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Current concepts on the use and adhesive bonding of glass-fiber posts in dentistry: a review

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Abstract

The aim of this study was to review and summarize the *in vitro* and clinical data on the use of glass-fiber posts concerning recent changes in the philosophy, materials, and technology that have impacted significantly the art and science of endodontic post placement. Original scientific papers or reviews listed in the Medline or ISI Web of Science databases from 1981 to 2013 were searched electronically using the following key words: endodontically-treated teeth, glass-fiber post, dentistry, resin cement, silane, and adhesive. The literature supports the use of a post when the remaining coronal structure is insufficient to provide retention for the restoration. Concerning which post to select, glass-fiber posts offer two important advantages: the elastic modulus is similar to that of dentin, and these posts and the respective core build-ups are cemented by an adhesive technique. However, some issues remain unclear. Randomized controlled trials are needed to confirm whether the use of silane influences the bonding and whether self-adhesive resin cements constitutes a reliable clinical option. Overall, the use of fiber posts is an important clinical option in dentistry, but clinicians should be aware of the difficulties in achieving good adhesion within the root canal.

Keywords: Adhesion; Bonding; Dentistry; Glass-fiber posts; Review

Introduction

Intra-radicular posts have been used to provide anchorage for dental restorations for over 250 years [1]. In the past decades, the increasing demand for aesthetics has led to the development of metal-free post-and-core systems, especially fiber-reinforced epoxy posts. To ensure a successful aesthetical outcome, the post-and-core system needs to be tooth-colored, reflecting and transmitting light similarly to a natural tooth [2,3]. Fiber posts have been developed to improve the optical effects of aesthetic restorations [4,5] and are widely used for restoring endodontically-treated teeth with insufficient coronal tooth structure as a core for the restoration [6,7]. The use of posts in cases in which the tooth structure has been destroyed due to caries, trauma, or overaggressive endodontic procedures is gaining widespread acceptance among dental clinicians [8,9].

Together with the increased use of pre-fabricated posts, especially fiber posts, an increase has also been observed in the number of publications on this subject, testing different cementation protocols, adhesive systems, and cements and discussing the indications for posts' use and the problems currently found in clinical practice. All this information should be revised and summarized to educate the dental practitioner about the current concepts and evidence for the use of fiber posts, in order to achieve

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the best results with the technique. Thus, the aim of this review was to discuss the current concepts for the use of glass-fiber posts (GFPs) as well as the problems that may interfere with their adhesive bonding within the endodontic post space. Knowledge and control of factors affecting the posts' bond strength to root canals may ultimately improve the clinical performance of GFP-retained restorations.

Review

Original scientific papers or reviews listed in the Medline or ISI Web of Science databases from 1981 to 2013 were searched electronically using the following key words: endodontically-treated teeth, glass-fiber post, dentistry, resin cement, silane, and adhesive. Papers published in all languages were selected, and the most up-to-date or relevant references were chosen. Additionally, the cross-referencing of important papers identified those of historical value, which were also selected. Although papers written in all languages were considered, all the relevant studies were written in the English language. In order to discuss each item from the clinical use perspective, the results from the literature search were divided into the following six subcategories: reasons for the use of posts in dentistry; post selection criteria: glass-fiber posts; bonding systems; luting agents; post surface treatments; and critical clinical points.

Reasons for use of posts in dentistry

One of the main reasons for the use of posts is that they are incorrectly believed to reinforce the tooth structure. The development of epoxy posts reinforced with glass-fibers derived from a need to minimize the mismatch among the elastic modulus of the post, luting agent, core material, and tooth. Fiber posts, although not actually reinforcing the tooth structure, may generate a more homogeneous stress distribution at the bonding assembly than rigid posts [10] (such as metal or zirconia posts) and thus may reduce the risk of root fractures. The potential risk is further reduced by the chemical bonding that occurs between the post and the luting cement. In addition to the favorable physical properties of GFPs, light can sometimes be transmitted through this type of post, allowing the light activation of photopolymerizable adhesive materials in the confines of the root canal [11].

The amount of remaining tooth structure after endodontic treatment or caries removal is a significant factor in determining the possibility of tooth fracture [12,13]. Posts are used to provide retention of the core material; whether and what kind of a post is needed depends on the remaining dental structure [14]. The literature suggests that the use of fiber posts and resin composite cements might reduce the occurrence of root fractures or post debonding [15]. In general, when the remaining coronal structure is insufficient to provide retention of the restoration, the use of an intraradicular post is indicated.

Post selection criteria: glass-fiber posts

In many long-term clinical studies, cast metal posts have shown good adaptability to the configuration and angulation of root canal walls as well as an ideal connection to the metal core, with no possibility of separation [1]. However, cast metal posts and cores are associated with inferior aesthetics because they do not allow light transmission. Other limitations include the risks that metal posts might corrode, causing gingival and tooth discoloration [1]; might be associated with possible biocompatibility concerns [16]; might trigger allergic reactions [17]; might offer less retention; and might lead to serious types of root fractures [18]. In addition, metal posts have low resilience and do not match the elastic modulus of the tooth structure [19].

Although carbon fiber posts were introduced as an alternative to metal posts, limitations as radiolucency, masking difficulty given all-ceramic or composite restorations, and stiffness similar to that of metal posts [20,21] led to their replacement with white and translucent GFPs, which produce better aesthetic results [22]. Thus, GFPs have become a realistic alternative to overcome these drawbacks and are probably the most widely used and studied type of posts in dentistry [3,20,23].

Two different types of fiber-reinforced epoxy posts can be used as post-and-core systems: customized and prefabricated posts. Customized post-and-core build-ups commonly involve the use of glass or polyethylene fiber-reinforced posts that are luted directly into the root canal [24]. Prefabricated fiber posts consist of fibers either of carbon, quartz, silica, zirconia, or glass [25] embedded in an epoxy resin component with a silane coupling agent binding the fibers and resin together. Posts comprised of a mix between glass and carbon fibers are also available [26].

Retrospective [24,27,28] and prospective [29,30] clinical studies have testified to the overall satisfactory performance of endodontically-treated teeth restored with fiber post-and-core systems. An important clinical remark is that the fracture of rigid posts can result in tooth loss, because it is nearly impossible to remove their apically-fixed part [31]. Fiber posts are easier to remove without the risk of root perforation because they can be burned out [32].

Prefabricated GFPs are made up of glass-fibers embedded in a resin matrix and may also contain inorganic particles [33]. The fibers are pre-stressed, and, subsequently, the resin is injected under pressure to fill the spaces between the fibers, giving them solid cohesion. In most posts, epoxy resin or its derivatives are the main component of the organic phase. It has been suggested the epoxy resin may attach to methacrylate-based resin and composites through common free radicals [4], which would allow cementation using adhesive resin cements [11,34]. However, it has also been suggested that the polymer matrix of the posts is virtually non-reactive, because the resin has a high degree of conversion and is highly crosslinked [35]. In this case, the adhesive cementation of GFPs relies on the bonding of the silane coupling agent to the inorganic glass-fibers.

The advantages of GFPs cited in the introduction have contributed to their popularity. An additional advantage of GFPs is that they are readily retrievable after failure [36]. An in vitro study intimated that fiber posts are less likely to cause vertical root fractures than stainless steel posts [37]. Forces in the tooth restored with a fiber post are distributed to the restored complex in a manner that does not put stress on the vulnerable root structure [4]. A finite element analysis also showed that a GFP resulted in the lowest stress generation inside the root because the stiffness of the post is similar to that of dentin [38], whereas a metal post-and-core system transferred higher stresses to the root, which might cause a higher incidence of vertical root fractures. Hence, two important characteristics of GFPs are that (i) their elastic modulus is similar to that of dentin [20] and that (ii) these posts and the respective core build-ups are cemented with an adhesive technique

[39]. These characteristics may improve the retention and mechanical performance of the restored teeth [33].

The use of GFPs still presents several difficulties. Bonding to intraradicular dentin is challenging for clinicians due to the complexity and sensitivity of the technique [40,41]. Because various resin cements and adhesives are used in clinical practice, it is imperative to know how they perform in relation to incompatibilities between adhesives and resin cements [42], which can lead to possible clinical failures.

Bonding systems

The need for the adhesive luting of GFPs has engendered debates [41,43]. It has been reported that the bonding of GFPs to the dental structure may be related more to the friction of the post along the canal walls than to the adhesive bonding to root dentin [41]. The use of resin cements, however, has been found to significantly increase the retention of fiber posts and improve the fracture resistance of the bonded structures when compared to other cements [33,44-47]. Adhesive cementation has also been shown to better withstand functional forces [43], improve marginal adaption with better apical sealing [48], increase retention with reduced post length [49], and optimize the fracture patterns in case of failures [50]. Therefore, the adhesive cementation of GFPs is preferred over non-adhesive luting.

Adhesion between resin and dentin is considered to be a weak point in the bonded assembly. The type of adhesive system used in association with the resin cement is of great importance. Current adhesive systems can react with the dental structures by either etch-and-rinse or self-etch approaches. In the former, micromechanical interlocking with the root dentin is obtained by a conditioning step using phosphoric acid followed by the application of a bonding solution. The latter approach uses non-rinse acidic monomers that simultaneously condition, prime, and infiltrate the dentin, resulting in adhesion by shallow hybridization with residual hydroxyapatite.

The presence of a thick endodontic smear layer has prompted researchers to recommend a preliminary etching step to remove debris from the canal walls and increase post retention [51-53]. Acid application might also dissolve the residual canal sealer [54], although the possibility of over-etching the dentin is a potential shortcoming of etch-and-rinse systems [55]. Some studies have demonstrated similarities between bond strengths for self-etch and etch-and-rinse adhesives in different regions of coronal dentin [56-59]. One study showed that a self-etch system may create a better bond to the cervical, middle, and apical thirds of the radicular dentin than an etch-and-rinse adhesive [60]. The difficulty in removing the smear layer may be a disadvantage of self-etch materials [51,61].

Numerous authors have reported that GFP cementation with the resin cement associated with etch-and-rinse adhesive may generate greater bonding potential than self-etch adhesive [51,61-64]. This result may be explained by the fact that the acidic monomers responsible for substrate conditioning in self-etch adhesives are less effective in etching the dental structure than the phosphoric acid used in the etch-and-rinse approach. The etch-and-rinse strategy, however, requires a wet dentin substrate for optimal bonding [65], and controlling the humidity within the root canal is critical. Because the self-etch approach does not require moisture control after etching, these systems can potentially simplify the technique.

Irrespective of the type of bonding agent, limited access to curing light within the root canal may hinder the photopolymerization of the adhesives. Studies show higher bond strengths [66] and improved hybridization along the root canal [67] for self or dual-polymerized adhesives. One study also showed that the use of a self-activating adhesive combined with a dual-cure regular cement enabled the effective luting of GFPs, regardless of the amount of light transmitted through the post [68]. Therefore, the use of dual-cured adhesives seems preferable, although other investigations suggest that the use of self-cure activators might not enhance the bond strengths of GFP to root canals [60,69]. In order to optimize the outcome of cementation procedures, the bonding system used by the clinician should be known thoroughly, and the clinical steps need to be strictly followed.

Luting agents

Contemporary resin cements may be classified into two main groups, according to the adhesive approach. In the first group (regular resin cements), the cement is used in association with an adhesive system, while in the second group (more recently introduced) the cement is self-adherent, i.e., no pre-treatment of the dental substrate using acid or primers is necessary, allowing simultaneous bonding between the intraradicular dentin and post. These latter materials are known as self-adhesive (or self-etching) resin cements and may simplify the adhesive luting procedures.

The bond properties of self-adhesive resin cements are based upon acidic functional methacrylate that may simultaneously demineralize and infiltrate the tooth substrates [70], with the additional potential to chemically bond to hydroxyapatite [71]. Studies have reported, however, limited etching potential for self-adhesive cements compared to etch-and-rinse and self-etch adhesives when luting GFPs [62,72-74], with one investigation showing the similar bonding potentials of the combination regular resin cement-self-etch adhesive and of a self-adhesive resin cement [51]. Self-adhesive cements may also present lower degrees of C = C conversion [75] and poorer mechanical properties [76] than regular resin cements. The lower etching aggressiveness and suboptimal properties may account for the low early (immediate) interfacial strengths reported for GFPs luted with self-adhesive cements [77]. Nonetheless, in a 3-year randomized controlled clinical trial, a self-adhesive resin cement performed well with GFPs; this finding was confirmed in a 5-year simulated clinical function and subsequent linear loading [78].

Resin cements may also be classified according to their polymerization mode as photopolymerized, self-polymerized, or dual-polymerized materials. Photocured cements cannot be used for post cementation because they need the curing light to penetrate into the bulk of the material; conversely, self-cured (or chemically-cured) cements have no problems related to their polymerization in the apical areas because the curing process is initiated by a redox mechanism, which is triggered upon the mixing of the base and catalyst pastes. Self-cured materials, however, offer worse handling characteristics due to their relatively fast, uncontrolled polymerization.

Dual-cured resin cements are mostly used for luting GFPs. There materials theoretically combine the favorable properties of extended working time and the capability of reaching proper polymerization in either the presence or absence of light. It has been demonstrated, however, that the attenuated light penetration interferes with the cement polymerization toward the apical areas of the root canal [79-81], sometimes even when translucent fiber posts are used [82]. In general, the self-cure mechanism for dual-cured materials alone is not only slower but also less effective than the use of light-activation [83-85].

It is also known that self or dual-cured resins cements are not compatible with simplified adhesives (i.e., two-step etch-and-rinse or one-step self-etch agents). This incompatibility is due to the low pH of simplified adhesives, which may react to the basic tertiary amines used as self-cure co-initiators, interfering with proper polymerization [42]. Thus, non-simplified adhesives (three-step etch-and-rinse systems, for instance) should be used for bonding GFPs to root canals using regular resin cements.

The recent introduction of self-adhesive cements has allowed the luting of GFPs using a simpler approach, potentially reducing the technique sensitivity. In such a situation, the clinician should focus more on the preparation of the canal for the post and not rely on the cement itself. The limited etching capability of self-adhesive materials in the presence of the compact smear layer created within the endodontic space [74] may still be a matter of concern. In most clinical investigations, GFPs were cemented using etch-and-rinse adhesives in combination with regular self-cured [27,86] or dual-cured [9,27,87-89] resin cements. Therefore, up to now, clinical studies showing the clinical performance of adhesively luted posts using self-adhesive cements (or even self-etch primers) are scarce, despite the number of recent laboratory investigations showing good results for self-adhesive resin cements [90-93]. The results of a recent systematic review and meta-analysis of *in vitro* studies suggest that the use of self-adhesive resin cement could improve the retention of glass-fiber posts as compared with regular resin cements [94]. Self-adherent materials are gaining fast popularity and may represent a reliable clinical option as soon as more clinical trials indicate results comparable to regular resin cements.

Post surface treatments

Various pretreatment procedures, such as silanization, acid etching, sandblasting, tribochemical silica coating, and the application of bonding agents are currently being investigated for enhancing the bond strength of GFPs to the luting cement [95-98]. Other treatments as plasma and dopamine treatment have also been described, with varying results [99,100]. Silanization is the technique used most often to achieve this goal. Silane coupling agents are bifunctional molecules, with one end of the molecule capable of reacting with inorganic glass-fiber and the other with organic resin [101].

The action mechanism of silanes relies on the formation of bonds between its functional alkoxy groups and the OH-covered inorganic fibers. Improvement in the post surface wettability is another effect of silanization. The highly crosslinked polymer matrix of GFPs is virtually non-reactive [102,103]; therefore, only the exposed fibers on the post surface could provide sites for chemical bonding with the silane molecules. The silane coupling agent most commonly used for dental applications is a pre-hydrolyzed monofunctional γ-methacryloxypropyltrimethoxysilane diluted in an ethanol-water solution.

The use of silanes to improve the bonding of resin luting agents to GFP is, however, a controversial topic [4]. Some studies reported that silanization does not have a significant effect on bond strengths of resin cements to GFPs [4,97,104], whereas others reported an increasing effect on bond strengths via silanization [105]. Silane coating of GFPs has also shown to increase the post-core bond strength and permit a more uniform adaptation of the composite core to the post [106]. A recent investigation has also demonstrated that the application of bonding solutions, especially combined with silane coupling agents, improves the bond strength of resin cement to the post surface [107]. However, randomized controlled trials are needed to confirm whether the use of silane influences the bond strength of GFPs.

Critical clinical points

Various factors may compromise the longevity of root-post-core-crown systems, such as humidity control inside the root canal [15]; anatomic variation and cavity configuration [41], which may lead to a non-homogeneous application of the etching and bonding procedures; incomplete cement polymerization in deeper root canal areas because of lack of light penetration, even with dual-cure cements [80]; chemical incompatibility between simplified adhesives and self or dual-cured cements [42]; and the design, length, and thickness of the post, cementation, and the quantity of remaining tooth substance [108].

Many combinations of different adhesive systems and resin cements can be used for post cementation. Adhesive procedures are technically sensitive, and the root canal environment is subjected to a number of variables that may directly affect bond strength [66]. Several factors have been described to affect the intraradicular bonding of resin-based materials [19,109]. The histological characteristics of root dentin [40]; the presence of primary and secondary endodontic smear layers created either by endodontic instruments and modified by irrigants or by post-space calibrated burs [110]; negative clinical factors, i.e., minimal residual dentin structure; and adverse geometric factors [54] are consistent problems that affect bond strength within the endodontic space.

Up to now, most failures involving endodontically-treated teeth restored with fiber posts have occurred through debonding [8,51,111] due to stress concentration between the cement and post [112]. However, it should be highlighted that these failures are mostly reported *in vitro*, and may not represent what takes place in the actual clinical situation. Clinical trials dealing with GFPs usually report post debonding, traumatic post fracture, and core build-up failure with fracture of the core/tooth as the most common reasons for failure [9,113]. The difficulty with some fiber posts is the cross-linked nature of the polymer matrix, which makes it harder for the composite resin to bond to the post [102,103]. Yet, in most cases, the failure is not between cement and post, but between cement/adhesive and dentin.

The bond strength between the resin luting agent and post-space dentin is influenced by the distribution of resin cement in the coronal, middle, and apical third of the root during the luting procedure and by the anatomic and histologic characteristics of the root canal, including the orientation of dentin tubule [114-117]. This circumstance is probably due to the limited ability of light to diffuse along the entire length of the resin cement, thus compromising the polymerization of the cement in the most apical regions [82,117]. Additionally, it is difficult to control for moisture and adhesive application toward the apical region of the canal [118].

Moreover, the apical third of the root canal is the location where most of the smear layer, debris, and sealer/gutta-percha residues are found after post space preparation and acid etching [54]. The bond strength between resin cements and root dentin is generally reported to be very low. Despite the fact that current dental adhesive approaches vary in dentin bonding ability [119], low bond strength values may not be capable of overcoming the shrinkage stresses generated during the polymerization of the resin luting agent, as a thin layer of curing resin with limited free surface for stress relief creates an undesirable scenario when C-factor is a concern [120].

Conclusions

Overall, it can be concluded from this review that the use of GFPs in clinical practice seems to be recommended to improve the retention of restorations and complete crowns in cases of great loss of tooth structure. However, in order to obtain the best results with GFP anchorage, clinicians should be aware of the difficulties in achieving good adhesion within the root canal. Clinicians should also pay attention to the selection of materials, and the manufacturers' recommendations should be thoroughly followed. More clinical research should be conducted to find out the influence of remaining tooth structure, i.e., the number of remaining walls, on the clinical performance of GFP-retained restorations. Also, state-of-the-art techniques, mainly concerning the use self-adhesive cements and silane for improving GFP retention to root canal, should be explored in future studies.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

APM conducted the literature search. All authors helped to draft the manuscript. All authors read and approved the final manuscript.

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