The effect of cyclic loading on fiber-reinforced resin post retention: push-out bond strength

ABSTRACT

Objective. To compare the micro push-out bond strength and mode of failure of a fiber-reinforced resin post cementing with a dual-cured resin using extracted human teeth, with and without simulated occlusal loading. Methods. Single-rooted, extracted human teeth were root canal–treated and divided into two groups of 16, by stratified, random sampling. The teeth were decoronated, and a prefabricated fiber-reinforced resin post was cemented in each using an ED primer. A layer of silicon sealant was painted over the root surface to about 2 mm below the cemento-enamel junction to simulate the periodontal ligament. Then, each tooth was embedded into an acrylic resin and secured in a jig so that it formed an angle of 135 degrees with a loading stylus (inter-incisal angle). The specimens were cyclically loaded up to 70 N for a total of 120,000 cycles. Then, the roots were retrieved and sectioned into slices of about 1 mm thick. Push-out tests were performed at a cross-head speed of 1 mm per minute in a universal testing machine. The data were analyzed using one-way analysis of variance or two-sample t tests as appropriate, at an alpha level of 0.05. Results. No significant difference was found in the micro push-out bond strength at various levels of the root canal for loaded and unloaded groups (analysis of variance, P>0.05). The loaded group demonstrated significantly lower bond strength (5.2 ± 3.0 MPa) compared with the non-loaded specimens (12.9 ± 5.0 MPa; P<0.05). Conclusion. The micro push-out bond strength of a fiber-reinforced resin post cementing with an ED primer was not influenced by the depth of the post space, but the value decreased after simulated occlusal loads.

Key words: Composite resins; Dental bonding; Dental materials; Tensile strength

Introduction

Endodontically treated teeth are regarded as more brittle (i.e. more prone to fracture) than vital teeth 1. Their strength is often jeopardized by pre-existing loss of tooth structure due to caries, trauma, or other conditions necessitating root canal therapy. Root canal posts are often required for their restoration. This is also an area where endodontists meet the prosthodontists in their fight for space to optimize treatment success. The aims of this paper were: (i) to provide a brief summary of concerns for post-endodontic restorations, and (ii) to examine the effect of occlusal loading on the retention of post-and-cores with dual-cured dentin adhesive cement.
Cyclic loading of fiber-reinforced resin post

Strength of a tooth

It has been shown that the loss of one or more marginal ridges can lead to the reduction of fracture strength for posterior teeth. On the other hand, endodontic procedures on an otherwise intact premolar resulted in a 5% reduction in cuspal stiffness, in contrast to a greater reduction for a MOD cavity preparation (a 63% loss of stiffness on average).

The dentin itself had been considered to be weakened by the loss of water following pulp extirpation, although others failed to confirm any significant loss of dentin moisture content after endodontic treatment. The loss of collagen cross-linking is probably due to the action of the metalloproteinase enzymes released after disintegration of pulp soft tissue. The loss of neural stimuli from the pulp might alter the sensory input to occlusal loads, so that root canal–treated teeth could become overloaded and fractured, before the patient perceives excess loads placed on the tooth.

Chemical agents used during root canal treatment can have an impact on the physical properties of dentin. Ethylenediaminetetraacetic acid (EDTA) could deplete the inorganic content of dentin, while calcium hydroxide and sodium hypochlorite (NaOCl) digest the organic content. The alternate use of NaOCl and EDTA can progressively remove organic and inorganic materials of the root dentin substrate, reducing its micro-hardness. The flexural strength of dentin may be reduced by the use of calcium hydroxide or 3 to 5% NaOCl. This calls for judicious use of concentrated irrigating agents and extra long-term use of calcium hydroxide dressings.

Root canal post

A root canal post is required for the teeth, with remaining dentin being insufficient to provide resistance or retention for the final restoration. Posts are available in various shapes, configurations and dimensions. Traditionally, they were metallic, either prefabricated or cast, and were cemented with either zinc-phosphate or glass ionomer cements. There are esthetic concerns with metallic posts, as well as an unrestorable mode of fracture if this should ensue. Nowadays, fiber-reinforced resin posts are gaining popularity. Having a modulus of elasticity similar to that of dentin is advocated as an advantage of fiber-reinforced resin posts, allowing them to flex slightly and mimic tooth movement upon functional loading. Another often-quoted advantage of fiber-reinforced resin posts is the ability to bond to dentin with adhesive resin cement. This is thought to mediate a union between the fiber-reinforced resin post and the tooth substance, providing reinforcement to the root and reducing the chance of root fractures. Clinically, a reduced amount of tooth and/or root fracture has been reported whenever the tooth is restored with a fiber-reinforced resin post, compared with a similarly restored tooth without a post. Should fracture occur, the fiber-reinforced resin post tends to break leaving the remaining root intact.

In addition to providing retention, root canal posts should play a role in preventing microleakage by limiting micro-movement at the margins of the coronal restoration due to occlusal loads; such micro-movement being a likely precursor of coronal leakage. Re-infection of the root canal system through a breakdown of the coronal seal can lead to failure of endodontic treatment. Thus, some authors consider the flexible nature of fiber-reinforced resin posts a disadvantage.

Cavity configuration factor (C-factor), being the ratio of the bonded to unbonded surface area of a cavity, is an important consideration for dentin adhesion. During polymerization of the resin cement, material at the unbonded surface can move and flow, thereby relieving the shrinkage stresses. However, as the unbonded surface area contracts, there is insufficient stress relief and a high probability for one or more bonded surfaces to debond, thus succumbing to shrinkage stress in the material. For the root canal, the C-factor is extremely high such that it could exceed a value of 200. To reduce the effect of the problem, the use of a slower-setting material may be advantageous. This concept was supported by a study that two chemically cured cements (C&B Metabond [Parkell Inc., USA] and Fuji PLUS [GC America Inc., USA]), with a longer setting time than dual-cured cement, showed a lower incidence of spontaneous cementation failure during specimen preparation.

The luting procedure is an important and critical aspect in the use of fiber posts. The majority of the clinical failures of teeth restored with fiber-reinforced resin posts occur by debonding.
The viscosity of the cement are important factors that may affect bond strength values and the complete setting of the post in the canal. It was previously reported that a uniform and favorable distribution of the cement layer could be obtained by using the lentulo spiral. Voids and bubbles formed during the application of the luting cement could impede the proper cementation of the post, which might cause debonding as a sequel. Several authors recommended the use of a lentulo spiral or an injection technique to apply the cement into the post space. The use of such an injection technique followed by the use of lentulo spiral for 4 seconds has been recommended, as it exhibits increased retention of the post. By contrast, D’Arcangelo et al. exhibited no difference in the retention of fiber-reinforced resin post systems despite application of these techniques.

From a review of the literature there seems to be a conflict between the desire for a flexible post and maintaining a crown margin free of micro-movement (and hence microleakage) during functioning. There is a scarcity of reports on the effects of functional loads on the retention provided by adhesively cemented fiber-reinforced resin posts. With that in mind, an experiment was devised to examine the retention of a tooth-colored fiber-reinforced resin post retained with chemically cured adhesive cement and the effect of simulated occlusal loads.

Methods

In all, 120 recently extracted, single-rooted human maxillary and mandibular teeth, including central and lateral incisors, canines and second premolars, were collected and stored in 1% chloramine-T solution. Teeth with root caries, hypoplasia, non-carious cervical cavities, any pre-existing restorations, root canal treatment, calcified canals, crack lines (examined under an operating microscope), open apices, and resorptive defects were discarded. Only those with an oval-to-round canal were chosen. Thus, for this study the total number of teeth was 32. They were immersed in 6% NaOCl solution (Clorox, Oakland [CA], USA) for 3 minutes to facilitate removal of the organic remnants from the root surfaces. An ultrasonic scaler was used to remove any hard deposits. The mesiodistal and buccolingual diameters at the cementoenamel junction (CEJ) of each tooth were measured, using a pair of calipers (Digimatic caliper; Mitutoyo, Hants, UK) and appropriately taken radiographs. The specimens were divided into two groups with 16 in each, using stratified random sampling so that the teeth in both groups had similar overall dimensions.

The selected teeth were decoronated using a diamond disc (Horico; Hopf, Berlin, Germany) under continuous air-water spray cooling at a level 1.5 mm coronal to the cementodentinal junction. Root canal treatment was performed at a working length, which was 1 mm short of the canal length (distance at which the tip of a size 10 K-file was seen at the apical foramen), using the ProTaper rotary system (Dentsply Maillefer, Ballaigues, Switzerland) at 250 rpm up to the F4 instrument. Canals were irrigated with 6% NaOCl and their patency checked after use of each rotary file. The final rinse consisted of 3 mL of 17% EDTA followed by 3 mL deionized water. All irrigants were delivered into the root canals using a 28-gauge end-exiting needle and a 3 mL syringe. All canals were obturated using the warm vertical compaction of gutta-percha with an AH Plus sealer (Dentsply Maillefer).

A post space (approximately 9 mm deep) was left after the down-pack. After 24 hours the post space was refined using proprietary drills of a fiber-reinforced resin post system (Radix fiber post; Dentsply Maillefer). The post was pre-fitted according to the manufacturer’s recommendations. After a trial, it was wiped with alcohol and air-dried. Then, the post hole was thoroughly rinsed with 3 mL 6% NaOCl, followed by 3 mL deionized water and finally 3 mL chlorhexidine, before it was dried with paper points.

The procedures for cementation of the post were the same for both groups. Equal amounts of ED Primers A and B (Panavia F 2.0; Kuraray, Okayama, Japan) were mixed in a dappen dish with a micro-brush. Two consecutive coats were applied on the post and into the post space. Excess primer was removed from the post hole using a paper point, followed by a gentle flow of air from a 3-in-1 syringe directed horizontally across the incisal/occlusal surface. Then, equal amounts of paste A and B (Panavia F 2.0) were mixed according to the manufacturer’s recommendations and applied into the post hole using a lentulo spiral as well as onto the post. The post was inserted with a smooth, steady motion and held in position with firm finger pressure for 5 minutes. Excess cement was removed using a No. 15 scalpel blade (Paragon, Sheffield, England) and a curing light was directed from the top of the post for 40 seconds. A core
build-up was performed using a dentin adhesive (All-Bond 2; BISCO, Schaumburg [IL], USA) and a composite resin material (Estheti-X; Dentsply DeTrey, Konstanz, Germany). The composite material, in not more than 2-mm thick increment, was syringed directly around the post and adapted to the shape with a plastic instrument. Each increment was light cured for 20 seconds. The final height of the core build-up was 5 mm with a stepped platform (2 mm wide and 2 mm tall) on the palatal surface, which was to be the site for load application for the loaded group.

Simulated occlusal loading

Prior to loading, a layer of silicon sealant was painted over the root surfaces to about 2 mm below the CEJ (on the buccal aspect), so as to imitate the periodontal ligament. The root portion was then embedded in a self-cured acrylic resin (Rapid Repair; Denstply DeTrey, Konstanz, Germany) to the same level of the silicon sealant, in order to simulate the crestal bone. As shown in Figure 1, the embedded tooth was secured in a holder to produce an ‘interincisal’ angle of 135 degrees with the loading stylus. Each specimen was cyclically loaded up to 70 N for a total of 120,000 cycles. After the cyclic loading, each specimen was inspected for the silicon layer intactness (under x 2.5 magnification) for signs of root fracture with the aid of a sharp probe. If such signs were evident, the specimen was discarded.

Micro push-out bond strength

All specimens were embedded in an acrylic resin (Rapid Repair) and then sectioned horizontally into slices (approximately 1 mm thick), with a microtome (SP-1600; Leica Microsystems, Wetzlar, Germany) using a 340-µm thick blade. The specimens were fed at a rate of about 50 µm per minute to avoid disruption of the cement lute. The first cut was made at the junction of the ferrule and the core material, i.e. at the top of the post hole. Depending on the length of the post, some five to six slices were obtained, from the top of the ferrule until the entire length of the post was included. The coronal side of each slice was marked for identification with an indelible marker.

For each specimen, the diameter of the post along the buccal-lingual (X-axis) and mesial-distal (Y-axis) on both coronal-facing and apical-facing surfaces were measured using a traveling microscope (Laour-Lux 12 MES; Leitz, Wetzlar, Germany). The thickness of the luting cement was similarly measured at the locations where it was noted to be thickest and thinnest. The thickness of each slice was measured to a precision of 0.01 mm, using a digital caliper. In turn, each slice was then placed on the platform of a universal testing machine (Instron; Testometric, Rochdale, UK) with the coronal surface facing down. For the various slices, plungers were custom-made to be 0.2 mm smaller in diameter than the post. Care was taken to center the plunger onto each cross-section, to avoid contacting the surrounding dentinal wall. Force was applied, with a cross-head speed of 1 mm per minute, until the post was completely dislodged from the tooth substance.

All debonded specimens were inspected using the traveling microscope (Laour-Lux 12 MES) to determine the mode of failure, based on the following classification: adhesive failure between the post and the luting material was termed type 1; adhesive failure between dentin and the
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Results

For all the specimens, the silicon layer was intact and no breakdown or deformation was noted. The core build-up for all the specimens was intact after loading, and no debonding, defects or fractures were observed in the tested samples. It has been shown that the teeth restored with fiber-reinforced resin post, core and a crown revealed micro-movement after loading, which leads to leakage [35]. Thus in this study the loads were directly applied to the cores to determine whether the loading affected the integrity of the core build-up itself [38].

Mean bond strength values

The mean bond strength values for various horizontal slices with and without loading are shown in Table 1. There was no significant difference in bond strength at different levels of the canal in both groups (P>0.05), although the value tended to be greater for coronal than the apical sections (Table 2). The data were pooled to examine the difference between the groups. The loaded group yielded significantly lower mean bond strength than the non-loaded group (t test; P<0.001). Adhesive failures (types 1 or 2) were the most commonly observed modes of failure (Table 2). There seemed to be a slight shift towards more type 4 and 5 failures after simulated occlusal loading, but the difference was not statistically significant (Chi squared test, P>0.05) [Table 2].

Discussion

A variety of experimental setups, including the pull-out, microtensile and micro-shear (push-out) tests have been used to determine the bond strength for root canal posts to the root dentin. For the pull-out technique, the post is clamped and a tensile stress is applied to dislodge it along the path of insertion. This method is liable to produce non-uniform stress distribution along the entire area of the adhesive interface [39]. Micro-tensile testing facilitates a more even distribution of stresses, due to the use of smaller-sized specimens [40,41]. However, testing the bond strength of endodontic posts using the microtensile technique is sensitive to the process of specimen preparation. The root has to be horizontally sectioned, then trimmed into small, uniform dimension slices. The applicability of microtensile tests is therefore limited. A high rate of premature failures
has been noted during specimen preparation. Micro push-out testing appears able to eliminate most of the problems with the microtensile technique for testing the retention of root canal posts. It supersedes macroscopic pull-out tests by eliminating non-uniform stresses at the adhesive interface that develop in thick sections. A compressive stress is applied on the apical end of the post, which is equivalent to pulling the post in the coronal direction. Such an experimental setup can be controlled much more easily.

Panavia F 2.0 is a resin-based, dual-cured cement that has a long track record. It contains a phosphate-based functional monomer, 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP). This molecule has been shown to chemically interact with hydroxyapatite that remains after dentin conditioning. Due to the low solubility of the MDP-calcium salt in water, this bond is expected to be stable in an aqueous environment. The cement mediates a bond of similar strength at various levels of the root canal, an observation also reported by others. On the contrary, some reported significantly higher bond strength in coronal than apical sections for both RelyX Unicem (3M ESPE, US) and Panavia F. Higher density of dentinal tubules and, hence, longer and greater number of resin tags in the coronal area, as well as better accessibility during the bonding procedure may contribute to higher bond strength in the coronal regions. In the present study, the lack of any difference in bond strength at different depths of the canal may be related to the effectiveness of the bonding technique used.

Not surprisingly, the retention of fiber-reinforced resin post decreases after repeated (functional) loading. Cyclic loads may cause microcracks to develop at the resin-dentin interface. While the origin of the crack is largely unknown, it might be related to a break in the integrity of part of the perimeter of the post, due to the high C-factor. When a post-and-core retained restoration is subjected to an oblique load (for an anterior tooth), stresses are concentrated in the coronal aspect of the post hole and micro-movements can occur at the restoration margin (especially on the palatal aspect). This results in increased leakage, demonstrable by dye penetration or using other molecules.

Other investigators have tested certain metallic posts (prefabricated stainless steel vs. cast), both cemented with Panavia F. Some failed to find an effect on bond strength due to cyclic loading but some did.

Analysis of the failure mode revealed that adhesive rather than cohesive or mixed mode failure was more common. A similar finding has been reported by others. Of the two adhesive interfaces present for root canal posts, the extent of failure observed between the post and the luting cement (type 1; Fig 1) was greater. Pretreatment of the fiber-reinforced resin posts to improve the union with the resin cement was expected to improve their retention in the root canal space. In summary, the results of our study indicated a deteriorating effect on the bond between a fiber-reinforced resin post and dual-cured resin cement.

Conclusion

Based on the limited scope of this research, we concluded that:
1. The bond strength mediated by dual-cured adhesive cement (Panavia F 2.0) is not affected by its location in the root canal.
2. Cyclic loading can have a significant influence on the bond strength between the fiber-reinforced resin post and the root canal dentin.
3. Adhesive failure is the most prevalent reason for loss of retention for fiber-reinforced resin post cemented with this brand of adhesive cement.

However, more research is required to test specimens restored with crowns under situations simulating actual clinical occlusal function (including both lateral and protrusive excursion).

References

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