tooth (*e.g*. the more apical slab was prepared at a maximum of 6 mm below the cementum-enamel junction) to avoid the risk of reduction in bond strength with proximity to the apex due to morphological and access problems. This portion of the root is also likely to show large variations in cement thickness because the shape of the canal of canines and mandibular premolars varies from elliptic at the coronal level to round at the apical foramen.[7]

Except for the ParaPost Cement, the results confirmed the

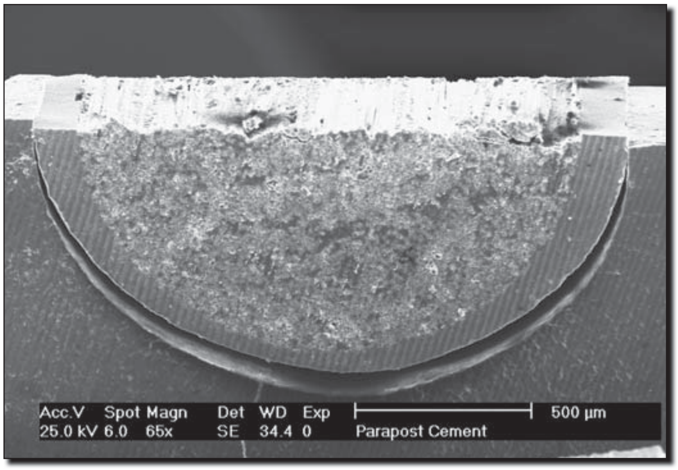

Fig. 5. SEM-photomicrograph of a ParaPost Cement specimen after testing (orig. mag. x65). The failure occurred at the luting cement-dentin interface. Cement thickness is approximately 170µm.

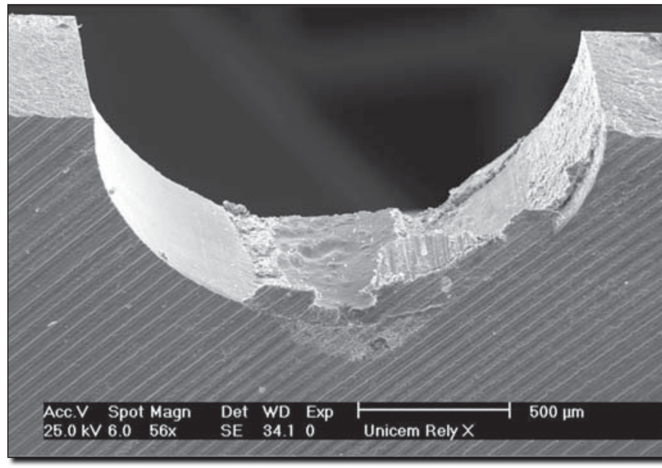

Fig. 6. SEM-photomicrograph of a Unicem Rely X specimen after testing (orig. mag. x56). The failure mostly occurred at the luting cement-dentin interface although areas of mixed failure were also observed.

superiority of the self-curing luting cements over the dual-curing cement (Table 1). This result is in agreement with previous reports[15,21,24] which showed that chemically cured composites generate less polymerization shrinkage stress and exhibit more flow than photocured and dual-cured resins. Surprisingly, the Rely X Unicem self adhesive luting cement gave similar push-out bond strengths to those obtained with SuperBond which rely on a more complicated application procedure. This finding is essentially in agreement with previous reports[25,26] which demonstrated the good bonding properties of Rely X Unicem when applied to dentin.

The adaptation of the endodontic posts inside the root canals was further evaluated using the image analysis test. Although most posts were correctly adapted to the canal walls with a mean cement thickness of 130 µm (as calculated from surface area measurements), the results indicate that thicker films of luting cement were also produced. For all materials, surface areas of luting cement ranging between 0.2 and 2.5 mm^2 were measured. Such large surface areas do not necessarily imply that the luting cement was uniformly distributed around the post but can be explained by the extrusion of the resin cement into the anatomical irregularities observed inside the root canal (Fig. 1). Calculations made to convert surface areas of luting cement into cement film thickness indicate that resin films varied between 50 µm (0.2 mm^2) and 490 µm (2.5 mm^2). A recent histological study[27] reported that the thickness of zinc-phosphate cement films observed around different types of prefabricated posts did not exceed 60 µm. In comparison, the thicker cement layers observed in this study could be explained by the high viscosity of resin-based luting cements and might reflect the difficulties clinicians have to perfectly reposition the post into the canal space filled with unpolymerized resin. These latter findings are essentially in agreement with a previous study[7] which showed that cement thickness around prefabricated fiber posts can vary between 130 and 610 µm.

A secondary outcome of the current study was the lack of strict correlation between the push-out bond strength measurements and the thickness of the luting cement. In the presence of thick layers of luting cement, an increase in bond strength is expected because thicker layers have better potential to compensate for high C-factors by increasing the unbonded surface area and permitting more stress release by resin flow.[28,29] On the contrary, the results of the current study indicate that when the surface area of luting cement increased from 0.6 mm^2 to 1.2 mm^2, a minor reduction (10-15%) but not an increase in push-out bond strengths was observed (Fig. 4). Therefore, it is assumed that the adhesion of luting cements inside the root canal not only rely on cement thickness and cavity configuration. A previous report[17] showed that other parameters such as the amount of volumetric shrinkage of the luting cement, the elastic moduli of the intraradicular dentin and the contribution of air voids within the luting cement are all likely to influence this result. The lack of relationship between bond strength and cement thickness could also be explained by the high variations observed among the specimens cemented with comparable thicknesses of luting cement. As previously reported,[30] canal walls after post space preparation exhibited large areas covered by smear layer and other debris which might interfere with the adhesive cementation of fiber posts. The adverse effects of some endodontic solutions (NaOCl, EDTA) on the bond strengths of adhesive cements to root dentin have been also reported.

Although a high percentage of specimens failed adhesively during testing (Table 2), SEM observations also indicated that either the luting cement, the root dentin or the fiber post were all likely to fracture. It is not surprising considering that the load applied to this assembly (*e.g*. dentin, cement and post) generated severe stress concentration at the luting cement-dentin and luting cement-post interfaces. A recent FEA analysis[32] demonstrated that the stress accumulation at the post-luting cement interface is likely to initiate debonding through brittle crack propagation from the top of the cement layer downward along the post surface. Furthermore, the deformation of the fiber post under load might have exerted some additional resistance to its dislodgment, thereby increasing stress concentration inside the luting cement and the root dentin. Others[22] have argued that when endodontic posts are perfectly bonded, more stress is transfered to dentin instead of being concentrated at the interface. These factors could explain the multiple fracture patterns observed after testing.

Within the limitations of the current study, it was shown that the SuperBond self-curing luting cement performed better than the other materials tested. Although there were large variations in cement thicknesses, the cementation of endodontic fiber posts with thicker cement layers did not affect the performance of the adhesive luting cement applied to root canal dentin.

a. MicroMega, Geneva Switzerland.
b. Maillefer Instruments, Ballaigues, Switzerland.
c. 3M ESPE, St. Paul, MN, USA.
d. Kuraray Co., Ltd, Osaka, Japan.
e. Coltene-Whaledent, Alstätten, Switzerland.
f. Sun Medical, Tokyo, Japan.
g. Buehler Ltd., Lake Bluff, IL, USA.
h. Fischione Instruments Inc., Evry, France.
i. Struers, Birmensdorf, Switzerland.
j. Carl Zeiss AG, Oberkochen, Germany.
k. Scion Corporation, Frederick, MA, USA.
l. John Chatillon & Sons, Greensboro, NC, USA.

Dr. Huber is in private practice in Neuchatel, Switzerland. Dr. Cattani-Lorente is Lecturer, Division of Dental Materials and Dr. Shaw is Clinical assistant, Division of Cariology and Endodontology, School of Dental Medicine, University of Geneva, Switzerland. Dr. Krejci is Professor and Chair, Division of Cariology and Endodontology and Dr. Bouillaguet is Associate Professor, Endodontic Course Director, Division of Cariology and Endodontology, School of Dental Medicine, University of Geneva, Geneva, Switzerland.

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