Dental Fiber-Post Systems

Subjects: Dentistry, Oral Surgery & Medicine
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The field of dental medicine is constantly evolving and advancing toward minimally invasive techniques. Several studies have demonstrated that bonding to the tooth structure, particularly enamel, yields the most predictable results. In some instances, however, significant tooth loss, pulpal necrosis, or irreversible pulpitis may limit the options available to the restorative dentist. In these cases, placement of a post and core followed by a crown is the preferred treatment option, provided all requirements are met.

restorative dentistry | dental fiber-post | dental post | dental materials | dental restoration | endodontically treated teeth

1. Introduction

The susceptibility of endodontically treated teeth (ETT) to fracture has long been a concern in dentistry. Initially, it was believed that changes in the tooth dentine, such as reduced moisture content and decreased collagen cross-linking, were the leading causes of ETT fractures [1][2]. However, ETT fractures are primarily caused by changes in tooth structural integrity [3][4]. Access preparation can result in structural integrity loss and increased cuspal deflection, which increases the risk of microleakage at restoration margins and tooth fractures [5]. Additionally, ETTs are more vulnerable to fractures due to the lack of proprioception. Nevertheless, Schneider et al. [6]. reported that vital and non-vital teeth have comparable tactile sensitivity. These factors contribute to making ETT final restorations a crucial consideration.

2. History of Dental Fiber Posts

According to their manufacturers, FRC posts were introduced to clinical practice for the first time in France in 1989. Duret published the first research article on dental fiber posts in 1990 [2]. Due to their suitable mechanical properties, such as tensile strength and stiffness, electrical conductivity, and low toxicity, carbon/graphite fibers were chosen for this application [3]. This material revolutionized dentistry since it was an efficient alternative to metal posts. The modulus of elasticity of these fiber-reinforced materials was closer to that of dentin than the previously used metal posts, and the results of clinical studies were promising [4]. Since their introduction, they have gained popularity among dental clinicians due to their reliable clinical performance and variety of advantages, such as their mechanical, esthetic, and elastic properties. However, the initial posts did have a disadvantage in terms of esthetics, as they were still visible beneath restorations made entirely of ceramic or composite. With the incorporation of quartz and glass fibers into the resin, more radiopaque fiber posts have been developed over time. This rendered them translucent or white and therefore more aesthetically pleasing. In addition, they have been widely adopted due to their additional benefits, which include high tensile strength, resistance to biochemical degradation and solubility, low electrical conductivity, and low electrical conductivity.

3. Longevity and Failure of Dental Fiber Posts

Although fiber posts have demonstrated good physical and mechanical properties in vitro, numerous failures have been reported in clinical practice [5][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20][21][22]. This demonstrates the limitations of the current fiber post materials.

The reported failure rate of ETTs with fiber-reinforced posts ranged from 2% to 40%. This wide range can be attributed to a number of variables, including (i) variability of teeth restored (anteriors vs. premolars vs. molars), (ii) anatomical variability for root canals, (iii) variability of statistical significance (study power analysis, sample size), (iv) variability of luting cement, and finally (v) variables in final restorations (direct vs. indirect).

Post-debonding failures were the most prevalent, followed by endodontic failures [8][17][18]. In general, post-related failure rates were lower than the actual reported failure rates. For instance, Ferrari et al. reported a failure rate of 7–11%, of which only 2.3% were attributed to post-failure [14]. Similarly, Mannucci et al. [9] study had a 2.5% post-related failure compared to the reported 3.8%.

Tooth type and remaining tooth structure (remaining walls) are the primary determinants of tooth longevity [15][16][17]. Cox regression analysis regarding tooth type revealed a significantly higher hazard ratio of 2–2.5 for posterior teeth [12][16][17]. Therefore, longevity of ETT in molars is higher than that in premolars and anterior teeth [16][17][21]. Moreover, the presence of one or fewer remaining walls was significantly associated with higher failure rates [15][17].

There were no significant differences in longevity between cast and fiber-reinforced posts; however, more unrepairable failures necessitated extractions [13][16]. In contrast, failed ETT with fiber-reinforced posts showed more repairable failures (up to 85%) [20].

The type of final restoration had an effect on the long-term success of ETT. Direct restoration, such as extensive amalgams and crowns, is similar if amalgam restoration was designed to protect undermined cusps with good resistance and retention forms. Full coverage restoration with enough remaining tooth structure and Furrel influenced the longevity more than the type of post used [21]. Self-adhesive resin cement for post-cementation demonstrated a statistically insignificant advantage over conventional cement [18][21] in terms of bond strength [18][21].

4. Composition of a Fiber Post

Several crucial properties of fiber composites, such as their optical, mechanical, and bonding properties, are determined by the type of fiber reinforcement and matrix used, in addition to the adhesion between their interfaces. Both the fibers and the matrix contribute in different ways to the stability of the material. The fibers provide stiffness and strength, while the polymeric matrix ensures the integrity of the composite structure and protects the fiber from damage due to high humidity and temperature. The matrix also distributes and transfers the load between the fibers. FRCs have been successfully employed in dentistry for many applications, such as orthodontic and periodontal splints, fixed partial dentures (FPDs), and removable prosthodontics [23].

FRCs can have either a thermoplastic (linear) or thermoset (cross-linked) matrix. The latter is most utilized in FRC canal posts and contains dimethacrylate or multifunctional resins, such as epoxy resin and bisphenol A-glycidyl methacrylate (Bis-GMA) and urethane di-methacrylate (UDMA). With their highly cross-linked networks, thermosetting polymers have superior mechanical properties, durability, thermal stability, and chemical resistance to thermoplastics; however, their surface adhesive properties are inadequate [24]. This is due to the resin in the luting cement or the core materials, which tend to swell or dissolve the polymers, negatively impacting the bond with the thermosetting matrix of FRC post [25]. This highly cross-linked structure also makes it difficult to remove the post if nonsurgical endodontic retreatment is required [26].

The fiber accounts for the largest proportion of FRCs (40–65 vol.%); therefore, the fiber determines the load-bearing capacity of the structure and significantly contributes to the matrix strength and stiffness [27]. Dental FRCs are reinforced with a variety of fibers, such as polyethylene, carbon, glass, and Kevlar (p-phenylene diamine). They are utilized with either uni-directional or woven orientation.

The effectiveness of the reinforcing role of fibers is dependent on a variety of factors, including their orientation, diameter, compatibility, quantity, and impregnation with the matrix resin [28]. For fibers to be effective in stress transmission and reinforcement, it is essential that the matrix saturate them with water; this also determines their mechanical properties and water absorption capacity. The adhesion between the fiber and matrix depends on the interaction between the two components, which may be chemical or mechanical. The degree of mechanical bonding depends on the surface texture and morphology of the fiber, whereas a coupling agent can be used to create a chemical covalent bond. Silanization of the fiber can improve its wettability, and the formation of hydrogen bonds and siloxane bridges on the fiber's surface can improve its adhesion [28].

5. Biomechanical Considerations for FRC Posts

5.1. Stress Distribution

Researchers and clinicians have been interested in the biomechanical changes that occur in ETTs restored with posts and cores for several years. For the past decades, cast posts were utilized, but this began to change with the introduction of FRC posts and increased demand [29]. Despite their popularity, the biomechanical properties of FRC posts and their associated tooth behavior remain controversial [30].

The main purpose of the post is to preserve the integrity of a coronal restoration on a tooth with extensive loss of coronal structure [31][32]. In order for the post to effectively serve its intended purpose, it is crucial to understand the biomechanical factors that affect its longevity [32]. Therefore, research has been carried out using finite element analysis (FEA) and photoelasticity [33] to examine various post systems and their associated stress levels in endodontically treated teeth. Once bonding has occurred between the post and the tooth's root canal, the biomechanical behavior of the former changes significantly [34]. Therefore, the material composition (zirconia, fiber, gold, quartz, titanium, or stainless steel) determines the concentration and distribution of stresses. The significance of analyzing stress lies in the fact that if stress is highly concentrated in a particular area, the risks of the tooth fracturing and the bonds between interfaces being broken increase.

In a maxillary central incisor during occlusion, the most damaging areas of stress concentration are the middle third of the root canal and the external cervical area of the tooth [35]. During occlusion, stress occurs in the root's external coronal section below the clinical crown. Conversely, after inserting a post, greater stress levels were observed at the point where the tooth and post came into contact, which was at the internal buccal plate of the root. The materials that resulted in the lowest stress levels at this point were glass fiber and carbon fiber [35]. When stress is concentrated around the post, there is also increased stress at the adhesive interface. This may threaten the bond affecting the longevity of the restoration. Therefore, the post-dentin-bonded interface is critical concerning the concentration of stress. The risk of root fracture is higher in cases of weakened tooth structure, especially if dental work involves unnecessary removal of sound tooth structure [36].

The survival of FRC posts that have been adhesively luted is good, attributed to the similarity in the mechanical behavior of FRC posts and natural tooth structure [37]. If the post and core are too stiff (e.g., stainless steel), loading stresses will increase, increasing the likelihood of catastrophic tooth or restoration fracture [38]. The likelihood of root fracturing is reduced when using FRC posts, and in case of failure, they are often repairable [39].

5.2. Influence of Ferrule on Fracture Resistance

The term 'ferrule' is believed to be a combination of 'viriola', which is Latin for a small bracelet, and 'fer-rum' (iron). It tends to be made from metal and it is an encircling band or clamp that is used to reinforce, join or fasten posts, wires or fibers. It is defined in dentistry as a "360-degree metal collar of the crown surrounding the parallel walls of the dentin extending coronally to the shoulder of the preparation. The result is an increase in resistance form of the crown from the extension of dentinal tooth structure". Its main purposes are to prevent fracture and increase resistance to dislodgment [40]. It is often misused to mean the quantity of sound dentin that persists above the finish line, but in reality, the ferrule effect is the bracing of the whole crown over the tooth structure above the preparation margin.

The ferrule is essential for the stability of restored teeth that have been treated endodontically and, therefore, for their prognosis [41]. Nonetheless, it should be remembered that the restoration of an endodontically treated tooth involves a complex process, of which the ferrule effect is just one element. Several other factors affect the clinical performance of the restorative complex, such as the material used for the post and core, the overlying crown, the luting agent, and the functional occlusal load [38].

One of the fundamental requirements for a stable restoration is ensuring that there is sufficient dentin height. Fracture resistance and the number of cycles required before the restoration fail to increase with ferrule height [42][43]. Some studies have reported that a minimum height of 1 mm remaining tooth structure is sufficient [40][43]. However, others have found that a better performance is achieved in the long term with 1.5–2 mm or more [44][45]. Some researchers have stated that a ferrule appears to offer no advantage [46][47], but it does seem to result in more favorable fracture patterns. Moreover, if a fracture occurs in a tooth that does not contain a ferrule, it is most likely non-restorable.

Another significant factor in fracture resistance is the ferrule width. This is the thickness of the coronal extension above the crown margin [48]. If preparation for the restoration is extensive due to esthetic requirements or large caries lesions, this can drastically affect the buccal wall's thickness. However, clinical practice does not recommend less than 1 mm dentin wall thickness [48][49]. However, walls of this thickness are more prone to fracturing than those with a thickness of 2 or 3 mm [50]. With this in mind, it is essential that dentin walls be preserved as much as possible and that the preparation for post and core buildup be executed with minimum invasiveness. This is essential to achieve an adequate ferrule.

Research has shown that the performance of a homogeneous ferrule with an even circumference is higher than that of a heterogeneous one that is not equal in circumference over all parts of the tooth [51][52][53][54]. However, achieving a circumferential ferrule that is the same height throughout can be challenging and sometimes impossible. A uniform circumferential 2 mm ferrule will prevent failure better than one that is not uniform, for example ranging between 0.5 mm proximal and 2 mm buccal and lingual, or a 2 mm ferrule that covers only the buccal or palatal buccal part of the tooth, or even a discontinuous ferrule caused by bi-proximal cavitations [52][54]. However, an uneven ferrule is better than no ferrule at all [53][54]. On the other hand, in a restored tooth with no ferrule, the survival rate is better if there is only a buccal or palatal wall [55][56]. In order to deliver an adequate ferrule, it may be necessary to employ techniques such as orthodontic forced tooth eruption or crown lengthening [48]. Therefore, a minimum of 2 mm ferrule should be present on the lingual and buccal walls.

5.3. Long or Short Post

Regardless of the material used to fabricate the post, the lengthier they are, the longer they will survive [57]. There is a proportional relationship between frictional retention and the contact area; the greater the contact area, the higher the retention level. This finding explains the results of the macro push-out and pull-out tests in which the entire post became detached.

Fracture resistance is also affected by the post length; however, there is no conclusive evidence on this issue. The biomechanical performance of cast posts and cores versus stainless steel and fiber posts was not affected by post length, according to a number of studies [39]. Zicari et al. studied short fiber posts used in ETT and reported that they could withstand fatigue similarly to long fiber posts [58]. According to the same study, failures in teeth with short posts may be more amenable to repair, allowing for reintervention and tooth preservation [58]. Short posts can also be more resistant to fractures due to their less invasive buildup approach.

In contrast to the previous findings, Giovani et al. [39] discovered that the fracture resistance of 10-mm-long posts was greater than that of 6-mm-long posts. Buttel et al. study assessed posts that were just 3 mm long against those of 6 mm; the posts underwent cyclic fatiguing in a chewing simulator, and the longer posts outperformed the shorter ones [59]. Therefore, they concluded that a minimum of 6 mm post length was to be used. This indicates that clinicians must carefully evaluate the length of posts for each case they deal with, considering the thickness of the remaining dentin, the concentration of stress, the bone support surrounding the root and the suggested type of restorative treatment.

Since the anatomic complexity is greater in the apex and there are numerous lateral and access canals, how much of the remaining root canal filling material is a crucial factor [60]. Apical periodontitis cases are low in teeth that have been endodontically restored and which have at least 5 mm gutta-percha remaining in the apex [61]. It is important to avoid gaps between the root canal filling and the apical tip of the post because this can lead to periapical pathosis. These gaps can have a substantial impact on the success of endodontic treatment [61].

5.4. Post Space and Cement Thickness

The fit and retention of the primary post are evaluated using pilot drills, through which a form-congruent root canal is created up to the apical third of the root, per standard clinical protocols for post-placement. This 'form-congruence' is intended to adapt the post to the surrounding root canal walls utilizing a thin and even layer of post-root cement [62]. If the fit between the post and the root canal is good, stress will be more evenly distributed along the canal wall during clinical function [63]. The retention of prefabricated, non-adhesive-cemented posts is diminished proportionally to the fit between the post and canal.

If a tooth's canals are oval or irregular in shape, the post space must be meticulously reshaped to produce a round and form-congruent shape. This necessitates the removal of a substantial amount of inner dentin, which weakens the tooth and reduces its resistance to fracture. If there is no form congruence in the canals, it is necessary to use oval posts and preparation tips to avoid excessive tooth reduction [64]. Posts are selected to preserve the inner dentin structure, which necessitates minimal preparation and a high degree of correspondence with the actual root canal diameter.

5.5. Thick or Thin Post

In regard to metal posts, the factor that appears to have the most significant effect on fracture resistance is the post diameter. The larger the diameter, the lower the fracture resistance [65]. This is probably due to the additional dentin that must be removed to make room for a thicker post.

In canals that are ideally shaped, data suggest that the amount of space filled with cement does not affect bond strength; however, this is not the case with root canals that are wide and flared. The high configuration cavity factor (C-factor) within the canal and the shrinkage of polymers in a thick layer of cement can lead to the formation of gaps. Gaps can form along the interface of cement and post or cement and dentin [66]. Moreover, a thick layer of cement increases the likelihood that bubbles or voids will form during application [66].

Solutions have been proposed to overcome the aforementioned issues by reducing the cement gap to a minimum and customizing the post to best fit the root canal shape. These include relining fiber posts with resins or fibers, as well as the use of additional auxiliary posts. It was proposed to use a relining technique to customize the post with RBC to fit the canal's shape, resulting in minimum cement thickness. This is advantageous for several reasons, including the retention of the post, the improvement of tooth fracture strength, and the reduction of stress transferred to the surface of the cervical root [66].

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