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Bonding of posts to tooth structure

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Abstract: The prognosis of endodontically treated teeth depends not only on the success of the endodontic treatment, but also on the type of reconstruction. These considerations include the decision of whether or not to use posts. While metal posts have been the standard for many years, nonmetallic posts have been introduced to address the need for a more esthetic material in the anterior region. One of the most important factors affecting post retention is the luting agent and the bonding procedure steps.

Keywords: Metal posts, fiber posts, resin based cements, self etch, total etch, dual cured resin cements

Introduction

In the recent years there have been significant advances in the development of bondable, fiber-reinforced and ceramic esthetic posts to reinforce endodontically treated teeth. The survival and long- term success of endodontically treated teeth with posts are affected by many different factors:

i. Factors related to the surface properties of the post that if not optimized, failure at cement-post interface may occur.

ii. Factors related to the adhesion strategy that if not adequately applied failure at cement-dentin interface could occur.(1)

Luting agent:

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One of the most important factors affecting post retention is the luting agent. The use of resinous cements has increased, and studies have reported higher retention values and resistance to fatigue for these cements compared to brittle zinc phosphate cements used widely in the past. This is due to, the modulus of elasticity of resin cements approaches that of dentin, and therefore they may have the potential to clinically reinforce thin-walled roots. On the other hand, resin cements are technique-sensitive because of their short working time, the number of operating steps involved, and the sensitivity to moisture, compared to zinc phosphate cements.(1)

Bonding of post to tooth structure:

a. Cement-post interface.

b. Cement-dentin interface.

a. Cement-post interface:

a.1. Bonding to fiber-reinforced posts:

Fiber-reinforced posts consist of fibers (glass, carbon, quartz, or polyethylene) embedded in a polymer–epoxy resin matrix. The purpose of the fibers is to increase the tensile and fatigue strength of the post and to enhance its volumetric stability. The epoxy matrix is highly cross-linked, with a very high degree of polymerization conversion. Its purpose is to support and protect the fibers.

Since fiber posts are passively retained into the root canal, the effectiveness of the adhesive cement and the luting procedure plays a relevant role in the overall clinical performance of the restorations. The most common technical complication of endodontically treated teeth restored with fiber posts is post debonding. This is due to:

◎ The high degree of polymerization conversion of the resin matrix in fiber posts that result in a poor bond between resin cements and the post surface because of the lack of free functional groups.(2)

To overcome this issue, ultra-high molecular weight polyethylene fibers coated with a dentine bonding agent (which contains free functional groups) are used to build-up endodontic posts and cores. As the fibers adapt to the root canal, canal enlargement is not required. The woven fibers have a modulus of elasticity similar to that of dentine and are claimed to create a dentine-post-core mono-block, through chemical bonding with the resin based adhesive system, allowing for a more favorable stress distribution along the root.(3)

Surface treatment of fiber posts:

Many techniques suggest surface treatment of the fiber post surface to increase the adhesion of resin cements. Surface treatment is a common method for improving the adhesion properties of a material, by facilitating chemical and micro-mechanical retention between different constituents. These procedures fall into three categories:

1) Chemical bonding between a composite and post:

Silane coupling agent is a hybrid organic-inorganic compound that is able to increase surface wettability and create a chemical bridge between the methacrylate groups of resin and the hydroxyl groups of the exposed quartz and glass fibers. A chemical bond may be achieved between the core resin matrix and the exposed glass fibers of the post at the interface level. Using silanization as a preparation of the post before the cementation is well investigated and it's known that the interfacial strength is still low because of the absence of chemical union between the methacrylate-based resin composites and the epoxy resin matrix of fiber posts (fiber posts don't have enough free functional groups to react with silane). However, silane could be effective when it follows other post pretreatment techniques.(1, 2)

2) Surface roughening of the post:

Non-treated fiber posts have a smooth surface area that limits mechanical interlocking between the post surface and resin cement.

◎ Sandblasting with alumina particles or silica oxide results in an increased roughness of the surface. In addition, by using silicate-coated alumina particles, surface area is not only increased, but also a silicate layer is welded onto the post surface. This silicoating that is followed by silanization is referred to as 'tribo-chemical coating' can be performed in the laboratory (Rocatec system) or at the chairside (Cojet system).

However, the treatment was considered too aggressive for fiber posts and the main problem related to this technique is that there is lack of selectivity; both the matrix and the fibers of the post are affected.(1, 4)

◎ Acid etching using hydrofluoric acid, because silica and quartz present in fiber posts are comparable in chemical structure with ceramic material, hydrofluoric acid has recently been proposed for etching fiber glass posts. It is intended to create a rough pattern on the glass fiber posts surface, which allows for micromechanical interlocking with the resin cement and composite. Despite the improvement in post-to composite bond strength, a remarkable surface alteration, varying from microcracks to longitudinal fractures was found. Although the bond strength was increased by prolonged acid etching, the microstructure of the FRC posts might have been damaged. Also, etching by 37% phosphoric acid (H3PO4) for 15 second is a better and comfortable alternative to other methods in improving the adhesion of fiber post to root canal dentin.(1)

Because these above-mentioned techniques can sometimes damage the glass fibers and affect the integrity of the posts, substances that selectively dissolve the epoxy matrix without interfering with the fibers have been studied. Potassium permanganate, methyl chloride, sodium ethoxide, and hydrogen peroxide (H2O2) remove the epoxy resin and expose the fibers which are then available to be silanated. H2O2 at concentrations of 10% and 24% effectively removes the surface layer of the epoxy resin. The main disadvantage in using H2O2 is the prolonged time for etching (20 minute).(1, 2)

The application of surface treatments might negatively affect the light transmission property of fiber posts which limits the curing rate. Also, the unreacted monomers as a result of incomplete polymerization of the resin cements, might leak through the apical root filling and could result in inflammatory, cytotoxic, and mutagenic reactions of periodontal tissue.

3) Combination of micromechanical and chemical components by using the two above-mentioned method:

◎ For example, Hydrofluoric acid in combination with a silane-coupling agent is often employed to increase the bond strength between composite resins and feldspathic ceramics.(1)

a.2. Bonding to zirconia posts:

High flexural strength, high fracture toughness, chemical stability, biocompatibility, and favorable optical properties are advantageous characteristics of zirconia as a restorative material. However, when used for endodontic posts, zirconia has revealed some major limitations. In relation to its rigidity zirconia posts are more prone to cause root fractures than fiber posts. Also, the surface of zirconia posts does not bond to resin composite materials. Zirconia posts can be pre-treated by silicoating followed by salinization which results in an increased surface. However its main disadvantages are the high modulus of elasticity of zirconia that can lead to vertical root fracture and it is practically impossible to grind off luted zirconia post if endodontic retreatment is required.(3)

a.3. Bonding to metallic posts:

Metallic posts can be fabricated from high noble alloys or various types of base metal alloys (nickel-chromium alloys, stainless steel, and titanium). A resin-based cement material could bond to a metal oxide layer through hydrophilic bonds. However, this bond is relatively weak and prone to hydrolysis. Techniques attempting to enhance the bond quality between metal surfaces and resin-based cements can be mainly divided into 2 categories: surface modification techniques and techniques involving the application of primers containing functional monomers.(2)

a.3.i. Surface modification techniques (2):

Generally, surface modification techniques could be used for both noble and base metal alloys:

◎ Include pyrochemical silica coating techniques, tribo-chemical coating systems, titanium dioxide coating systems, and spark erosion. These techniques create a silicified oxide layer on the metal surface.

◎ The tinplate technique increases the bond strength of composite resins to noble alloys through the electrochemical deposition of a layer of tin.

◎ The disadvantage of those techniques is that they are more complicated procedures and require special equipment. Also, they cannot be easily applied chairside.

a.3.ii. Techniques involving the application of primers containing functional monomers (2):

Functional monomers contain groups of atoms or bonds that are responsible for a specific chemical reaction. These functional monomers have a chemical affinity to metals and copolymerize with the structural monomers of resin-based materials. Primers can be divided into primers for base metal alloys/titanium, primers for noble alloys, and universal primers.

◎ Base metal alloy primers include functional monomers that contain phosphate or carboxylic acid functional groups. Examples include 10-methacryloyloxydecyl dihydrogen phosphate and 4-methacryloyloxyethyl trimellitate anhydride, which create an ionic bond with resin-based products.

◎ Noble metal alloy primers include functional monomers that contain thionic groups. An example is 6-(4-vinylbenzyl-n-propyl) amino 1,3,5-triazine-2,4-dithiol, dithione tautomer, which also creates an ionic bond.

Finally, the universal primers consist of a combination of monomers, one for base metal alloys and one for noble alloys. They may consist of dual functional monomers, which contain both phosphate and thionic functional groups in a single molecule. An example is thiophosphate methacryloyloxyalkyl. The main advantage of universal primers is that only one primer is necessary and can be applied to any kind of alloy.

Air-particle abrasion with aluminum oxide (Al2O3) particles is necessary for the primers to be effective. The chemical affinity of aluminum particles to phosphate monomers may be responsible for the improved performance of primers after air-particle abrasion. It may act through increasing the surface area (micromechanical retention), decrease of surface tension (adhesion and wettability) and/or oxidization of base metal alloys (chemical bond). However, air-particle abrasion may alter the character of the metal surface. Aluminum oxide particles may get trapped and partially cover the original alloy elements in the superficial layer.

b. Cement-dentin interface (bonding to radicular dentin):

Procedures related to endodontic treatment, post space preparation, and post cementation may further impact the quality of the adhesive interface and there are ways to overcome some of these potential problems.(2)

◎ Achieving stable adhesion to intra-radicular dentine, particularly at the apical level, remains a clinical challenge, due to the negative influence of several intervening factors. Chemo-mechanical preparation materials containing peroxides, sodium hypochlorite and glycol (RC-Prep) may decrease the bonding capability of resin cements to radicular dentin. Residual peroxides may oxidize the dentin collagen network or may further break down into oxygen, inhibiting the polymerization of resin-based products. Glycol lubricant may be difficult to be removed and may inhibit proper monomer polymerization. Therefore, the solution is using ascorbic acid or sodium ascorbate which act as reducing agents and may reverse the negative oxidizing effects of sodium hypochlorite (NaOCl) or RC-Prep on certain adhesive systems.(5)

- The use of eugenol-based sealers during endodontic treatment has adverse effects on the polymerization of composite resin materials. The effect of eugenol is also time dependent because it may continue to penetrate the dentin tubules over time. Therefore, the solution is that the remnants of eugenol in the root canal can be removed by irrigating ethyl alcohol or etching with 37% phosphoric acid. In addition, the use of eugenol based sealers has been limited in favor of resin based sealers or ceramic sealers that do not inhibit the polymerization of composite resins.(6)

- During post space preparation, reamers are used to remove gutta-percha (GP), which results in a heat-plasticized smear layer (secondary smear layer) rich in endodontic sealer and GP remnants. There is no scientific data to suggest that this type of smear layer can be successfully removed by etching. Also, the absence of a chemical bond between the polyisoprene component of GP and the methacrylate component of resin cements may further jeopardize the bond to dentin. Therefore, the solution is using EDTA, phosphate etching and sodium hypochlorite (NaOCl) or chlorhexidine irrigation that may eliminate the radicular smear layer more efficiently. However, the oxidizing effect of NaOCl may not be compatible with all bonding agents. In addition, the use of ultrasonic instrumentation in association with EDTA rather than rotary instruments has been suggested.(2, 5)

- Etchants may not flow completely in the root canal, causing inadequate exposure of the collagen fibers. Furthermore, etchants cannot be removed completely, and residual etchants (self-etch adhesive that contains acidic monomer etchant & no rinsing) may cause low pH-related inhibition of polymerization of resin-based materials (due to the reaction between acidic components and amide groups present in the resin system. The amide groups are susceptible to protonation under acidic conditions, leading to a change in their chemical structure and they become less reactive towards the polymerization reaction. This protonation reaction can inhibit the polymerization reaction at low pH levels). Also, the presence of excessive amounts of moisture is another challenge in the root canal environment and voids between posts and root canal walls are evident when resin cement is used. Therefore, the suggested solutions are:

1. Self-etching and self-adhesive systems with co-initiator/co-activator may perform better than etch-and rinse systems in the root canal because they are less sensitive to the moist radicular environment. These alternative co-initiators/co-activators offer advantages in terms of stability, reactivity, and compatibility with acidic environments. By incorporating these initiators into self-etch adhesives, manufacturers aim to ensure efficient polymerization and enhance the overall performance of the adhesive systems. In addition, the adhesion mechanism of self-adhesive systems is related with the micromechanical bonding and chemical interaction between the acid monomers and hydroxyapatite.(1)

2. Intracanal air-drying could be more effective than paper points in the removal of solvents and water, resulting in improved push-out bond strength when a self-etching adhesive is used.(2)

3. The use of an injection delivery cement system or a rotary spiral paste filler may also reduce voids and air entrapment, resulting in enhanced bond strength of fiber posts to dentin.(2)

4. Preparation of radicular dentin with chlorhexidine solution or ethanol may improve the durability of the bond when a self-etching system is used. Chlorhexidine inhibits degradation caused by dentin matrix metalloproteinases, and ethanol facilitates better penetration of hydrophobic monomers into dentin.(2)

- Incomplete light penetration in the post space can result in incomplete polymerization of both the adhesive agent and the resin cement. Therefore, the solution is using translucent glass or quartz fiber posts that allow more transmission of light into the root canal space, resulting in increased cure depth. In addition, enhanced light penetration combined with dual cured resin cements may result in improved polymerization and provide the most reliable option for achieving proper cement polymerization all along the dowel space. Self-cured is not advisable because they have worse handling characteristics because of their fast and uncontrolled polymerization.(3, 7)

- Even if there was successful etching and monomer penetration into the radicular dentin, the configuration of the root canal (C-factor) may not be favorable. The root canal simulates a very deep class I cavity in which the c-factor value may exceed that of 200, resulting in uncontrolled resin polymerization contraction. The resulting stress from volumetric shrinkage may exceed the bond strength with radicular dentin. Therefore, the solution may be using slow setting cements which have the potential to provide stress relief during polymerization. Some manufacturers claim that self-adhesives have lower polymerization stresses. In addition, others suggested that using low filled composite resin results in lower stresses due to its lower modulus of elasticity.(2)

Microleakage and Degradation of Adhesive Systems (2):

Microleakage is a phenomenon that happens in both adhesive and non-adhesive systems with a gap size of 10–20 μm. Microleakage follows nanoleakage, which occurs in non-visible gaps within the hybrid layer that have an approximate size of 20–100 nm. Nanoleakage may be due to incomplete polymerization of the adhesive or the presence of nanometric spaces around the collagen fibers that were not completely infiltrated by the adhesive monomers. These phenomena have been identified in teeth restored with fiber posts in which gaps occur between the dentin and the cement and not between the cement and the post surface. Microleakage results in the presence of water molecules in the adhesive interfaces. Both composite resin materials and fiber posts absorb water over time through a process called diffusion. Hygroscopic expansion of composite resin materials may partially counteract polymerization shrinkage stress, which causes the cement to fill shrinkage-related voids.

Degradation of the endodontic adhesive systems can be chemical or mechanical. Chemical degradation is a direct result of microleakage and is related to the presence of water and enzymes. These enzymes can cause hydrolysis of resin components, detachment of resin fillers, and hydrolysis of the exposed collagen fibers. Mechanical degradation is related to the forces that an adhesive interface is subjected to while chewing. The materials used in adhesive systems exhibit different moduli of elasticity, causing stress concentration at the various interfaces. When the adhesive interface degrades, separation and micromovement between different bonded materials may occur then further leakage and caries are expected. In addition, subsequent contamination of the apical terminus can occur. (7) Also, thermal changes that occur due to the differences in the coefficient of thermal expansion and contraction of the materials at the adhesive interfaces can induce further stress. Therefore, the chance of failure increases as the number of participating interfaces increases.

Additional factors affecting post retention(1):

a) Post length:

The length of the post influences stress distribution in the root, and thus affects its resistance to fracture. When the length of the post is increased the retentive capacity also increases, but a long post preparation increases the risk of root perforation. A common recommendation has been that the length of the post should be equal to or bigger than the length of the crown. Other criteria concern is the apical seal of the root canal. It has been suggested that leaving at least 4-5 mm of root-filling material is necessary to maintain the apical seal.

b) Post diameter and remaining dentin:

Ideally, the post diameter should be less than one third the diameter of the root at the cementoenamel junction and 1 mm or more of dentin should remain around the post. Post removal, internal resorption, or current coronal flaring to gain access to the apical aspect may result in decreased dentin thickness at the coronal part. The reduced thickness of the coronal walls may reduce the effect of the ferrule. The restorative procedures required for endodontically treated teeth are dependent upon the amount of coronal dentin remaining.

c) Post design

The design of the post affects the retention and the success of the restoration. Regarding the post taper, parallel-sided posts are more retentive than tapered posts and they distribute stress more uniformly along their length during function. The greater the taper, the less the retention. The shape of the post can be cylindrical, conical or combined. The combined shape is preferred because the cylindrical half is placed at the coronal part of the root and the conical half of the post is positioned in the apical part of the root. Double-tapered posts better adapt to the shape of the endodontically treated canal, thus limiting the amount of dentine tissue to be removed in post space preparation. Some marketed posts exhibit a coronal head or serrations for retentive purposes.

Oval-shaped glass fiber posts were recently introduced for better adaptation into ovoid-shaped canals. For ovoid-shaped canals, the use of an ultrasonic oval-shaped tip has been suggested for a more conservative post space preparation.(3)

Conclusion:

The adhesive system used to bond a fiber post to tooth structure is a dual cure self-adhesive system with co-initiator/co-activator which involves several steps. Firstly, the tooth is prepared, and the root canal space is shaped. Then, an acidic etchant is applied to the tooth to create a micro-retentive surface. A bonding agent is subsequently applied and light-cured to form a hybrid layer on the etched tooth surface. The fiber post is coated with dual-cure resin cement and carefully inserted into the prepared root canal. Excess cement is removed, and the cemented post is light-cured for complete polymerization. Proper isolation, moisture control, and meticulous technique are crucial for achieving a durable and reliable bond between the fiber post and the tooth structure.

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