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Bonding of fibre-reinforced composite post to root canal dentin

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KEYWORDS
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Summary *Objective*. The aim of this study was to determine bonding properties of two types of fibre-reinforced composite (FRC) posts cemented into root canals of molars. Serrated titanium posts served as reference.

Methods. Prefabricated carbon/graphite FRC posts with cross-linked polymer matrix and individually formed glass FRC posts with interpenetrating polymer network (IPN) polymer matrix were compared. The crowns of extracted third molars were removed and post space (diameter: 1.5 mm) was drilled, etched and bonded. The posts were treated with dimethacrylate adhesive resin, light-polymerized and cemented with a dual-polymerizing composite resin luting cement. After thermocycling (6000×) the samples were cut into discs of thicknesses: 1, 2 and 4 mm ($n=12$/group). Push-out force was measured by pushing the post from one end. Assessment of failure mode was made under a stereomicroscope (1, adhesive failure between post and cement; 2, cohesive failure of post-system; 3, adhesive failure between cement and dentin).

Results. The push-out force increased with increased height of dentin disc in all groups (ANOVA, $p<0.001$). In the 4 mm thick dentin discs the individually formed glass FRC posts showed highest push-out force and the difference to that of the titanium posts was significant (ANOVA, $p<0.001$). The other differences were not statistically significant. None of the individually formed glass FRC posts showed adhesive failures between the post and the cement.

Conclusions. Contrary to the other posts, there were no adhesive (post-cement) failures with the individually formed glass FRC posts, suggesting better interfacial adhesion of cement to these posts.

Introduction

The development and use of fibre-reinforced composite (FRC) root canal posts has increased rapidly over the last 10 years. Many attempts have

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been made to develop a FRC post with appropriate characteristics for functioning as a homogenous and biomechanically suitable structure in an endodontically treated tooth. [1] The most frequent mode of failure with posts made of metal alloys has been found to be loss of retention of the post, while root fracture is still the most serious type of failure. [2] Many investigations have been made to increase the attachment of the post to the dentin, to the luting cement and to the core material for example by developing the post material, [3] the design of the post [4-7] and the surface treatment of the post. [8-10] A problem with the material of commonly used prefabricated FRC posts is that the polymer matrix between the fibres is highly cross-linked and due to the high degree of conversion nonreactive, which makes it very difficult to bond the prefabricated FRC posts to composite resin cement and tooth structure. [11] With a novel FRC material, [12] which consists of continuous unidirectional E-glass fibres and a multiphase polymer matrix, studies have shown increased bond strength between FRC material and composite resin compared to prefabricated FRC material or other cross-linked composite resin. This was based on the semi-interpenetrating polymer network (semi-IPN) polymer matrix of this FRC material. In the semi-IPN structure, there are both linear polymer phases and cross-linked polymer phases. The monomers of the adhesive resins and cements can diffuse into the linear polymer phase, and by polymerization form an interdiffusion bonding. [13,14]

Because bonding of the FRC root canal post to a root depends on the adhesion of luting cement to the post and to the root canal dentin, the aim of this study was to determine bonding properties of two types of FRC posts to root canal dentin. The hypothesis was that individually formed glass FRC post gives better bonding to root canal than prefabricated FRC post.

Materials and methods

Human third molars were extracted and stored for 1 week in chloramine (0.5%) and after that in 0.9% NaCl w/v in a refrigerator at +8 °C for 3-6 months until preparation. Teeth selected for the study, were intact and cariesfree. The crowns of the teeth were removed at the cemento-enamel junction by grinding (grit 180 FEPA, Federation of European Producers of Abrasives) and post space preparation was made with Parapost drills (diameter 1.5 mm) to the thickest root of the tooth. The post space was etched for 15 s with 35% phosphoric acid (Ultra-Etch; Ultradent, South Jordan), washed thoroughly and lightly air dried. The post space was painted and scrubbed for 20 s with EBS Multi Primer (ESPE, Seefeld, Germany). After lightly air drying, the post space was painted with EBS Multi Bond (ESPE, Seefeld, Germany) for 20 s, air dried and light-cured (axially towards the end of the root) for 20 s, according to the manufacturer's instructions. A light-curing device (Optilux 501, Danbury, USA) with a halogen lamp radiating blue light (wavelength ranging between 500 and 700 nm) and with an intensity of 780 mW/cm^2 (Optilux 501, Danbury, USA) was used. When taking out the light-curing resin impregnated continuous unidirectional E-glass fibre reinforcement (everStick®, Stick Tech Ltd, Turku, Finland) from the package, it was individually formed by hand into cylindrical post shape. These posts contained a semi-IPN polymer matrix after light polymerization and are referred as individually formed FRC posts in this study. After that the three different types of posts (Table 1) were treated with light-polymerizable dimethacrylate monomer resin consisting of BisGMA and TEGDMA (Stick™ Resin) for 3 m protected from light. After gently air-drying, the posts were light-cured for 40 s on two sides of the posts. The posts were cemented with a dual-curing composite resin

Table 1 The studied posts.

Brand	Manufacturer	Type of post	Surface	Fibre	Polymer matrix	Mean post diameter (mm)
everStick®	Stick Tech Ltd, Turku, Finland	Individually formed	Smooth	Glass	IPN[a]	1.55
C-Post	Bisco, Inc., Schaumburg, USA	Prefabricated	Smooth	Carbon	Cross-linked[b]	1.40
ParaPost® XP	Colténe/Whaledent, Inc., Mahwah, USA	Prefabricated titanium post	Serrated			1.50

[a] Semi-interpenetrating polymer network of PMMA (Polymethylmethacrylate, Mw 220.000) and BisGMA (2.2-bis [4-(2-hydroxy-3-methacryloxypropoxy)phenyl] propane).
[b] Epoxy resin matrix.

cement (Compolute Caps Cement, ESPE, Seefeld, Germany) into the prepared post spaces of the roots. The cement was light-cured (in 45° angle, close to the root of the post) for 40 s. After leaving the samples for further polymerization for half an hour, they were stored in water (37 °C). After 26 days the samples were thermocycled in water (6000×, 5/55 °C, dwelling time of 30 s).

Prior to testing the samples were wet ground (grit 180 FEPA, Federation of European Producers of Abrasives) into discs of different thicknesses: 1, 2 and 4 mm (±0.15 mm) ($n=12$ for each disc thickness and each post type) and stored in water (37 °C) for 3-5 days. From one tooth only one disc was made.

The push-out force was measured by pushing the post from one end using a universal testing machine (Lloyd LRX, Lloyd Instruments Ltd, Fareham, UK) with a custom-made jig and a cross-head speed of 1.0 mm/min (Fig. 1). The force at the point of interfacial failure between the post, cement and dentin was observed from the loading curve. The force (Newton) required to debond the post from the dentin disc was registered for all posts.

Assessment of the failure mode was made by two independent operators under a stereomicroscope (Wild M3B, Heerbrugg, Swizerland) and the samples were divided into groups according to the failure mode: 1, adhesive failure between post and cement; 2, cohesive failure of post-system; 3, adhesive failure between cement and dentin (Fig. 2).

A scanning electron microscope (SEM) (JSM 5500, Jeol Ltd, Tokyo, Japan) was used for microscopic examination of the fracture surfaces of each post type after the loading test. SEM photomicrographs were taken for the visual analysis.

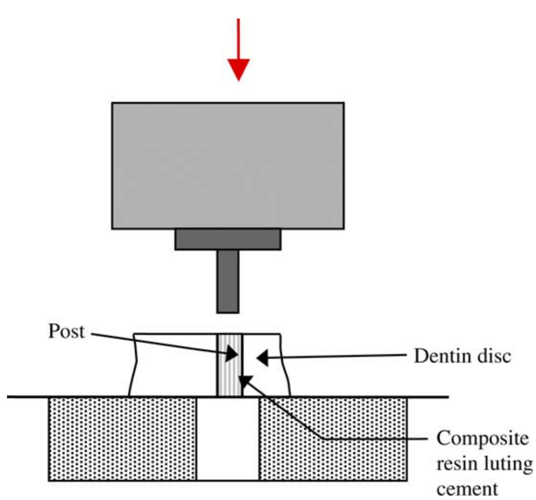

Figure 1 A drawing of the custom-made jig (cross-head speed of 1 mm/min) for measuring the push-out force (arrow).

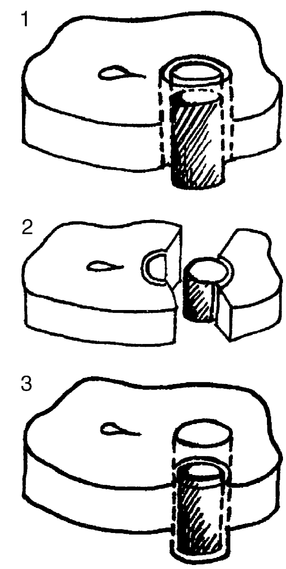

Figure 2 A schematic drawing of the three failure modes: 1, adhesive failure between post and cement; 2, cohesive failure of post-system; and 3, adhesive failure between cement and dentin.

The data was subjected at first stage to ANOVA and subsequent comparisons between post groups were performed with Dunnett T3 Post Hoc Tests. The level of statistical significance was considered to be 0.05.

Results

ANOVA revealed that both the type of post and the height of dentin disc had a significant effect ($p=0.030$ and $p<0.001$, respectively) on the push-out force. The push-out force increased with increased height of dentin disc in all groups (Fig. 3) (Table 2). The individually formed glass FRC posts showed highest push-out force (393.6 N) in the 4 mm thick dentin discs and the difference to that of

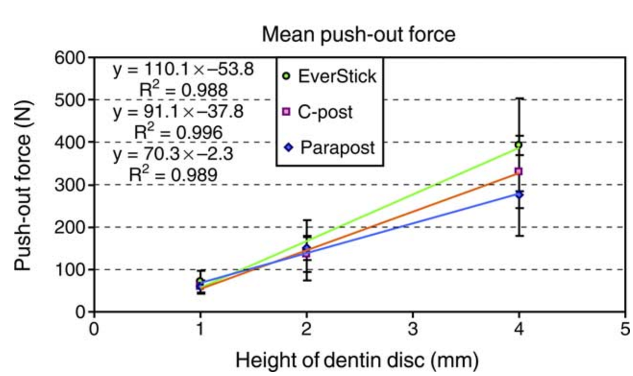

Figure 3 Mean push-out forces in Newton (N) with regression lines and standard deviations (vertical lines) for studied posts.

Table 2 Mean push-out forces in Newton (N) and standard deviations (SD) for studied posts.

Brand	Type of post	1 mm disc Force (N) (SD)	2 mm disc Force (N) (SD)	4 mm disc Force (N) (SD)
everStick®	Individually formed glass FRC post	70.3 (26.9)	145.2 (70.4)	393.6 (108.4)
C-Post	Prefabricated carbon/graphite FRC post	59.5 (13.4)	135.3 (40.5)	329.9 (84.2)
ParaPost® XP	Prefabricated titanium post	59.8 (13.6)	150.7 (28.3)	275.0 (94.9)

the titanium posts was statistically significant ($p < 0.001$). The differences between the other posts were not statistically significant. In the assessment of the failure mode under a stereomicroscope it was found that none of the individually formed glass FRC posts showed adhesive failures between the post and the cement, whereas 55% of the prefabricated carbon/graphite FRC posts and 70% of the titanium posts showed either complete or partial adhesive failure between the post and the cement (Table 3). The individually formed FRC posts failed mostly cohesively (56%) and adhesively between the cement-dentin interface (30%) or in a mixed way of these two modes (14%). In the 4 mm thick dentin discs neither the titanium nor the prefabricated carbon/graphite FRC posts showed any cohesive failures as did the individually formed glass FRC post. The SEM analysis confirmed the results (Figs. 4, 5 and 6).

Discussion

In this study bonding of two different FRC posts to root canal dentin discs was investigated. Various thicknesses of root canal dentin discs were tested to evaluate if some of the posts could be attached to thinner discs, which would clinically mean that shorter posts could be used. Obviously, this is relevant only in terms of vertical debonding forces because a short post, even though well bonded and attached may provocate root fractures. On the other hand, one should note that in some studies, the use of FRC posts has been justified by their isoelastic properties resembling those of dentin. This could allow their use also in shorter post lengths without provocating root fractures.

In the case of bonding composite resin luting cement to a FRC post of cross-linked nature, the surface of the post is well polymerized and little if any reactivity is left for free radical polymerization bonding and therefore, no actual chemical bonding is taking place. When the FRC post with the semi-IPN polymer matrix is bonded with composite resin luting cement, the interdiffusion bonding can take place. The FRC material with the semi-IPN polymer matrix used in this study (everStick®, Stick Tech Ltd, Turku, Finland), consisted of both linear and cross-linked polymer phases. The linear phase in this material, which is Polymethylmethacrylate (PMMA), can be dissolved if a suitable adhesive resin is added on the surface of the post. The suitable adhesive resin should contain monomers, having dissolving parameters equal or close to that of PMMA. BisGMA based adhesive resins have been shown to be capable of dissolving PMMA.

When bonding composite resin luting cement to the metal post, which in this study was used as reference, the surface serrations were mechanically interlocked to the composite resin luting cement of the surface of the post. In this study the titanium posts, as well as the other posts, were treated with dimethacrylate resin. This may have negatively influenced the ability of the surface serrations to interlock the cement to the post surface. According to an earlier study made with similar post materials bonded to composite discs without an intermediate resin layer on the post surface, the titanium showed highest force values compared to FRC posts with a semi-IPN polymer matrix or with cross-linked polymer matrix. [15] In that study, pull-out force was measured, instead of using push-out force measurement, which might have influenced the bonding force values. It has

Table 3 The results of failure mode assessment.

	Adhesive failure between post-cement interface (failure mode = 1) (%)	Other failure mode (failure mode = 2, 3 or mixed) (%)
Titanium post (ParaPost® XP)	70	30
Carbon FRC post (C-Post)	55	45
Individually formed glass FRC post (everStick®) (%)	-	100

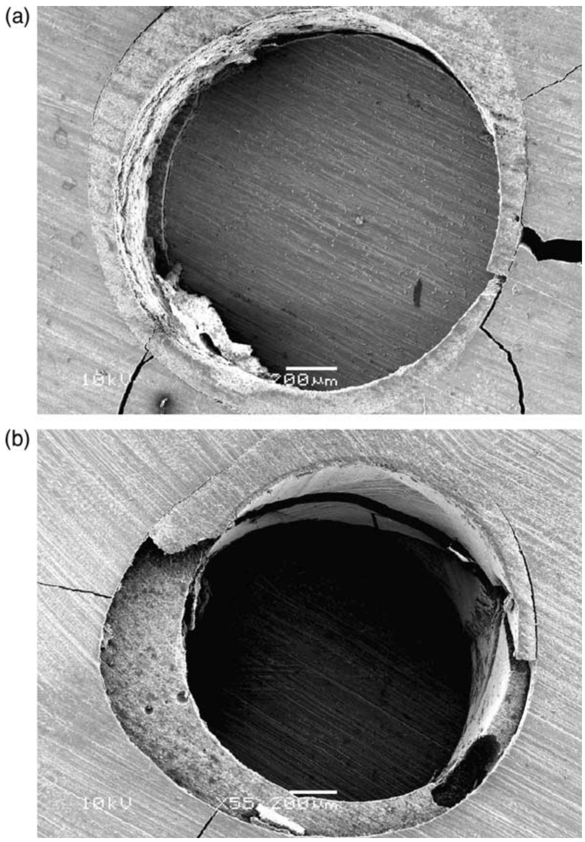

Figure 4 SEM-photomicrographs of typical failure modes of the titanium post (Parapost® XP) after the loading test (original magnification $\times$55, bar = 200 μm). (a) Adhesive failure between post and cement (failure mode = 1), (b) adhesive failure partly between post and cement, partly between cement and dentin (failure modes = 1, 3)

been shown that the push-out force test is more sensitive to the thickness of the disc than is the pull-out force test. [16]

In a study by Ferrari et al. [17] it was found that different areas of the same root canal did not respond equally to acid etching and therefore, dentin bonding ability may be different at different depths of the same root canal. Also anterior teeth behaved in a different way than did molars to acid etching in their study. Therefore, there may be variations in bonding ability also depending on what kind of teeth and what area of the root canal space is used. In this study, third molars were used and the area of root dentin used for bonding was similar to the area that is used clinically when bonding posts. The posts were placed into the drilled post spaces and when the different heights of discs were ground, effort was made to use the most homogenous area of the root in order to get a more solid and homogenous area for cement space.

The push-out force values for C-Post and Para-Post® XP increased linearly when the height of the dentin discs increased, while the increase of bonding force values of everStick® post was non-linear. This finding suggests that mechanically and friction attached posts increased the push-out force in direct relation to surface area. On the contrary to this, posts with better adhesion i.e. interdiffusion bonding, may form a root-post system in which debonding stress is more evenly distributed and less shear stress is formed at the interphase of dentin and post. This may have led to higher push-out forces with thick dentin discs.

This study showed that although the force at the point of failure was equal, the failure mode and sight on the samples were different. This is important because it indicates the quality of bonding between post and cement–dentin and therefore, it can apparently influence the clinical longevity of a post-system. The load bearing capacity is not only related to the strength of

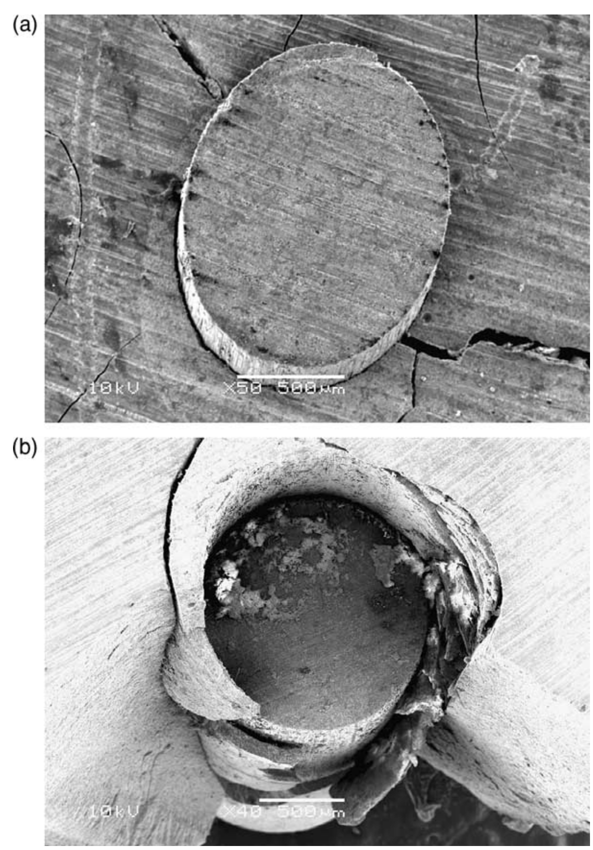

Figure 5 SEM-photomicrographs of typical failure modes of the carbon FRC post (C-Post) after the loading test (original magnification $\times$50 and $\times$40, bar = 500 μm). (a) Adhesive failure between post and cement (failure mode = 1), (b) partly adhesive failure between post and cement, partly cohesive failure (failure modes = 1, 2).

(a)

(b)

Figure 6 SEM-photomicrographs of typical failure modes of the individually formed glass FRC post (everStick®) after the loading test (original magnification $\times 50$ and $\times 45$, bar = 500 μm). (a) Adhesive failure between cement and dentin (failure mode = 3), (b) cohesive failure (failure mode = 2).

the adhesive interfaces, but also to the design of the post system in simulating the structure of tooth.

The bond strength and integration between luting materials, root dentin and FRC posts have been studied through push-out tests and SEM-images before. In these studies the importance of the homogenity and integration between the materials (dentin, post, luting cement and core composite) were emphasized [18,19].

Conclusions

There was almost no difference in push-out force between the posts, only in the 4 mm thick dentin discs the individually formed glass FRC post showed statistically higher push-out force compared to the titanium posts. However, contrary to the other posts, there were no adhesive (post-cement) failures with the individually formed glass FRC posts, suggesting better interfacial adhesion of cement to these posts.

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