Cement system and surface treatment selection for fiber post luting

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Abstract
This literature review summarizes the recent research on fiber posts and provides information regarding their bonding to resinous cement or composites, based on the results of original scientific full-papers from peer-reviewed journals listed in Pub Med.
The search was conducted evaluating the different materials available for luting fiber posts to radicular dentin. A consistent number of *in vitro* studies investigating different combinations of adhesive systems and luting agents for improving bond strength have been published so far. Their results have been summarized in the following categories: conventional resinous cements and self-adhesive cements. Low bond strength values and the lack of long-term clinical data limit the application of recently marketed self-adhesive cements. The choice of the total-etch technique using dual-curing adhesive systems and cements represents the most predictable methodology for luting fiber posts.
Particular attention has been deserved also to the post surface treatment for improving their adhesiveness: the methodology may include chemical and/or micro-mechanical treatments. The majority of available literature data is based on studies that investigated different "chair-side" post superficial treatments. According to the in vitro results, surface conditioning improves fiber post bonding properties and bond strength of pre-treated fiber posts to restorative materials is satisfactory. Long-term clinical studies are needed prior to making a general recommendation for their use.

Key words: *Fiber-posts, luting procedure, cements, root dentin.*

Introduction
The longitudinal success of restorative or prosthetic rehabilitations of endodontically treated teeth depends on the quality of the restoration, on its clinical adaptation and on the health of the supporting tissue (1).
Fiber posts chronologically represent the latest solution proposed for restoring endodontically treated teeth and have introduced a new restorative concept, since the post in combination with adhesive materials (luting cement and restorative material) can form a structurally and mechanically homogeneous complex with dentin (2). In longitudinal clinical studies, the very low number of failures has been underlined (3,4). Prefabricated FRC (fiber-reinforced composite) posts have been used since the beginning of the 90s with the introduction of carbon fiber posts (5). Other types of FRC posts have been developed in the attempt of improving aesthetics, thanks to the

selection of glass or white quartz fibers and translucent resinous matrixes (6).
A consistent number of *in vitro* and in *vivo* studies that investigated the application fiber posts have been published so far. This literature review, based on the results of original scientific full-papers from peer-reviewed journals listed in PubMed aimed to summarize recent research conducted *in vitro* on fiber posts, particularly regarding adhesives and resin cements selection and post surface treatments to improve bondability.

Luting agent selection

1. Conventional resin cements

Bonding to dentin may be achieved using etch-and-rinse (i.e. total-etch) and self-etch adhesives (7). Simplified versions of these adhesives have made bonding simpler, faster, and more user-friendly (8). Some currently available one-step self-etch adhesives have been marketed as single-bottle versions (9,10). At the other end of the restorative spectrum, self-adhesive glass-ionomer and resin-modified glass-ionomer cements remain the workhorse for site-specific dentin adhesion (11,12). The luting systems suitable for fiber post bonding are the same that are clinically indicated for indirect restorative techniques. They can be divided into two subgroups according to the bonding agent used before cementation. One group utilizes etch-and-rinse adhesive systems (e.g. Variolink II, Ivoclar-Vivadent, Schaan, Lichtenstein; Calibra, Dentsply Caulk, Milford, DE, USA; Nexus, Sybron-Kerr, Orange, CA, USA). In the other group, self-etching primers are applied (e.g. Panavia 21, Panavia F and Panavia F 2.0, Kuraray Medical Inc., Tokyo, Japan; Multilink, Ivoclar-Vivadent). Manufacturers recommend either self- or light-curing adhesive systems for cementation of prefabricated endodontic posts (13).
Self-curing adhesive systems are mainly used for this procedure, since doubts as to whether bonding of photo-activated materials to root dentin is effective, especially in areas of difficult light access, such as the middle and apical root canal thirds (14). More recently, dual polymerizing resin luting agents have been introduced. Compared with light-cured composites, it is generally accepted that dual-cured and self-cured composites produce lower shrinkage stresses due to their lower curing rates that allow more stress relief by polymer flow (15). However, using the same dual-cured composite in the light-cured or self-cured mode, it was found that a lower elastic modulus was present using the self-cured mode, despite similar shrinkage values and degree of conversions exhibited by both curing modes (15).
Currently available resin cement systems have been mostly tested in root canals, even if their use in the endodontic space remains undoubtedly the most unfavorable from the clinical point of view and selecting an adhesive system that provides reliable and long-lasting bonding to root canal dentin remains difficult. Limited moisture control (16) and the unfavourable configuration factor (C-factor) (17,18) have been reported as adverse factors in bonding adhesive materials to radicular dentin. In particular, the use of simplified adhesives for bonding to root dentin may determine incompatibility between acidic resin monomers that are present in the oxygen inhibition layer of these adhesives and the binary peroxide-amine catalysts employed in dual-cured or self-cured methacrylate-based resin cements (19-21). This issue is now well taken care of by manufacturers. Dual-cured adhesive versions are available in which ternary catalysts (i.e. sodium benzene sulphinate) are employed to offset the acid-base reaction between the acid resin monomers and the basic amines along the composite-adhesive interface (22). Light-cured adhesives and self-cured composites are compatible when the pH of the adhesives is higher than approximately 4.3. Conversely, self-cured composites combined with light-cured adhesives with a pH lower than 1.8 can result in significantly lower bond strength (23).
Recent *in vitro* investigations (published between 2004 and 2007) performed with the specific purpose of evaluating bond strength to root canal dentin and fiber posts during luting, have been revised in the paper. The search was conducted using the terms “fiber posts and resin cement”, “fiber post and bonding”, “fiber posts and radicular dentin”.
Post retention in the different regions of the post space is measured meanly with microtensile and “thin slice” push-out tests. Micromorphologic examinations of the adhesive interfaces through scanning electron microscopy have been often performed (24). Research protocols on this topic have been developed combining different adhesives with one resin cement or comparing various luting systems. Heterogeneous results have been reported in the literature.
Perdigao and colleagues evaluated the effect of luting systems and root region on the push-out bond strengths of glass fiber-reinforced and zirconia posts. Independently from the luting agent, higher bond strengths values were recorded when using fiber post, mainly at the cervical third of the dowel space (25).
A similar behavior has been reported when testing Panavia F in combination with a dual-curing bonding agent (Clearfil Liner Bond) for luting three different types of fiber posts or when testing self- and light-curing adhesive systems in combination Rely X ARC: the highest bond strength was recorded at the cervical third when using translucent fiber posts (26-28).
The interfacial strength and ultrastructure of total-etch, self-etch and self-adhesive resin cements (Variolink II, Panavia 21and RelyX Unicem) used for luting endodontic glass fiber posts was assessed with the "thin-slice" push-out test and transmission electron microscopy (TEM). The values achieved by Variolink II were significantly

higher than Panavia and RelyX Unicem. TEM analysis revealed that the acidic resin monomers responsible for substrate conditioning in Panavia 21 and RelyX Unicem did not effectively remove the thick smear layer created on root dentin during post space preparation (29). Similarly, Valandro and colleagues concluded that more reliable bond strengths in the dowel space might be achieved when using multiple bottle total-etch adhesive systems instead of self-etching adhesives (30).

Mallmann and collegues recently evaluated the microtensile bond strength of two adhesive systems to root dentin with different fiber posts concluding that both autopolymerized and photo-activated adhesives may achieve reliable bonding to root canal dentin when cemented with dual-curing resin cement, apart from using translucent or opaque fiber posts (31).

Le Bell and colleagues determined the bonding properties of two types of FRC posts cemented into root canals. The posts were treated with dimethacrylate adhesive resin, light-cured and cemented with a dual-curing composite resin luting cement. Titanium posts served as control. No adhesive (post-cement) failures were recorded using FRC posts, revealing a better interfacial adhesion of resinous cement to these posts (32).

The tensile bond strength to ceramic and carbon fiber post materials as well as titanium and stainless steel post materials was evaluated using three different luting cements (Panavia F, Vitremer, and ProTec Cem). The study concluded that bonds to carbon-fiber post materials were weaker than to metallic post materials, but stronger than to zirconium oxide. Panavia F provided the highest bond strengths independently from the post type (33).

2. Self-adhesive cements

Self-adhesive cements were introduced in 2002 as a new subgroup of resin cements (e.g. RelyX Unicem, 3M ESPE, St. Paul, MN, USA). These materials were designed with the purpose of overcoming some limits of both conventional and resin cements. Self-adhesive cements do not require any pretreatment of the tooth substrate: once the cement is mixed, application is accomplished through a single clinical step. Clinicians' demands for simplification of luting procedures are addressed, as the application procedure leaves little or no room for mistakes induced by technique sensitivity.

Self-adhesive cements are still relatively new and detailed information on their composition and adhesive properties or clinical data regarding their effectiveness are limited or lacking.

However, several products are already available in the market differing in terms of delivery systems, working/setting times and composition. All these products are dual-cured materials that are indicated for adhesive cementation of any indirect restoration, including fiber posts. RelyX Unicem is the most investigated self-adhesive cement in the current literature published in Medline cited journals. Features of RelyX Unicem (3M ESPE) are by far the most extensively explained by the manufacturer (3M ESPE product profile; RelyX Unicem). The adhesion mechanism is claimed to rely on micromechanical retention and chemical interaction between monomer acidic groups and hydroxyapatite. Limited information is also available on Maxcem (34-36) while no studies that investigated other currently marketed self-adhesive cements have been published so far. All published articles are based on *in vitro* investigations.

RelyX Unicem bonding to root dentin has been investigated when using the cement for luting fiber posts (37-40) or titanium dowels (41). Thin-slice push out tests (37-39), retention tests (40,41) and morphological evaluations of the cement-root dentin interfaces (38) were performed to assess the effectiveness of cementation. Similarly to coronal dentin, the push-out bond strength of RelyX Unicem was comparable to Panavia F 2.0. However, both cements recorded significantly lower bond strengths compared to Variolink applied in combination with the etch-and-rinse dual-cured adhesive Excite DSC (Ivoclar Vivadent). Different results were reported in another investigation, where RelyX Unicem push-out strength was significantly higher than that of Panavia F, Variolink and other resin cements investigated. Moreover, values were significantly higher after thermo-cycling: the authors speculated that the self-adhesive cements moisture tolerance may explain its favorable adhesion in the root canals (39). A significant increase in RelyX Unicem push-out strength was found after 24 h of water storage in comparison to immediate testing (37). Retention of quartz fiber posts luted with RelyX Unicem was comparable to the results obtained with RelyX ARC in combination with an etch-and-rinse adhesive (40). When RelyX Unicem was used for titanium dowel cementation it performed comparably to a zinc phosphate, glass ionomer and a resin cement (Panavia 21) (41).

One study assessed RelyX Unicem bonding to zirconia (CosmoPost, Ivoclar Vivadent) and fiber posts (FRC Postec, Ivoclar Vivadent) after CoJet ® treatment (3M ESPE) using push out test (42). The push-out strength of RelyX Unicem was significantly higher on fiber posts than on zirconia posts cemented in artificial post spaces (42).

The application of RelyX Unicem (36,38) and Maxcem (36) to radicular dentin does not result in the formation of hybrid layer or resin tags and inability to etch through the smear layer formed in the root canal were observed when they were used for adhesive cementation of fiber posts. The morphological findings at the cement-dentin interface formed by self-adhesive cements are noticeably different in comparison to the interface formed with resin cements applied in combination used with etch-and-rinse adhesives.

Surface conditioning treatments for improving adhesion to fiber posts

Although the adhesion in the root canal represents the weakest point of the restoration, the post/composite adhesion needs to be considered. Bonding of fiber posts to composite materials relies only on the chemical interaction between the post surface and the resin material used for luting or building-up the core. In an attempt to maximize resin bonding to fiber posts, several surface treatments have been recently suggested. These procedures may be divided into three categories: 1. silanization and/or adhesive application; 2. acid etching, sandblasting and silica coating (i.e. Co-Jet ®); 3. alternative etching techniques (treatments that combine both a micromechanical and a chemical component).

Most of the articles published in Medline cited journals evaluated the efficacy of chair-side procedures to improve bond strength to fiber posts. Silanization and/or adhesive application represent the most investigated surface treatment in the current literature. Less information is available on chemo-physical surface treatments performed for enhancing/modifying the surface area available for bonding. All published articles are based on *in vitro* investigations and have been mainly performed using bond strength tests (microtensile and push-out) in combination with microscopic analysis. Few of them include aging procedures in their experimental design, like thermocycling and/or water storage in the experimental design.

The search was conducted using the terms "fiber post" or "surface treatment" "surface conditioning", "etching", "sandblasting".

1. Silanization and/or adhesive application

Several studies suggest the use of silane coupling agents in coating fiber posts for enhancing adhesion to composite resins. However, opinion differs about the efficiency of post silanization.

According to some authors (43), silane treatment did not enhance the bonding between glass fiber posts and six different resinous cements. Even if silanization proved to be significant in terms of bond strengths to FRC posts, the clinical relevance of the differences have been considered of minor importance (44). On the contrary, Goracci and colleagues reported an improvement in bond strength between silanized fiber posts and flowable composite cores (45). Similarly, Aksornmuang and colleagues confirmed the benefit of silane application in enhancing the microtensile bond strength of a dual-cure resin core material to translucent fiber posts (46-48). These results rely on silane capability of increasing surface wettability resulting in chemical bridges formation with OH-covered substrates, such as glass or quartz fibers. However, interfacial strength is still relatively low in terms of MPa (45,49).

The absence of chemical union between resin composites (methacrylate-based) and the matrix of fiber posts (often made of epoxy resin) represent one possible explanation. MPS silanes are commonly applied in dentistry (50,51), but do not bond well with the epoxy matrix of fiber posts. This lack of compatibility may exert an influence in the way silane molecules can absorb, condense or interact with a substrate (52,53). The chemical bond may be achieved only between the composite resin and the exposed glass fibers of the post. As a consequence, bond strength between the epoxy resin-based fiber posts and methacrylate-based resin composites could not be fully enhanced by silanization. Moreover, silane coupling is considered a technique-sensitive step. Among factors influencing its efficacy, the composition (pH, solvent content, molecule size etc.) and application mode are mostly involved. Solvent evaporation plays an important role since an incomplete removal may compromise coupling (54).

To optimize the chemical interaction between silane and inorganic surfaces, the reaction may be catalyzed by acid treatment or heating (55,56). Heat treatment of silane solutions is routinely performed in dentistry to maximize bond strength and has been proven to increase ceramic-composite bond strength when repairing chipped ceramic restorations (51,57,58) or when bonding ceramics to composite resins (56,58-60).

A similar technique has been recently proposed for improving silane coupling to translucent fiber post (61). In the study, single-phase pre-activated solutions based on different silane molecules (3-MPS and GPS, respectively) and a two-component system in which the hydrolysis occurs when mixing the silane coupler (γ-MPTS) with the acidic monomer (4-META) just before its application were tested (62,63). The application of a warm air stream (38ºC) for air-drying the fiber post surface, seemed a clinically feasible chair-side procedure to overcome some of the problems related to silane composition and/or application (55,56,60).

Some authors and manufacturers have proposed adhesive systems as a possible alternative to silane solutions in fiber post couplings (64). The use of silane couplings and the consecutive application of a bonding agent have been recently evaluated with controversial results. Ferrari and colleagues (65) reported no substantial improvement in bond strength by separately applying silane and different dentin adhesives on methacrylate-based quartz fiber posts: the formation of a thick multi-phase coupling layer in which flaws may easily produced during each separate phase of application possibly explain these outcomes. Some recently marketed coupling agents rely on the combination of a silane/primer solution and a bonding agent. In these two-component systems for "on-demand" hydrolysis, the silane is rapidly hydrolyzed by the acidic phosphate monomers present in the water-containing dentin adhesives, enabling the fresh silanes to perform more efficiently than completely pre-hydrolyzed solutions (66). Satisfactory results have been reported both on zirconia and epoxy resin-based translucent fiber posts (46,47,67).

These combined silane/bonding agents have the advantage of the simultaneous formation of siloxane bonds and polymerization of functional groups in the resin. The selection of the bonding agent represents a possible limitation of the technique. Recently marketed adhesive systems include large amounts of water and organic solvents, acidic monomers or 2-hydroxyethylmethacrylate (67). Due to their composition simplified one-step self-etch adhesives are prone to phase separation during solvent evaporation, creating a non-uniform adhesive interface. This aspect may expedite the post/composite interface degradative phenomena, rendering their use with silane coupling agents as questionable. Conversely, the inclusion of a separate hydrophobic resin coating applied after the silane/adhesive primer solution created a more reliable seal of the post surface.

2. Acid etching, sandblasting and silica coating

Surface treatments are common methods to improve the general adhesion properties of a material, by facilitating chemical and micromechanical retention between different constituents (68). In adhesive dentistry, surface conditioning techniques have been developed for natural substrates (i.e. enamel, dentine) (69) as well as restorative materials. Non treated fiber posts have a relatively smooth surface which limits mechanical interlocking with resin cements and purely adhesive failure modes are commonly recorded at the post/composite interfaces. Since chemical adhesion alone may not guarantee a strong and durable fiber post-to-composite bond, different conditioning procedures initially proposed for ceramics have also been tested on fiber posts.

Ceramic etching with hydrofluoric acid is able to create a rough surface that allows for micromechanical interlocking with the resinous cement. This methodology has been recently proposed for etching glass fiber posts (70-73). The acid effect was time-dependent and influenced by the post composition (type of matrix and/or fibers). The technique produced substantial damages to the glass fibres and affected the integrity of the post (72). This is due to the extremely corrosive effect of hydrofluoric acid on the glass phase of a ceramic matrix (51,74). These findings were confirmed by Vano and colleagues (75) when hydrofluoric acid was used for conditioning methacrylate-based fiber posts: despite of the improvement in post-to-composite bond strength, a noteworthy surface alteration ranging from micro-cracks to longitudinal fractures of the fiber layer was detected. Suggesting general guidelines for using hydrofluoric acid for surface etching of aesthetic fiber posts seems not possible.

It is well accepted that sandblasting with alumina particles results in an increased surface roughness and surface area. The Co-Jet® system (Co-Jet®, 3M ESPE, St Paul, Mn, USA) for intraoral use is a modification of the Rocatec® system introduced in 1989 for laboratory use. It relies on the use of aluminium oxide particles modified by silica. As a result, a silicate layer is welded onto the treated surface by high spot heat produced by blasting pressure in a process called tribochemical coating. These procedures are followed by silanization of the pre-treated surface, thus combining chemical and micromechanical retention.

Several studies investigated the bonding of resinous materials to different types of fiber posts evaluating the effect of these surface treatments. Air abrasion with silica coated aluminium oxide particles creates a silica layer on the post surface due to the high velocity impact of the silica on the substrate, allowing a penetration of the particles of about 15 microns (72). The treatment improved the bond strength between quartz FRC and resin cements when compared with phosphoric acid or hydrofluoric acid etching (72).

Sahafi and colleagues evaluated the efficacy of blasting the surface of zirconia and fibre posts with silica oxide (Co-Jet ® System) (49,76). Although the satisfactory bond strengths, the treatment was considered too aggressive for fiber posts with the risk of significantly modifying their shape and fit within the root canals (76). Application time, alumina particle size and pressure may have influenced the results. On the other hand, the treatment appeared beneficial when performed onto zirconia posts. Bitter and colleagues (44) reported a little influence of CoJet ® treatment on the bond strength between fiber posts and resinous cements depending of the luting materials used.

More promising results were recently achieved by Balbosh and Kern (77) and Asmussen and collegues (78): epoxy resin-based fiber posts were air-born particle abraded with 50 microns alumina particles at 2.5-bar pressure for 5 sec and a distance of 30mm. This regimen did not produce visible changes of the shape of the post and resulted in increased surface area and mechanical interlocking with the resin cement. Similarly, Radovic and colleagues (79) reported a significant increase in surface retention when Rocatec-Pre aluminium oxide particles were used for treating FRC posts. The mechanical action of blasting probably determined the removal of the superficial layer of resinous matrix, creating micro-retentive spaces on the post surface.

3. Alternative etching techniques

The lack of selectivity represents the main problem of these conditioning techniques: both the matrix as well as the fibers of the post is affected by the treatment, resulting sometimes in a damage of the post's inner structure. To achieve optimal properties in fibers-reinforced composite materials, adhesion between fibers and composite is usually optimized through selective surface treatments (68,80).

It was of interest to verify whether and to what extent the adhesive potential of the fiber post could be improved through these treatments. Different chemicals and laboratory and industrial techniques have been evaluated in the attempt of finding a possible application in dentistry. As previously reported, the absence of chemical interac-

tion between methacrylate-based resin composite and the epoxy resin matrix of fiber posts (51) represent the main cause of weakness in post-to composite bonds.
Different solutions and solvents are known to be effective on epoxy resin (81,82). Surface pre-treatment of the resin phase of fiber posts may be beneficial in improving their adhesion to methacrylate-based resin composites.
For industrial applications, potassium permanganate is usually applied for conditioning epoxy resin surfaces for metal plating of printed circuits boards (83,84). This treatment, called desmearing consists on the subsequent application of three chemical solutions (swelling, etching and neutralizing). It was tested on translucent fiber posts achieving interesting results (85).
With a similar purpose, hydrogen peroxide and sodium ethoxide are commonly employed in immunological electron microscopy to partially dissolve the resin surface of epoxy resin-embedded tissue sections during immunolabeling techniques. The etching effect of these chemicals depends on partial resinous matrix dissolution, breaking epoxy resin bonds through substrate oxidation (82,86).
A similar approach has been proposed for fiber posts surface pre-treatment to increase their responsiveness to silanization, achieving satisfactory results for both the tested chemicals (87,88).
The conditioning treatment consisted on fiber posts immersion in the solutions for a relatively short period (10-20 min). By removing a surface layer of epoxy resin, a larger surface area of exposed quartz fibers is available for silanization. The spaces between these fibers provide additional sites for micromechanical retention of the resin composites. In particular, H2O2 etching (10% H2O2 for 20 min) represents an easy and clinically feasible method for enhancing interfacial strengths between fiber posts and resin composites, without employing extremely corrosive liquids in a clinical setting (88).

Conclusions

The scientific literature is generally approving fiber posts application in clinical practice. Most *in vitro* and in *vivo* studies agree that fiber posts failure mode is more favorable than with metal posts and the level of success seen in short-term published clinical studies is being confirmed by ongoing long-term evaluations. If certain basic principles are followed it is possible to achieve high levels of clinical success with most of the current fiber posts available in the market.
The choice of resin cements that rely on the use of etch-and-rinse adhesives has been shown to achieve higher interfacial strengths in post spaces when compared with those that utilize mild self-etching adhesives or a self-etching resin cement (3,89,90).
For self-etching adhesives and the self-etching resin cements, the acidic monomers incorporated in these systems were not strong enough to etch through thick smear layers to form hybrid layers along the walls of the post spaces. Dual-cured and self-cured adhesives and composites are generally favored for post cementation.
Self-adhesive cements offer a new approach in indirect restorative procedures. However, many recently marketed products are not known, and few data are available in the literature regarding their *in vitro* or clinical performance, these materials needs to be assessed prior to making a general recommendation for their use.
Surface post treatments represent one important factor for improving the bonding of resin cements or core materials to FRC posts especially when dealing with epoxy resin-based fiber posts. The possibility of combining chemical and micromechanical retention on the post surface provides the most promising adhesion mechanism. Clinicians should be aware of the specific indications for the treatments they can perform. However, chair side post pre-treatments are still considered a technique-sensitive step. The possibility of an industrial conditioning of the fiber post surface may be of some help in the attempt to simplify clinical procedures.
Pre-coated epoxy-resin based fiber post have been proposed, these coating films give excellent surface properties, thanks to the stability of their bonds and the ability to form highly hydrophobic substrates. Moreover, the epoxy resin matrix of the post is not directly involved in the adhesion mechanism, avoiding the risk of incompatibility with methacrylate-based restorative materials. Further investigations are needed to evaluate the long-term durability of these bonds through accelerated aging conditions (91).

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