Review

Laboratory assessment of the retentive potential of adhesive posts: A review

Cecilia Goracci a,*, Simone Grandini b, Maurizio Bossù c, Egidio Bertelli d, Marco Ferrari a

aDepartment of Fixed Prosthodontics and Dental Materials, University of Siena, Policlinico Le Scotte, Viale Bracci, Siena 53100, Italy
bDepartment of Endodontics, University of Siena, Policlinico Le Scotte, Viale Bracci, Siena 53100, Italy
cDepartment of Pedodontics, University 'La Sapienza', 287/A Viale Regina Elena, Roma 00161, Italy
dDepartment of Restorative Dentistry, University of Siena, Policlinico Le Scotte, Viale Bracci, Siena 53100, Italy

ARTICLE INFO

Article history:
Received 19 May 2007
Received in revised form
22 July 2007
Accepted 23 July 2007

Keywords:
Adhesion
Retention
Post
Microtensile
Push-out
Pull-out
Laboratory

ABSTRACT

Objectives: This review aimed at summarizing the laboratory evidence collected on the retentive ability of adhesive posts since their introduction in dentistry.

Data: Data were searched in articles published or in press in peer-review journals listed in MEDLINE.

Sources: Papers were retrieved through Pubmed.

Study selection: To collect the evidence of interest, the following search terms were used: bond AND fiber post AND in vitro; push-out AND fiber; pull-out AND fiber; microtensile AND fiber post. “Related Links” were also considered and articles cited in the initially retrieved papers were included if relevant. No time limit was given to the query.

Conclusions: Seventy relevant papers were reviewed. The retentive ability of adhesive posts has been tested with the microtensile technique, post-push-out and push-out tests. If small-sized specimens are obtained, such as in microtensile and thin-slice push-out, stress uniformity is favoured, local differences in bonding conditions can be discerned, and the number of teeth needed for the test can be reduced. Although adhesion to intraradicular dentin is more challenging to achieve than bonding to crown tissues, the post-retention achieved with current luting systems and techniques is adequate to ensure the clinical success of adhesive post-retained restorations. To enhance the bond at the post-core and post-cement interfaces, several chemical pre-treatments of the post-surface have been tested with positive results. Self-adhesive resin cements, recently proposed to simplify the post-luting procedure, should be investigated further with regard to durability.

© 2007 Elsevier Ltd. All rights reserved.

1. Introduction

The introduction of fiber posts has further extended the applications of adhesive dentistry in endodontics. As they are passively retained inside the root canals, fiber posts owe their dislocation resistance mainly to the luting agent and the success of the luting procedure to intraradicular dentine. Adhesive interfaces are also established between the post-surface and core material, and between the latter and residual coronal dentine.
With the constant development of new post-systems, adhesives, and composite resins for abutment build-up, research is called to continually screen new products. Although clinical trials remain the ultimate test for bonding effectiveness, laboratory research has the potential to provide first-hand information on newly launched materials.

Adhesion testing involves qualitative and quantitative assessments. In the investigation of qualitative aspects of bonding, microscopic techniques for high-resolution imaging of interfaces, such as scanning electron microscopy (SEM) and transmission electron microscopy (TEM), have found the applications. For quantitative estimation of adhesion reliability, laboratory research usually resorts to bond strength tests, based on the assumption that the stronger the bond at the tooth-material interface, the better it will resist stresses originated from setting and clinical service of the materials.1

The objective of this study was to summarize the laboratory evidence so far collected on the retentive potential of adhesive posts. A literature search was conducted including original articles published or in press in peer-reviewed journals indexed in MEDLINE. Papers were searched in the free digital archive of biomedical literature PubMed, using the following query terms: bond AND fiber post AND in vitro; lut* AND fiber post AND in vitro; push-out AND fiber post; pull-out AND fiber post; microtensile AND fiber post. Also “Related Links” were considered and the articles referenced in the initially retrieved papers were included if pertinent. No time limit was given to the query. Seventy relevant papers were reviewed.

2. Conventional shear, conventional tensile, and microtensile bond strength tests

Several bond strength tests have been developed. When fiber posts were first introduced in the 1990s,2 conventional shear and tensile tests, at that time largely employed for bond strength testing had become the object of criticism from some researchers.3-6 The limitations of these methods include the heavy dependence of recorded strengths upon experimental conditions, such as material-substrate misalignments, possibly affecting stress uniformity. Stress distribution was likely to be non-uniform anyway over a large bonded surface, in relation to the density of intrinsic faults within the substrates or at their interface, functioning as crack propagating areas. Yet, the most critical shortcoming of conventional shear and tensile tests, emerged with the advent of adhesive systems able to achieve dentine bond strengths over 20 MPa, was the frequent occurrence of cohesive dentine fractures, that prevented the assessment of interfacial strength.7

The microtensile technique for bond strength testing was thus introduced8 and credited with the potential to more closely reflect the true interfacial bond strength, the ability to measure adhesion to small surfaces, the capacity to assess local variations over the bonding substrate, and the convenience of obtaining multiple specimens from a single tooth.9 The microtensile method was originally developed for ultimate tensile strength testing of dental tissues,8 and later applied to bond strength measurements on crown dentine and enamel (Fig. 1).5,10
Fig. 2 - A schematic presentation of the specimen preparation procedures for the trimming version of the microtensile technique for testing the retention of luted posts. (a) The post-cemented root is transversely sectioned into a series of 1 mm thick slices. (b) By means of a water-cooled diamond bur, each slice is trimmed to an hourglass profile. As a result of the trimming the tensile load is concentrated at the post-cement-dentine interfaces (adapted from Goracci et al. with modifications).

For the laboratory assessment of retention of luted endodontic posts the methods initially employed were pull-out and push-out tests, with preference to the latter as being more akin to clinical conditions, according to Suda-Sangiam and Van Noort. However, when performed by loading the entire post, 13-15 or thick root sections, 16,17 push-out tests were susceptible to the criticism of generating highly non-uniform stress at the adhesive interface, that possibly accounted for the relatively low recorded strengths. 27

The microtensile method, on the other hand, also appeared promising in intraradicular dentine adhesion testing for its expected ability to measure bond strength on small surfaces and discern regional differences at the various levels of root canal walls (Figs. 2 and 3). The first applications of the technique were directed at assessing the bond strength of resin cements to root canal walls, by filling the entire dowel space with the luting agent alone. 17-22 In some tests, roots were ground longitudinally to expose the full length of the canal, thus gaining unrestricted access to intraradicular dentin in the bonding procedure, 17,20,26 or else posts custom-made out of pre-polymerized resin composite were luted. However, these tests represent simplified models, as retention of bonded posts actually involves the establishment of a complex of interfaces at the post-cement-adhesive-dentine boundaries.

When attempting to apply the microtensile technique to measure the bond strength of luted posts, either the trimming or the non-trimming variant of the method (Figs. 2 and 3) appeared to be affected by severe limitations, encompassing the number of testable specimens and data variability. 13,20,27 It was then concluded that any cutting action during specimen preparation was probably too aggressive to be borne by the relatively weak bonds established at the post-cement-dentine interfaces. 27 In addition, the non-trimming variant of the microtensile technique would find limited application to teeth with large and straight roots, such as upper central incisors and canines.

In summary, the microtensile technique can accurately assess the retention of luted posts only if measurements are not affected by numerous pre-test failures and trimming is performed in a controlled manner, by the MicroSpecimen Former developed at the University of Iowa. 1

In a recent investigation, the non-trimming microtensile design was applied to assess the retention of luted glass fiber posts. However, no information was provided whether pre-test failures are occurred. 28

Mallmann et al. 24,25 have measured the retention of luted posts by loading dumbbell-shaped specimens. These were obtained by trimming 1 mm thick root slices with a tapered diamond rotary cutting instrument and the aid of a X4 magnifying glass. The percentage of lost slices varied between 2.5 and 20.5%. 26 Although it was reported that root slices were held with finger pressure, it was not clear whether the rotary instrument was held free-hand or worked like a lathe. 26,27

3. Thin-slice push-out test

The potential of the push-out test to reliably assess the dislocation resistance of luted posts was also investigated. Particularly, a variant of the method known to materials scientists as the "thin-slice" push-out test was employed. The modification involved sectioning the posted root into a series of 1 mm thick slices, and compressively loading the post-section within each slice with an adequately sized plunger, until bond failure (Fig. 4). Root slicing was justified by the intention to favour stress uniformity by loading smaller-sized specimens. In addition, sectioning allowed the differentiation of the bonding conditions existing at different root levels. By consistently providing useful measurements with limited variability, the "thin-slice" push-out test was revealed as a more practical tool than the microtensile technique for evaluating the retentive strength of luted posts. 27

The "thin-slice" push-out test has been largely utilized in laboratories to investigate the multiple variables possibly affecting the retention of posts, such as the root canal treatments preceding post-cementation, 31-33 the timing of post-cementation, 24 post-material, 34-36 the type of adhesive and polymerization mode, 37,38 the properties of the luting agent, 39-41 and the thickness of the cement layer. 42 Also the degree of bond maturation over time 38,42 and of bond degradation under fatigue loading 43-46 have been studied with the push-out design.

It is known that comparisons among the results from different in vitro studies may be inappropriate because of the dependence of the collected data upon laboratory set-ups and experimental conditions. 1
Fig. 3 - A schematic presentation of the specimen preparation procedures for the non-trimming version of the microtensile technique for testing the retention of luted posts. (a) A composite build-up is created on the external root surface to allow for adequate specimen gripping on the loading machine. (b) As a result of two longitudinal cuts running at the post-periphery throughout its length, a root slab is created exhibiting the luted post in the center, overlaid on each side by the root dentine portion and the composite build-up (c). (d) From the slab 1 mm thick beams are serially sectioned (adapted from Goracci et al. with modifications).

Nevertheless, some findings can be reported that have been confirmed by the majority of in vitro investigations, including microtensile and push-out bond strength testing. For instance, it is generally agreed that achieving a valid adhesion to intraradicular dentine is more challenging than to coronal dentine. The preponderance of laboratory data discriminating differences in local conditions of bonding along the root canal indicates that adhesion is less predictable in the apical third. Also, failure most often occurs at the dentine-adhesive cement interface. In addition, clinicians should abstain from performing adhesive post-cementation immediately after filling the root canals with a zinc-oxide eugenol sealer, as delayed post-space preparation and cementation was found to exhibit higher interfacial strengths. Residues of unset root canal sealer moved from apical to coronal by paper points or microbrushes during the bonding procedure may contaminate the post-space walls and interfere with curing of the resin cement. When an eugenol-containing sealer was used, Baldissara et al. reported a reduction in post-retention for mechanically cycled restorations. Kurtz et al. found the eugenol-based sealer to have no influence on the push-out strength of adhesive posts cemented one-week after root canal obturation.

With regard to luting agents, there are indications that simplified self-etch and self-adhesive resin cements, such as Panavia 21 (Kuraray Medical Inc., Tokyo, Japan) and RelyX Unicem (3M ESPE, Seefeld, Germany) exhibit an etching potential insufficient to dissolve the thick smear layers created in post-space preparation with burs. The superficial interaction with dentine resulting from the limited demineralization may yield to the high shrinkage stresses developed by the thin cement layer setting within the boundaries of the dowel space. The consequent opening of interfacial gaps may account for the relatively low push-out strengths recorded for ED Primer/Panavia 21 (5.0 ± 2.8 MPa) and for RelyX Unicem (5.0 ± 2.6 MPa), as compared with the results obtained (10.2 ± 2.9 MPa) with the use of the total-etch system Excite DSC/Varilink II (Ivoclar-Vivadent, Schaan, Liechtenstein).

SEM observations revealed that Panavia 21 formed only a thin hybrid layer, with discontinuities between the adhesive layer and the underlying dentine. When using RelyX Unicem no distinct hybrid layer was seen. The cement interacted only superficially with the smear layer, that was substantially retained along with smear plugs. Gaps were visible between the smear layer and the underlying intact dentin.

Fig. 4 - A schematic presentation of the "thin-slice" push-out design for testing the interfacial strength of luted posts. (a) The portion of each root that contains the post is sectioned into five to six of 1 mm thick slices with a diamond blade under water-cooling. (b) On each slice the post is loaded by a plunger which is sized and positioned so as to contact only the apical aspect of the post on loading, introducing shear stresses along the bonded interfaces. The load is applied in an apical-coronal direction until bond failure occurs and the post-fragment is extruded from the root slice (adapted from Goracci et al. with modifications).
As the ultrastructure of the interface between root dentine and simplified resin cements was generally not suggestive of a solid micromechanical interlocking, knowing that chemical reactions are marginally involved in the adhesion mechanism of resin-based cements, the hypothesis may be raised that a contribution to fiber post-retention is provided also by sliding friction between cement and dentine along the canal walls. In order to test this hypothesis, on luting fiber posts using a total-etch or a self-etch adhesive cement (Variolink II and Panavia F 2.0, respectively), the application of the adhesive system was either performed as per manufacturer’s instructions or omitted. In the absence of any dentine hybridization, the push-out strengths were inferior, yet statistically comparable to those achieved with the proper use of the adhesives and were ascribed to the frictional behavior of the cement-coated post within the dowel space. Far from suggesting practitioners abandon the use of dentine bonding systems in the adhesive cementation of fiber posts, the significance of such findings was rather to point out that there is a greater than expected contribution of sliding friction to the reported clinical success of bonded posts.

Subsequently, any property of the luting cement favouring friction along root canal walls should be expected to enhance the post load carrying ability. Such a beneficial effect on post-retention was attributed to the expansion undergone by glass ionomer-based cements following water sorption after one-week storage.

The influence of frictional sliding on post-retentive strengths measured under shearing loads, might be pull-out or push-out forces, requires further investigation. Higher frictional resistance is developed in a push-out design, in relation to the Poisson’s expansion of the post-segment under the compressive load. The contribution of sliding friction to the overall load carrying ability of post-retained restorations could be estimated by plotting load–displacement curves during the push-out tests.

It would be ideal from a clinical standpoint that the luting cement rapidly reaches its maximum retentive ability, so as to effectively resist stresses transmitted early during abutment preparation and temporization. However, it has been shown that both resin-based and glass ionomer-based cements take time to fully express their retentive potential. A significant increase in post-push-out resistance was reported after 24 h for several resin cements.

According to Perez et al. an increased cement thickness surrounding the fiber-reinforced composite post does not impair bond strength.

Concerning the influence of the type of adhesive and polymerization mode, Mallmann et al. tested Scotchbond Multipurpose Plus in self-cure mode and the light-cured Single Bond, in combination with the proprietary resin cement RelyX ARC. A significant difference emerged only for the retentive strengths in the cervical third of the root, where Scotchbond Multipurpose Plus yielded the highest values. According to Akgunoglu, the self-etching primer Clearfil Liner Bond 2V did not demonstrate regional differences in post-space bonding, unlike the single bottle adhesive Excite, that exhibited significantly reduced strengths at the apical level. Also, bond strength of the tested adhesives was not improved by dual polymerization. Kurzt et al. and Perdigão et al. reported that the bonding agent had no significant effect on post-retention, that was rather affected by the type of post and the root region. With regard to the post-type, Cosmopost, a smooth parallel-sided zirconia post, had a significantly weaker retention than glass or carbon fiber posts.

Still on the influence of the post-type, Kalkan et al. referred that opaque and electrical glass fiber posts (Snowpost and Everstick, respectively) exhibited comparable retentive strengths, that were significantly higher than those of the translucent glass fiber post FiberMaster. Bell et al. found similar bond strengths for a carbon/graphite fiber post, an individually formed glass FRC post with interpenetrating polymer network (IPN) matrix, and a serrated titanium post that was tested as control.

Push-out tests have been performed to measure the bond strength between posts and luting agents or core materials. These same aspects have also been addressed using the microtensile non-trimming design (Fig. 5). In some studies post-surface silanization was found to increase the bond strength of resin composites to quartz or glass fibers. Conversely, silanization would not be so effective on carbon posts. Since carbon fibers do not have a significant number of hydroxyl groups on the surface, their reaction with the silane would be unlikely.

Omission of an intermediate adhesive layer following silanization had no effect on post-core adhesion. In some other investigations the contribution of silanization to post-cement adhesion or to the overall retention of luted fiber posts appeared irrelevant.

Chemical treatments of the post-surface such as etching with 10% hydrogen peroxide for 20 min or 24% hydrogen peroxide for 10 min, 21% sodium ethoxide for 20 min, potassium permanganate for 10 min, preliminarily to silanization were found effective at enhancing the adhesion of resin composites used for abutment build-up. Hydrogen peroxide, sodium ethoxide, and potassium permanganate have been tested for their ability to partially dissolve the epoxy resin by breaking epoxy resin bonds through a mechanism of substrate oxidation. With the dissolution of the outer layer of epoxy resin, a greater surface of undamaged fibers would be exposed and become available for the reaction with the silane.
coupling agent would bridge between the fibers and the methacrylate-based luting or core material.59-68

The effects of temperature,69 combination with a one-step self-etch adhesive69 and hydrolytic degradation70 of silane coupling agents when bonding to quartz fiber posts were also investigated by Monticelli et al.70 Wett air-drying of the silane at 38 °C was thought to promote the evaporation of solvents from the coupling agent, thus enhancing the post-resin composite bond.70 The combination of silane with self-etch adhesives improved the bond of composites to fiber posts etched with sodium hydroxide. However, when combining the silane with a single-step self-etch adhesive, extensive nanoleakage occurred along the post-surface, possibly exposing the post-core interface to hydrolytic degradation.71 The use of the hydrophilic resin monomer 4-META for on-demand hydrolysis of the γ-MPTS silane in the two-component coupling agent Porcelain Liner M resulted in greater interfacial water sorption and hydrolytic degradation, as compared with the pre-activated MPS silane MonoBond-S.70

Recently acquired data indicated tribochemical treatment of the post-surface (Rocatec-Pre, 3M ESPE St. Paul, MN, USA) followed by silanization as a very effective chairside procedure to increase the bond strength of resin cements72-75 and flowable composites in abutment build-up to the level of 20 MPa on average. In these studies, methacrylate-based fiber posts had been tested. Mean interfacial strengths exceeding 20 MPa were also reported for resin cements on epoxy resin-based fiber posts, following a tribochemical pre-coating treatment provided by the manufacturer.75

Similarly beneficial effects of silicating and silanization were documented for the adhesion of resin composites to zirconia posts.56-58

With regard to the composite resins, for abutment build-up, a filler content adequate to effectively limit curing shrinkage and low viscosity for the purpose of flow ability represent the combination of properties favorable to achieve good adaptation and bond strength to the post.76-78 Moreover, thanks to their wettability, low viscosity composites penetrate into the microirregularities created by chemical post-surface treatments, achieving an increased bonded surface area and a better micromechanical interlocking.66

5. Static versus dynamic test designs

It is worth mentioning that bond strength tests, such as the microtensile and push-out tests, are performed with quasi-static loading until fracture. Clinically, however, restorations rarely fail under an acute tensile or shear stress. More often, failure occurs after repeated sub-critical loads (i.e., cyclic fatigue), well below the ultimate tensile strength of a material, or the maximum stress that an interface can resist. Dynamic laboratory tests such as fatigue tests have been considered as being more realistic in predicting the clinical behavior of restorations.

The response to fatigue loading of teeth restored with fiber posts and resin composite cores was investigated by Bolhuis et al.,44,45 with post-push-out tests and SEM observations of the cement layer. Neither post-retention nor cement integrity appeared to be significantly affected by fatigue.44,45 Also, the fatigue resistance of eight commercially available fiber posts (one carbon, one quartz, and six glass fiber posts) was assessed with a three-point bending test (Fig. 6).62 Only DT Light-Post and FRC Postec posts were able to withstand the fatigue test. The tests that failed presented with various degrees of structural damage when observed under a scanning electron microscope. Fatigue response did not significantly correlate with structural properties of the posts such as fiber diameter, fiber density, and surface occupied by fibers per square millimeter of post-surface. In line with what engineers have found for several types of fiber-reinforced composites, also for endodontic fiber posts an important role in fatigue resistance may be played by the effectiveness of the adhesion between reinforcing fibers and embedding matrix.61 It was still with the three-point bending test that an elastic modulus similar to dentine and a flexural strength four times higher than that of root dentine were recently reported for carbon, silica-zirconium, and zirconia-glass fiber posts.62 Flexural strengths in the order of 800 MPa were recorded for quartz fiber posts by

4. Micromechanical pull-out test assisted by FEA

De Santis et al.79 and Frisco et al.80 have proposed a micromechanical pull-out test assisted by finite element analysis simulation as a specific design to accurately characterize the post-cement interface. With this test, different combinations of fiber post-luting cements were assessed. The loading geometry was conceived so as to preferentially load the post-cement interface, leaving the dentine-cement interface basically stress-free. In both studies the post-hole was drilled through a disk of coronal dentine. Notwithstanding the authors intention to focus on the post-cement interface, it should however be noticed that coronal dentine is rather a different substrate from the intraradicular dentine of endodontically treated teeth.

Fig. 6 - The three-point bending machine used to test fatigue resistance of fiber posts (adapted from Grandini et al.81 with modifications).
6. Aging methods

Besides cyclic fatigue evaluation, specimen aging is another method that may add to the predictive potential of laboratory tests. Several aging techniques have been proposed in dental materials research, from long-term water storage, to thermomechanical and thermo-mechanical loading. The objective of these methods is to gain insights on the durability of the biomaterial-tooth bond. According to Bitter et al., thermomechanical loading has no significant effect either on the bond strength between fiber posts and resin cements or on the overall retention of luted RCF posts. Several investigations have indicated that the degradation of the bond established on coronal dentine by single step adhesives is of concern. While self-etch and self-adhesive resin cements are being proposed for luting of indirect restorations and their simplified handling seems appealing for the use with fiber posts, data are still scarce regarding the durability of these materials when they are used for adhesion to intraradicular dentine. In a recent study by Bitter et al., the self-adhesive resin cement Relíx Unicem was reported to actually increase its post-retentive ability following thermo-cycling. The authors admit that this finding is difficult to explain.

The issue of bond durability should indeed be further addressed by future research.

7. Conclusions

The retentive ability of adhesive posts has been assessed in numerous laboratory studies over the last decade. Microtensile, post-pull-out and push-out tests have been performed in order to estimate the retention of luted posts or, selectively, the strength at the post-cement or cement-dentine interfaces.

Designs that use small-sized specimens, such as the microtensile and thin-slice push-out tests, favour stress uniformity, allow to discriminate regional differences and to limit the number of teeth needed for data collection.

In test set-ups that involve shearing, such as pull-out and push-out, a contribution to what is measured as post load carrying ability is given by frictional sliding along the canal walls. Frictional resistance is more relevant in push-out testing, in relation to the Poisson’s expansion of the post-segment under the compressive load. The reliability and applicability of the microtensile non-trimming technique in testing the retentive strength of luted post may be limited by the occurrence of numerous pre-test failures, affecting data distribution. Although bonding to intraradicular dentine is more challenging than adhesion in the crown, the retention of adhesive posts is adequate to ensure clinical success. Over 10 years of successful service have been documented for fiber post-retained restorations.

The bond strength at the post-core and post-cement interfaces may be improved by chemical pre-treatment of the post surface. Tribo-mechanical treatment followed by silanization currently emerges as the most effective and convenient one among those so far experimented.

The use of self-adhesive resin cements is being proposed also for intra-canal posts. Simplification of the luting procedure is the most obvious advantage with these new materials. The durability of their bond to dental and restorative substrates should be addressed by future research.

REFERENCES


