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REVIEW ARTICLE

Post Placement and Restoration of Endodontically Treated Teeth: A Literature Review

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The restoration of endodontically treated teeth is a topic that is extensively studied and yet remains controversial from many perspectives. This article reviews the major pertinent literature on this topic, with an emphasis on major decision-making elements in post placement and restoration of endodontically treated teeth. Recommendations are made for treatment planning, materials, and clinical practices from restorative and endodontic perspectives.

There are few subjects in dentistry that have been studied more than the restoration of endodontically treated teeth. Yet, many practical questions and controversies remain in this clinically important element of the treatment plan. Unfortunately, the diversity of published opinions is confusing and may lead to less than optimal treatment selections. Fortunately, there are a number of areas in which the preponderance of research supports specific clinical procedures. The purpose of this review is to organize this topic into its component parts and provide evidence-based principles that are sound from a restorative as well as an endodontic perspective. The article focuses primarily on recent publications, although some of the classic literature also is discussed. With one exception, all the references cited are full-text articles from refereed journals.

ARE ENDODONTICALLY TREATED TEETH DIFFERENT?

Several classic studies have proposed that the dentin in endodontically treated teeth is substantially different than dentin in teeth with "vital" pulps (1–3). It was thought that the dentin in endodontically treated teeth was more brittle because of water loss (1) and loss of collagen cross-linking (3). However, more recent studies (4, 5) dispute this finding. In 1991, Huang et al. (4) compared the physical and mechanical properties of dentin specimens from teeth with and without endodontic treatment at different levels of hydration. They concluded that neither dehydration nor endodontic treatment caused degradation of the physical or mechanical properties of dentin. Sedgley and Messer (5) tested the biomechanical properties of dentin from 23 endodontically treated teeth with an average of 10 yr of post treatment. They compared them to their contralateral "vital" pairs. Aside from a slight difference in hardness, the properties were comparable. The study did not support the conclusion that endodontically treated teeth are more brittle.

These and other studies support the interpretation that it is the loss of structural integrity associated with the access preparation, rather than changes in the dentin, that lead to a higher occurrence of fractures in endodontically treated teeth compared with "vital" teeth (6). Access preparations result in increased cuspal deflection during function (7, 8) and increase the possibility of cusp fracture and microleakage at the margins of restorations. In most endodontically treated teeth, there also is missing tooth structure caused by caries or existing restorations. Randow and Glantz (9) reported that teeth have a protective feedback mechanism that is lost when the pulp is removed, which also may contribute to tooth fracture. Fennis et al. (10) studied more than 46,000 patients from insurance claims and reported significantly more fractures in teeth with endodontic treatment. Taken together, these studies indicate that restorations that enhance structural integrity would be expected to increase the prognosis of endodontically treated teeth exposed to heavy masticatory loading forces.

RESTORATIVE FACTORS THAT AFFECT THE PROGNOSIS OF ENDODONTIC TREATMENT

Contamination of the root-canal system by saliva, often referred to as "coronal leakage" or "coronal microleakage," is a potential cause of endodontic failure (11). In addition, recurrent caries or fractured restorations may lead to recontamination of the root-canal system. Under the best of conditions, the oral environment is rich in microorganisms, and dental restorations must withstand repeated exposure to physical, chemical, and thermal stressors. It is a difficult environment in which to maintain a hermetically sealed system. In vitro studies have shown that exposure of coronal gutta-percha to bacterial contamination can lead to migration of bacteria to the apex in a matter of days (12, 13). Bacterial byproducts and endotoxins can penetrate to the apex in an even shorter time than bacteria (14). When the root canal space has been

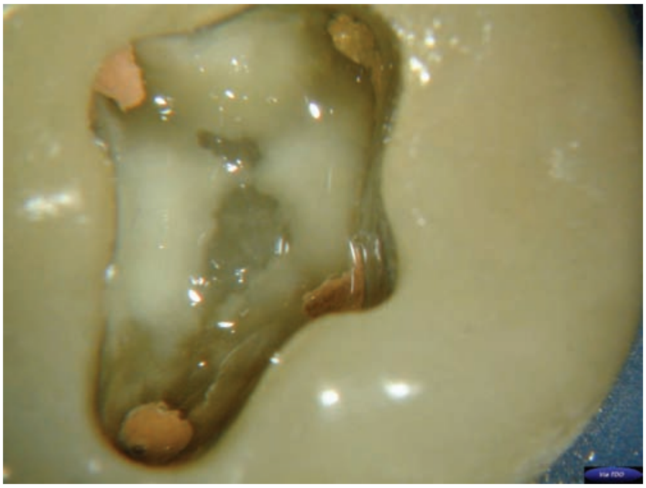

FIG 1. An example of orifice barriers. The orifices were countersunk with a round bur; the floor of the chamber was etched and primed and then sealed with a clear resin. Note how the gutta-percha is visible and easily accessible. Photo courtesy of Dr. Bill Watson, Wichita, Kansas.

grossly contaminated, retreatment should be considered. This is especially true if there has been persistent contamination (15).

Contamination of the root-canal system with bacteria must be prevented during and after endodontic treatment. Aseptic treatment techniques should be used, including the use of a rubber dam. Once root-canal treatment is completed, immediate restoration of the tooth is recommended whenever possible (15). When this is not possible, the root-canal system should be protected by sealing the canals and floor of the pulp chamber with intracoronal barriers (16) (Fig. 1). Bonded materials such as glass-ionomer cement or composite resin are preferred. The canal orifices are countersunk with a round bur, and the floor of the chamber is cleaned of excess gutta-percha and sealer. The chamber floor is etched and primed if a resin material is used or "conditioned" if using glass-ionomer cement or resin-modified glass ionomer. The barrier material is then placed over the floor of the chamber and light cured, and a temporary restoration is placed with or without a cotton pellet in the chamber. The intracoronal barrier protects the root-canal system from contamination during the period of temporization and while the restorative dentistry is performed.

When the tooth is restored with a "permanent" restoration, bonded restorations should be used as much as possible to minimize microleakage (17). The quality of the restorative dentistry performed after root-canal treatment directly impacts the prognosis of the endodontically treated tooth (18–21).

Post spaces, in particular, should be restored immediately because of the difficulties associated with maintaining the temporary seal. In vitro studies by Fox and Gutteridge (22) and Demarchi and Sato (23) showed that teeth restored with temporary posts had about the same amount of contamination as the controls that had no restorations.

There is convincing evidence that cuspal coverage should be provided for posterior teeth. An in vitro study by Panitvisai and Messer (7) demonstrated that access preparations result in greater cuspal flexure, increasing the probability of cuspal fracture. A retrospective study evaluated 1273 endodontically treated teeth to determine which factors were significant causes of failure and concluded that the presence of cuspal coverage was the only significant restorative variable to predict long-term success (24). This conclusion was replicated in an independent, retrospective study of 608 endodontically treated teeth that evaluated the factors that affected survival during a 10-yr period (25). Again, the presence of a cuspal coverage was one of the significant factors that predicted long-term success (25). A recent retrospective study of 400 teeth during a 9-yr period found that endodontically treated teeth with cuspal coverage were six times more likely to survive than those with intracoronal restorations (26). Fennis et al. (10) surveyed private dental practices and reported that "unfavorable," subgingival fractures occurred more often in endodontically treated teeth, a further argument for cuspal coverage. On the contrary, a study by Mannocci et al. (27) reported no difference in failures of endodontically treated teeth treated with fiber posts and composite, with or without cuspal coverage. The recall time was only 3 yr, which may not be long enough to detect differences in failure rates.

Despite strong evidence of the benefits of cuspal coverage, a study of insurance claims by Scurria et al. (28) found that only approximately 50% of endodontically treated, posterior teeth were restored with cuspal coverage restorations. Eckerbom and Magnusson (29) reported similar findings from a survey of restorative dentists.

Preservation of tooth structure is important when restoring the coronal portion of the tooth. Coronal tooth structure should be preserved to provide resistance and retention form for the crown (25, 30–33). This will be discussed in more detail in a subsequent section.

INDICATIONS FOR A POST

The primary purpose of a post is to retain a core in a tooth with extensive loss of coronal tooth structure (34, 35). However, preparation of a post space adds a certain degree of risk to a restorative procedure. Procedural accidents may occur during post-space preparation (Fig. 2). Although rare, these accidents include perforation in the apical portion of the root or into the lateral fluted areas of the midroot, a so-called "strip perforation." The placement of posts also may increase the chances of root fracture (36) and treatment failure (37), especially if an oversized post channel is prepared (38). For these reasons, posts should only be used when other

FIG 2. Post space preparation involves risk. An unnecessary post was placed in this largely intact mandibular molar. Perforation occurred, resulting in eventual loss of the tooth.

options are not available to retain a core. The need for a post varies greatly between the anterior and posterior teeth.

Anterior Teeth

Anterior teeth with minimal loss of tooth structure may be restored conservatively with a bonded restoration in the access opening (24). A post is of little or no benefit in a structurally sound anterior tooth (36, 39, 40), and increases the chances for a nonrestorable failure (36). The same conclusion holds for an anterior tooth with a porcelain veneer (41).

If an endodontically treated anterior tooth is to receive a crown, a post often is indicated. In most cases, the remaining coronal tooth structure is quite thin after it has received root-canal treatment and been prepared for a crown. Anterior teeth must resist lateral and shearing types of forces, and the pulp chambers are too small to provide adequate retention and resistance without a post. The amount of remaining coronal tooth structure and the functional requirements of the tooth determine whether an anterior tooth requires a post.

Molars

Endodontically treated, molar teeth should receive cuspal coverage, but in most cases, do not require a post. Unless the destruction of coronal tooth structure is extensive, the pulp chamber and canals provide adequate retention for a core buildup (42). Molars must resist primarily vertical forces. In those molars that do require a post, the post should be placed in the largest, straightest canal, which is the palatal canal in the maxillary molars and a distal canal in the mandibular molars (Fig. 3). Rarely, if ever, is more than one post required in a molar.

Premolars

Premolars are usually bulkier than anterior teeth, but often are single-rooted teeth with relatively small pulp chambers. For these reasons, they require posts more often than molars. Premolars are more likely than molars to be subjected to lateral forces during mastication. The remaining tooth structure and functional demands are, once again, the determining factors. Because of the delicate root morphology present in some premolars, special care must be exercised when preparing a post space.

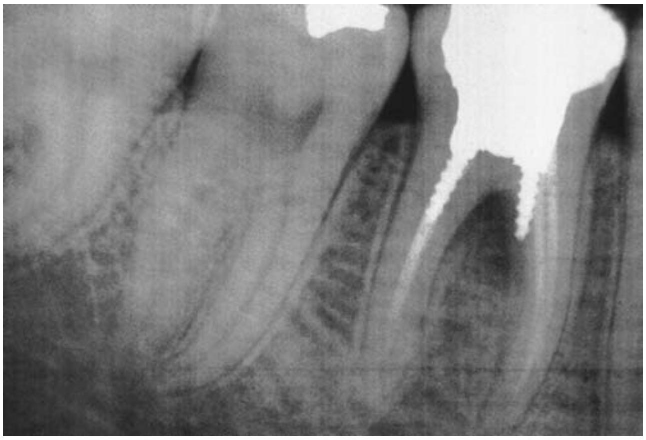

FIG 3. The mesial roots in mandibular molars tend to be thin mesiodistally and the canals often are curved. They are a poor choice for post placement.

FIG 4. This cast post and core had adequate length for retention, but failed because of the lack of resistance form.

IMPORTANT PRINCIPLES FOR POSTS

Retention and Resistance

Post retention refers to the ability of a post to resist vertical dislodging forces. Retention is influenced by the post's length, diameter and taper, the luting cement used, and whether a post is active or passive (43–45). Increasing the length and diameter of the post can increase retention. Parallel posts are more retentive than tapered posts (44, 46). Active posts are more retentive than passive posts (44). Diameter is less important than the other factors listed (47). Even though retention can be increased slightly by enlarging the post diameter, the loss of tooth structure weakens the tooth. Therefore, this is not a recommended method to increase retention.

Resistance refers to the ability of the post and tooth to withstand lateral and rotational forces. It is influenced by the remaining tooth structure, the post's length and rigidity, the presence of antirotation features, and the presence of a ferrule. A restoration lacking resistance form is not likely to be a long-term success, regardless of the retentiveness of the post (Fig. 4) (31, 48).

Failure Mode

An important factor related to resistance is failure mode. All post systems have some percentage of clinical failure. However, some posts cause a higher percentage of failures that result in teeth that are nonrestorable. For example, teeth restored with less rigid posts, such as fiber posts, tend to have failures that are more likely to be restorable (49–52). Teeth prepared with a ferrule also tend to fail in a more favorable mode (53, 54). The type of core material also can affect failure mode. Pilo et al. (55) reported that composite cores tended to fail more favorably than amalgam or gold.

Preservation of Tooth Structure

Whenever possible, coronal and radicular tooth structure should be conserved. In most cases, preparation of a post space should require minimal removal of additional radicular dentin beyond the requirements for root-canal treatment. Further enlargement only weakens the root (36, 38). It has been shown that cemented metal posts do not strengthen the root (39, 40). Bonded posts are reported to strengthen the root initially (56, 57), but this strengthening effect is probably lost over time as the tooth is exposed to functional stresses and the resin bond to dentin weakens (36). Minimal enlargement of the post space means the post must be made of a strong material that can withstand functional and parafunctional forces.

The Ferrule Effect

The "ferrule effect" is important to long-term success when a post is used. A ferrule is defined as a vertical band of tooth structure at the gingival aspect of a crown preparation. It adds some retention, but primarily provides resistance form (33, 54, 58) and enhances longevity (25). Stankiewicz and Wilson published a good review of the topic in 2002 (54). A ferrule with 1 mm of vertical height has been shown to double the resistance to fracture versus teeth restored without a ferrule (58). Other studies have shown maximum beneficial effects from a ferrule with 1.5 to 2 mm of vertical tooth structure (31, 32, 54, 59, 60). A study by al-Hazaimeh and Gutteridge (53) reported no difference in fracture resistance with or without a 2-mm ferrule using prefabricated posts and resin cement. However, the fracture patterns were more favorable when a ferrule was present. The majority of the fractures in the teeth without a ferrule were nonrestorable. A study by Saupe et al. (57) also reports no difference in fracture resistance of teeth with bonded posts with or without a ferrule. In some cases, particularly with anterior teeth, it is necessary to perform crown lengthening or orthodontic eruption of a tooth to provide an adequate ferrule.

Retrievability

Although nonsurgical endodontic treatment enjoys a reputation as a highly successful treatment, some studies have reported lower rates of success (25, 61–63). For this reason, it is important that posts can be retrieved if endodontic retreatment becomes necessary. In most cases, metal posts can be removed effectively and safely. A case series by Abbott (64) reported only one root fracture of 1600 posts removed. Most fiber posts also are reported to be easy to retrieve (65). In contrast, ceramic and zirconium posts are considered to be very difficult and sometimes impossible to retrieve. Retrievability should be considered when treatment planning a post.

PROGNOSIS FOR ENDODONTICALLY TREATED TEETH RESTORED WITH POSTS

Longevity studies are sometimes hard to compare because of differences in study design and because the amount of remaining coronal tooth structure and the quality of the coronal seal are unknown. Nonetheless, they provide some insight. Mentick et al. (66) reported 82% success in 516 anterior teeth restored with metal posts for more than 10 yr. Torbjorner et al. (67) reported a 2.1% failure rate per year for 788 teeth with metal posts during a 5-yr period. Another study calculated the median survival rate of teeth with metal posts to be 17.4 yr (68). Weine et al. (69) reported 9 failures of 138 teeth restored with cast post and cores. The minimum recall time was 10 yr. In a study with a 25-yr follow-up, the longevity of teeth restored after endodontic treatment with a cast post and core and crown were the same as teeth with vital pulps and crowns (70).

Most of the recent clinical studies with posts have examined teeth restored with fiber posts, and the recall periods are fairly short. In a retrospective study, Ferrari et al. (71) reported 3.2% failure of 1306 fiber posts in recalls of 1 to 6 yr. Three types of fiber posts were used. A study of carbon fiber posts reported a 7.7% failure rate in 52 teeth with an average follow-up of 28 months (72). A study of quartz fiber posts reported a 1.6% failure rate in 180 teeth with an average recall period of 30 months (73). Although these studies have relatively short recall periods, the initial results seem promising with this relatively newer technology. However, it will be necessary to continue to monitor for future studies that have longer follow-up periods.

TYPES OF POSTS

Posts are categorized a number of different ways. For the purpose of this review, they will be classified as active or passive, parallel or tapered, and by material composition.

Active Versus Passive Posts

Most active posts are threaded and are intended to engage the walls of the canal, whereas passive posts are retained strictly by the luting agent. Active posts are more retentive than passive posts, but introduce more stress into the root than passive posts (45, 74, 75). They can be used safely, however, in substantial roots with maximum remaining dentin (45). Their use should be limited to short roots in which maximum retention is needed. Representative active and passive post systems are listed in Tables 1 and 2.

TABLE 1. Common passive post systems

Brand Name	Type of Post	Manufacturer
C-Post	Carbon fiber	RTD/Bisco
Aestheti-Plus	Quartz fiber	RTD/Bisco
D.T. Light-Post	Quartz fiber	RTD/Bisco
FibreKor	Glass fiber	Jeneric/Pentron
Cosmopost	Zirconium	Vivadent
Snow Post	Zirconium	Danville
Dentatus metal post	Brass, titanium	Dentatus
Lucent Anchor	Glass fiber	Dentatus
Parapost	Stainless steel, titanium	Coltene/Whaledent
Parapost White	Glass fiber	Coltene/Whaledent

TABLE 2. Common active post systems

Brand Name	Type of Post	Manufacturer
V-Lock	Titanium	Brassler
Flexi-Post	Titanium	EssentialDentalSystems

FIG 5. A titanium alloy post (left) and a stainless-steel post.

Parallel Versus Tapered Posts

Parallel metal posts are more retentive than tapered posts (44, 46), and this also is reported to be true for fiber posts (76). Parallel posts induce less stress into the root, because there is less of a wedging effect, and are reported to be less likely to cause root fractures than tapered posts (49, 58, 77). In a retrospective study, Sorensen and Martinoff (78) reported a higher success rate with parallel posts than tapered posts. Tapered posts, on the other hand, require less dentin removal because most roots are tapered. They are primarily indicated in teeth with thin roots and delicate morphology.

Prefabricated Post and Cores

Prefabricated posts are typically made of stainless steel, nickel chromium alloy, or titanium alloy (Fig. 5). They are very rigid, and with the exception of the titanium alloys, very strong. Because they are round, they offer little resistance to rotational forces. This is not a problem if adequate tooth structure remains, but if minimal tooth structure remains, antirotation features must be incorporated into the post preparation with slots or pins. A bonded material should be used for the core.

Passive, tapered posts offer the least retention of the prefabricated posts, but allow minimal removal of radicular dentin because their tapered shape resembles the overall canal morphology. If adequate canal length is available, they are a good choice, particularly in thin roots such as maxillary premolars (79). Adequate length is considered to be greater than 8 mm (80). Additional retention can be gained with a parallel post (44), by the use of resin cement (81), or by the use of an active post (44).

Many of the prefabricated posts are made of titanium alloys and some are made of brass. Titanium posts were introduced because of concerns about corrosion. Most of the titanium alloys used in posts have a radiodensity similar to gutta-percha and sealer (Fig. 6) and are sometimes hard to detect on radiographs. Titanium posts have low fracture strength, which means they are not strong enough to be used in thin post channels. Removal of titanium posts can be a problem because they sometimes break when force is applied with a post removal instrument. Extended use of ultrasonic energy may be necessary to remove titanium posts, which can be damaging to the tooth or surrounding tissues (Figs. 7–9). For these reasons, titanium and brass posts should be avoided, because they offer no real advantages over the stronger metal posts.

FIG 6. Despite excessive thickness, the titanium alloy post in the maxillary right central incisor fractured. Titanium posts lack adequate strength and can be difficult to remove because of the softness of the metal. Note the similarity in the radiodensity between the titanium alloy post and the gutta-percha and sealer.

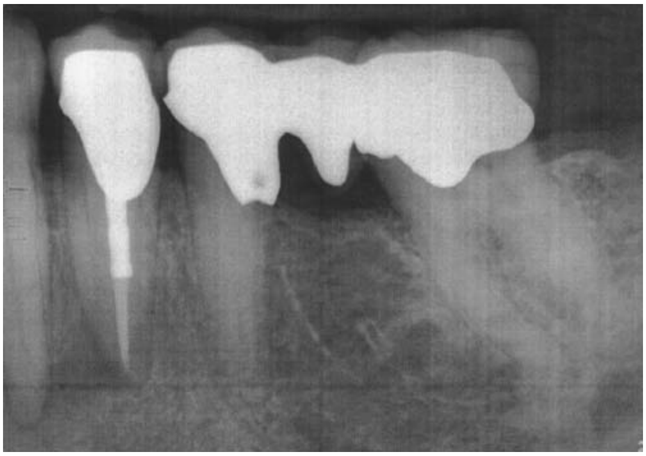

FIG 7. Preoperative view of mandibular left first premolar before post removal and retreatment. Water spray was not used for cooling, and excessive heat was generated during the post removal procedure.

FIG 8. Photograph taken approximately 1 month later. Soft tissue is necrotic adjacent to the tooth.

FIG 9. Radiograph taken shortly before extraction shows necrosis of the alveolar bone.

Custom Cast Post and Cores

Cast post and cores were the standard for many years and are still used by some clinicians. Generally, they do not perform as well as other types of posts during in vitro tests (77) and clinical studies (67). They have fallen from favor because they require two appointments, temporization, and a laboratory fee. Nonetheless, there are studies that report a high rate of success with cast post and cores (69, 82), and they offer advantages in certain clinical situations. For example, when multiple teeth require posts, it is sometimes more efficient to make an impression and fabricate them in the laboratory rather than placing a post and buildup in individual teeth as a chair-side procedure. A cast post and core may be indicated when a tooth is misaligned and the core must be angled in relation to the post to achieve proper alignment with the adjacent teeth. Cast post and cores also may be indicated in small teeth such as mandibular incisors, when there is minimal coronal tooth structure available for antirotation features or bonding. Cast post and cores are generally easy to retrieve when endodontic retreatment is necessary.

Perhaps the biggest disadvantage for cast post and cores is in areas that require an esthetic temporary restoration. Temporary post/crowns are not effective in preventing contamination of the root-canal system (22, 23). When a temporary post and crown is needed, a barrier material should be placed over the obturating material, and the cast post and core should be fabricated and cemented as quickly as possible.

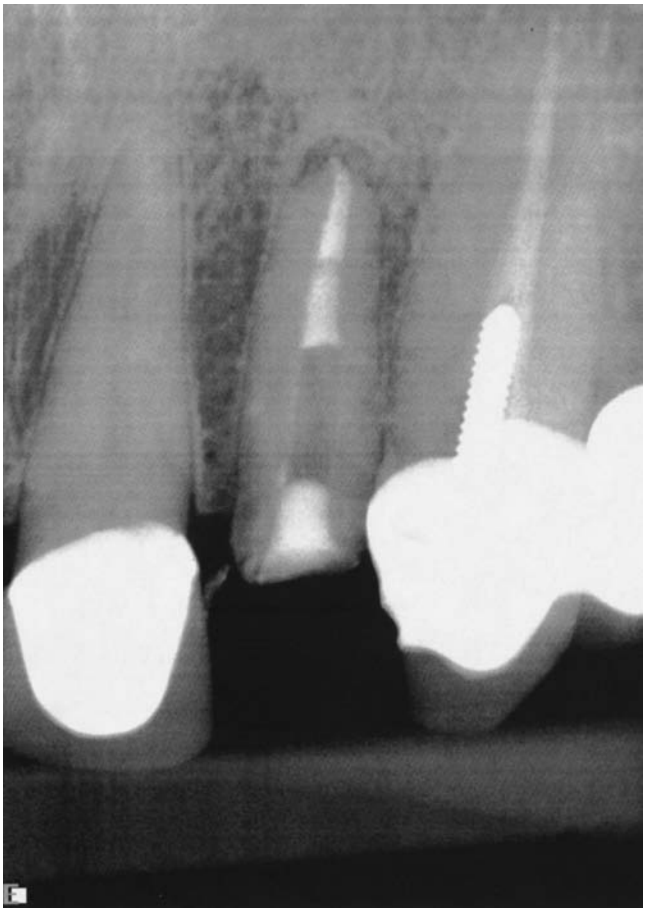

FIG 10. Temporary post/crowns do a poor job of preventing contamination of the apical gutta-percha. If a post and buildup can not be placed immediately, a barrier should be placed at the apical extent of the post space.

In Fig. 10, a post was removed and endodontic treatment was performed. The apical segment was packed with gutta-percha and a self-curing, glass-ionomer material was placed adjacent to the gutta-percha to protect it from contamination during the period of temporization and while clinical procedures are performed by the restorative dentist. A self-curing material should be used in most cases because of the difficulty of obtaining effective light curing deep in the canal. Other materials may be used for this purpose such as zinc oxide and eugenol materials or self-curing dentin adhesives and composites.

Ceramic and Zirconium Posts

One factor that has reduced the use of metal posts is esthetics. Metal posts are visible through the more translucent all-ceramic restorations and even with less translucent restorations may cause the marginal gingiva to appear dark. These concerns have led to the development of posts that are white and/or translucent. Among the materials used for "esthetic" posts are zirconium and other ceramic materials. These posts will work clinically, but have several disadvantages. As a group, they tend to be weaker than metal posts, so a thicker post is necessary, which may require removal of additional radicular tooth structure. Zirconium posts can not be etched, therefore, it is not possible to bond a composite core material to the post, making core retention a problem (83). Retrieval of zirconium and ceramic posts is very difficult if endodontic retreatment is necessary or if the post fractures. Some ceramic materials can be removed by grinding away the remaining post material with a bur, but this is a tedious and dangerous procedure. It is impossible to grind away a zirconium post. For these reasons, ceramic and zirconium posts should be avoided.

Fiber Posts

Carbon fiber posts gained popularity in the 1990s. Their main proposed advantage was that they were more flexible than metal posts and had approximately the same modulus of elasticity (stiffness) as dentin. When bonded in place with resin cement, it was thought that forces would be distributed more evenly in the root, resulting in fewer root fractures. This is generally born out with in vitro and in vivo studies (Tables 3 and 4).

The original carbon fiber posts were dark, which was a potential problem when considering post-restorative esthetics, as discussed previously. More recent versions are white. They are relatively easy to remove (65) by boring through the middle of the post with an ultrasonic or rotary instrument. The orientation of the fibers helps keep the removal instrument in the proper alignment.

Other types of fiber posts also are available, including quartz fiber, glass fiber, and silicon fiber posts (Figs. 11 and 12). They are claimed to offer the same advantages as the carbon fiber posts, but with better esthetics. Because they are newer, there is currently less research available on them than carbon fiber posts. Most fiber posts are relatively radiolucent and have different radiographic appearance than traditional posts (Figs. 12 and 13).

Studies Comparing Post Systems In Vitro

Most of the in vitro studies comparing fracture strength of post systems used continuous or intermittent loading. In tests of fracture load or failure load, the post/tooth complex is loaded with a continuous force on a test machine until failure, and the load values are recorded and compared. In recent years, cyclic or intermittent loading has become more popular, because it is thought to be more representative of the forces that occur in vivo (84). Cyclic loading is continued until failure, or to a specified number of cycles, and the results are reported as the number of cycles to failure, or as the number of failures when cycling loading was stopped. Some of these studies also reported on failure mode.

The results were mixed among studies using continuous loading, but are slightly more favorable toward metal posts. Cormier et al. (51) studied posts made of stainless steel, gold, and four commercial brands of fiber posts and found that teeth with stainless-steel posts had the highest fracture load, whereas teeth with one of the quartz fiber post systems had the lowest. Martinez-Insua et al. (49) reported higher fracture loads with cast gold than carbon fiber. Newman et al. (52) compared stainless-steel posts with three brands of fiber posts and found higher failure loads in teeth with the stainless-steel posts. Sidoli et al. (85) compared cast gold, stainless steel, and carbon fiber and reported that teeth containing metal posts were equivalent and had significantly higher failure loads than teeth containing carbon fiber posts. Akkayan et al. (50) compared titanium posts with glass fiber, quartz fiber, and zirconium. They reported the highest failure loads for the teeth with quartz fiber posts. Ottl et al. (86) reported the highest failure loads with carbon fiber, followed by stainless steel and ceramic. Zirconium had the lowest values. Raygot et al. (87) found no difference between cast gold, stainless-steel, and carbon fiber posts.

Similar mixed results were reported in studies that used intermittent loading, also called cyclic loading. Isador et al. (88) compared cast gold, titanium, and carbon fiber posts and reported better results with the metal posts than the carbon fiber post. Reid et al. (89) compared titanium posts with three carbon fiber post and one quartz fiber post, and reported no differences. Butz et al. (83) used cyclic loading, followed by continuous loading, to compare cast gold, titanium with a composite core, and zirconium with composite or ceramic cores. The zirconium/composite group performed significantly worse than the other post systems, which were equivalent.

Four of the studies evaluated failure mode in addition to fracture loads. Three of the studies reported more favorable failure modes with fiber posts than metal posts (50–52). Martinez-Insua et al. (49) reported similar results but commented that the fracture loads exceeded those ordinarily found clinically.

Several studies compared the retention of post systems. Purton and Love (90) reported greater retention with stainless-steel posts than carbon fiber posts. Both were luted with resin cement. Gallo et al. (91) reported that stainless-steel posts luted with zinc phosphate cement had greater retention than a variety of fiber posts luted with resin cement. Qualtrough et al. (76) reported higher retentive values with a quartz fiber post than titanium, glass fiber, or carbon fiber posts. The same resin cement was used for all post systems. Drummond (92) reported no difference in retention between stainless steel and three fiber posts, all with the same resin-luting agent. The results of studies that compared post systems in vitro and in vivo are summarized in Tables 3 and 4.

PREPARING THE POST SPACE

As stated earlier, preservation of radicular dentin is important, so there should be minimal enlargement of the canal beyond the shape that was developed during root-canal instrumentation. In most cases, it is best that the clinician who performs the root-canal treatment also prepares the post space, because that person is intimately familiar with the canal anatomy. Gutta-percha can be removed with the aid of heat or chemicals, but most often the easiest and most efficient method is with rotary instruments. The classic literature generally states that the timing of the post-space preparation does not matter (93, 94). A more recent article showed that immediate post preparation was better (95), whereas another showed no difference (96).

A number of authors make recommendations about post length. A review article by Goodacre and Spolnik (97) recommends post length equal to ¾ of root canal length, if possible, or at least equal to the length of the crown. They caution that 4 to 5 mm of gutta-percha should remain apically to maintain an adequate seal. In a retrospective study, Sorensen and Martinoff (78) reported 97% success if the post length at least equaled the crown height. According to Neagley (80), 8 mm is the minimum length required for a post. It has been shown that forces concentrate at the crest of bone during masticatory function (38). In teeth with metal posts,

TABLE 3. In vitro comparative post studies

Study	Post Systems	Test(s)	Results	Comments
Akkayan et al., 2002 (50)	Titanium, glass fiber, quartz fiber, zirconium	Failure load	Highest failure loads for quartz fiber posts Failure mode more favorable with fiber posts	Supports the use of fiber posts over titanium and zirconium
Butz et al., 2001 (83)	Cast gold, titanium/composite, zirconium/composite, zirconium/ceramic	Cyclic loading in an artificial mouth, and then static loading to fracture	Zirconium/composite 63% survival in artificial mouth, others 94% or better; Zirconium/composite lowest fracture strength	Zirconium/composite combination not recommended for clinical use
Cormier et al., 2001 (51)	Stainless steel, cast gold, and four fiber posts	Fracture load and restorability	Stainless-steel posts had the highest failure threshold, glass fiber (Fibrekor) the lowest	Most of the fiber post failures were restorable, most of the metal failures were nonrestorable
Drummond, 2000 (92)	Stainless steel and three fiber posts with single and multistep bonding systems	Retention and flexural strength with thermocycling	No differences in retention. Fiber posts flexural strength decreased with thermocycling	Clinical significance of the loss of flexural strength of fiber posts caused by thermocycling is not known
Drummond and Bapna, 2003 (84)	Zirconium, carbon, quartz, glass fiber bar specimens tested dry and wet	Flexural strength, static and cyclic loading, with/without thermocycling	Carbon and glass fiber had the highest flexural strength. The fiber posts lost 11–24% of their flexural strength with cyclic loading and thermocycling	Many of the other fiber post studies were performed without cyclic loading or thermocycling
Gallo et al., 2002 (91)	Stainless steel/zinc phosphate 1.25 mm diameter, fiber post/resin in 1, 1.25, 1.5 mm diameters	Retention	SS post more retentive than any of the fiber post groups	Contradicts the belief that resin cements provide more retention than zinc phosphate cements
Heydecke and Peters, 2002 (129)	Cast gold and prefabricated metal posts	Meta analysis of 10 in vitro and 6 in vivo studies	No difference in fracture data between groups	Survival rates for cast post and cores 86–88% in vivo
Isidor and Brondum, 1992 (77)	Tapered cast gold post and cores, prefabricated parallel titanium posts with composite cores	Intermittent loading until failure	Titanium posts were more resistant to failure	Specimens were sectioned after failure. The titanium posts showed better adaptation to canal walls
Isidor et al., 1996 (88)	Cast gold, carbon fiber, titanium and composite	Intermittent loading	Carbon fiber posts had lowest failure rate	Studied carbon fiber and compared with 1992 results
Martinez-Insua et al., 1998 (49)	Cast gold, carbon fiber	Fracture load	Higher fracture load with cast post and core, but failure mode was more unfavorable	Fracture loads required for failure are rarely seen clinically.
Mannocci et al., 1999 (56)	Carbon-quartz fiber, quartz fiber, zirconium, controls with no post	Intermittent loading in a wet environment	Fewer fractures in the fiber posts than zirconium or controls	Authors concluded that the fiber posts strengthened the roots
Newman et al., 2003 (52)	Stainless steel and two glass fiber posts, Polyethylene fiber reinforced composite (Ribbond)	Fracture resistance in narrow and flared canals	SS posts had higher failure loads than fiber posts for narrow or flared canals	Fiber posts had more favorable failure modes.
Ottl et al., 2002 (86)	Five metal post systems, ceramic, zirconium, carbon fiber, all cemented with resin, no post (control)	Fracture load	Carbon fiber posts had the highest fracture loads followed by metal posts and ceramic posts. Zirconium values were lowest	The roots were made of a composite material with properties similar to dentin. Controls were slightly higher than the zirconium group.
Purton and Love, 1997 (90)	1-mm stainless steel, carbon fiber, both with resin cement	Rigidity and retention	The stainless steel posts were more rigid and more retentive	Author does not recommend carbon fiber posts for use in thin diameters.

SS = stainless steel.

TABLE 3. *Continued*

Study	Post Systems	Test(s)	Results	Comments
Qualthrough et al., 2003 (76)	Titanium, quartz fiber, glass fiber, carbon fiber with one resin cement	Retention	Quartz fiber was the most retentive. The other posts were equivalent.	Parallel fiber posts were more retentive than tapered fiber posts.
Raygot et al., 2001 (87)	Cast gold, stainless steel, carbon fiber	Fracture load	No difference in fracture load or failure mode	Authors concluded the fiber post offered no advantages over the metal posts.
Reid et al., 2003 (89)	Titanium with zinc phosphate, three carbon and one quartz fiber post with composite	Cyclic loading, microleakage with thermocycling	No difference in displacement of cores, metal posts exhibited more microleakage	Using two cements confuses the issue of microleakage and post materials. Was the post or the cement responsible for the difference?
Sidoli et al., 1997 (85)	Cast gold, stainless steel, carbon fiber with resin cement, controls with no post	Fracture load	Metal posts equivalent, carbon fiber posts lowest mean values	Control teeth had the highest values.

SS = stainless steel.

forces also concentrate at the end of the post. Therefore, a post should always extend apically beyond the crest of bone (38).

According to traditional teachings, a minimum of 3 to 5 mm of gutta-percha should remain in the apical portion of the root to maintain an adequate seal (93, 98, 99). A recent study by Abramovitz et al. (100) demonstrated that 3 mm of gutta-percha provides an unreliable apical seal, therefore, 4 to 5 mm is recommended.

LUTING CEMENTS

Any of the current luting cements can be used successfully with a post if the proper principles are followed. The most common luting agents are zinc phosphate, resin, glass ionomer, and resin-modified glass-ionomer cements.

The recent trend has been toward resin cements, because they increase retention (33, 101), tend to leak less than other cements (89, 102, 103), and provide at least short-term strengthening of the root (33, 56). A study by Bachicha et al. (102) reported less leakage when resin cement was used with stainless-steel and carbon fiber posts compared with zinc phosphate or glass-ionomer cements. Similar results were reported by Reid et al. (89). Junge et al. (81) reported that posts cemented with resin cements were more resistant to cyclic loading than those cemented with zinc phosphate or resin-modified glass-ionomer cement. Bonded resin cements have been recommended for their strengthening effect in roots with thin walls (57, 104). Examples include immature teeth or teeth with extensive caries. Resin may be bonded to some types of posts, so theoretically, the dentin/resin/post can be joined via resin adhesion into one unit, at least for a period of time.

Unfortunately, resin cements have some disadvantages. Resin cements are more “technique sensitive” than most of the other luting cements. They require extra steps such as preparing the canal walls with acid or EDTA and placing a dentin-bonding agent. Contamination of the dentin or post can be a problem. Predictable delivery of etchants and adhesive materials deep into the canal space also can be problematic. The post should be cemented with an auto-cure or dual-cure resin cement (105) that is mixed and placed with the post. These steps must be performed quickly and carefully to assure that the post is completely seated.

It is generally believed that eugenol-containing root-canal sealers inhibit the polymerization of resin cements. It is reported that this problem can be avoided by thorough cleaning and etching of the canal walls (16, 103, 106, 107). According to a study by Varela et al. (108), concerns about negative effects of sodium hypochlorite irrigants on resin adhesion to dentin also are unfounded.

The fourth-generation adhesives systems (3-step systems) provide a better adhesive seal to radicular dentin than the more recent fifth-generation 2-step systems (103, 109). Self-cure or dual-cure cements should be used because of limited light penetration into the root, even with translucent posts (105).

CORE MATERIALS

The purpose of the post is to retain the core, which in turn helps retain the crown. With cast post and cores, the core is formed on the post directly on the tooth or indirectly on a cast. The general shape and orientation of the core is developed during fabrication. Prefabricated posts are used in combination with a restorative build-up material which is formed after cementation of the post. The choices are amalgam, composite resin, or glass-ionomer materials.

The glass-ionomer materials, including resin-modified glass ionomer, lack adequate strength as a buildup material (110, 111) and should not be used in teeth with extensive loss of tooth structure. When there is minimal loss of tooth structure and a post is not needed, glass-ionomer materials work well for block-out, such as after removal of an MOD restoration.

Amalgam has been used as a buildup material, with well-recognized strengths and limitations. It has good physical and mechanical properties (112, 113) and works well in high-stress areas. In many cases, it requires the addition of pins or other methods to provide retention and resistance to rotation. Placement can be clumsy when there is minimal coronal tooth structure, and the crown preparation must be delayed to permit the material time to set. Amalgam can cause esthetic problems with ceramic crowns and sometimes makes the gingiva look dark. There also is a risk of tattooing the cervical gingiva with amalgam particles during the crown preparation. For these reasons, and potential concern about mercury, it is no longer widely used as a buildup material. Amal-

TABLE 4. Retrospective post studies

Study	Post Systems	Test(s)	Results	Comments
Ferrari et al., 2000 (71)	1304 carbon or quartz fiber posts, 4 luting agents	Failure rates at 1–6 yr recalls	3.2% failure	25 posts debonded during removal of temporary crowns
Ferrari et al., 2000 (128)	100 cast posts, 100 carbon fiber posts	Failure rates at 4 yr	Cast posts 16% failure, fiber 5%	9% root fracture with cast posts
Fredricksson et al., 1998 (130)	236 carbon fiber posts	Failure rates at 27–41 months	No post-related failures	Five teeth extracted
Glazer, 2000 (72)	59 carbon fiber posts	Failure rates at 6.7–45.4 months	7.7% failure	Cumulative survival rate of 89.6%
Malferrari et al., 2003 (73)	180 quartz fiber posts	Failure rate at 30 months	1.7% failure	All failures occurred during temporary crown removal
Mentink et al., 1993 (66)	516 cast post/cores by dental students	Survival rate	82% survival in anterior region	Loss of retention most common reason for failure
Torbjorner et al., 1995 (67)	456 cast tapered posts and 322 prefab parallel posts	Failure rate at 4–5 yr	Cast posts 15% failure, prefab posts 8% failure	Loss of retention most common reason for failure for both systems
Walton, 2003 (82)	Cast or prefabricated posts under 515 metal-ceramic FPDs	Failure rate at 1–14 yr	No difference in failure rates	No difference in anterior teeth and premolars
Weine et al., 1991 (69)	Cast post and cores	Failure rate at >10 yr	6.5% failure	5/9 of failures were not post-related

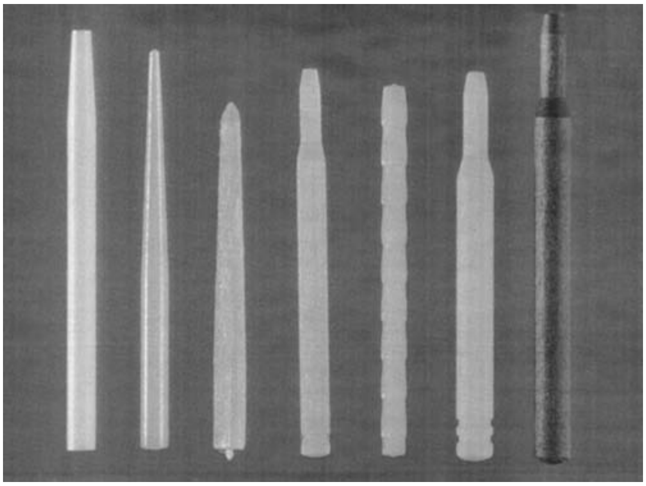

FIG 11. Examples of nonmetal posts. From left: two zirconium posts, two glass fiber posts, two quartz fiber posts, and a carbon fiber post.

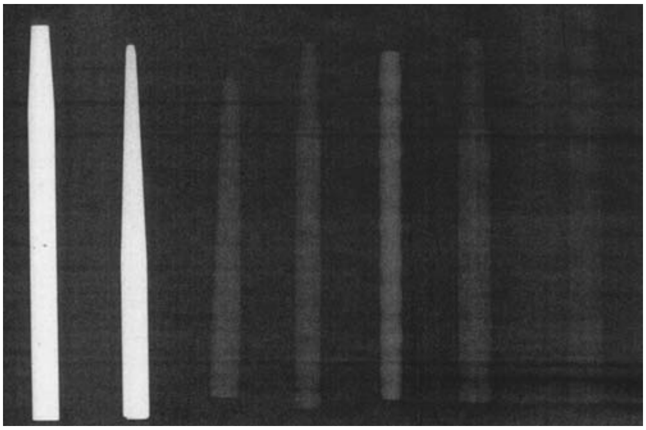

FIG 12. Radiographic images of the posts in Fig. 11.

gam has no natural adhesive properties and should be used with an adhesive system for buildup (17).

Currently, composite resin is the most popular core material and has some characteristics of an ideal buildup material. It can be bonded to many of the current posts and to the remaining tooth structure to increase retention (114). It has high tensile strength and the tooth can be prepared for a crown immediately after polymerization. Pilo et al. (55) showed that composite cores have fracture resistance comparable to amalgam and cast post and cores, with more favorable fracture patterns when they fail. It is tooth colored and can be used under translucent restorations without affecting the esthetic result. On the negative side, composite shrinks during polymerization, causing gap formation in the areas in which adhesion is weakest. It absorbs water after polymerization, causing it to swell (115), and undergoes plastic deformation under repeated loads (112, 113). Adhesion to dentin on the pulpal floor is generally not as strong or reliable as to coronal dentin (116). Strict isolation is an absolute requirement. If the dentin surface is contaminated with blood or saliva during bonding procedures, the adhesion is greatly reduced. Although composite resin is far from ideal, it is currently the most widely used buildup material. Composite is not a good choice, however, with minimal remaining coronal tooth structure, particularly if isolation is a problem.

FIG 13. Radiographic view of a glass fiber post in the maxillary left central incisor. Radiographs courtesy of Dr. Sashi Nallipati, Ocho Rios, Jamaica.

ARE THE NEW NONMETAL POSTS BETTER?

Metal posts have been the standard for many years in restorative dentistry, but the recent trend in clinical practice has been toward nonmetal posts. Many claims have been made about the fiber posts, in particular, by the manufacturers and their spokesmen. Although bonded, nonmetal posts seem promising, the research is not entirely supportive and there are still unanswered questions.

Do Bonded Posts Really Strengthen Roots?

That answer seems to be "yes," at least in the short term. Bonded posts are reported to strengthen the root initially (57, 103), but this strengthening effect is probably lost with time. Resin adhesion to dentin has been shown to decrease with time in vitro (117–120) and in vivo (121). Thus, it is likely that any initial benefit obtained from dentin adhesion may be lost because of the repeated thermal, chemical, and mechanical stresses of the oral cavity. Laboratory research on the strengthening effects of bonded posts needs to incorporate aging and cyclic loading to determine if the strengthening effect is lasting or only transient.

Is Bonding to Radicular Dentin a Problem?

Dentin adhesion can be somewhat unpredictable because of the variability of dentin in general (122), and radicular dentin in particular. With the exception of one study (123), adhesion to radicular dentin is reported to be more unpredictable than to coronal dentin, so the quality of the bond may be somewhat compromised and subject to degradation (105, 109, 124–126). Because of morphological differences in radicular dentin (i.e. reduction in dentinal tubule density and altered collagen expression), adhesion is more problematic in apical dentin compared with coronal dentin (127).

Is it Beneficial to Have a Post with the Same Modulus of Elasticity as Dentin?

This is a difficult question to answer based on current research. In theory, a post that flexes together with the tooth during function should result in better stress distribution and fewer fractures. This part of the question is supported by the literature (51, 52, 128). The unanswered question is whether having a "flexible" post allows movement of the core, resulting in increased microleakage under the crown. This question is especially important when there is minimal remaining coronal tooth structure. Because the post is considerably thinner than the tooth, it may be necessary that the post have a higher modulus of elasticity (greater stiffness) to compensate for the smaller diameter. Additional research is needed to optimize the mechanical properties of fiber posts.

Other Unanswered Questions About "Flexible" Posts

Studies by Drummond and colleagues have demonstrated that fiber posts lose flexural strength after thermocycling (84, 92) and cyclic loading (84). The significance of these findings is not clearly understood, but according to these articles, "utilization in the oral environment enhances their degradation and potentially shortens their clinical life" (84). Further research in the laboratory and long-term clinical studies will determine whether these findings are clinically significant.

CONCLUSIONS

If certain basic principles are followed in the restoration of endodontically treated teeth, it is possible to achieve high levels of clinical success with most of the current restorative systems. These principles include:

1. Avoid bacterial contamination of the root-canal system
2. Provide cuspal coverage for posterior teeth
3. Preserve radicular and coronal tooth structure
4. Use posts with adequate strength in thin diameters
5. Provide adequate post length for retention
6. Maximize resistance form including an adequate ferrule
7. Use posts that are retrievable.

Most post systems can be used successfully if these principles are followed, but some posts should be excluded because of inadequate strength and difficulty in retrieval. Titanium alloys are relatively weak and may be subject to fracture in thin diameters. They also are more difficult to retrieve than other metal posts. Any benefits they offer are more than offset by their disadvantages. Active, threaded posts should only be used when maximum retention is required. They impart stress into the root structure and are difficult to retrieve. Ceramic and zirconium posts are not retrievable in most cases and should be avoided.

The trend in clinical practice is toward fiber posts, and the literature is generally, although not overwhelmingly, favorable toward them. Their performance in vitro approximates that of metal posts and most studies agree that their failure mode is more favorable than with metal posts. Clinical studies have been favorable to date. The use of fiber posts will probably continue to grow, assuming that future long-term clinical research studies report similar levels of success as seen in the relatively short-term studies already published. Further modifications of their physical and mechanical properties will probably also improve their clinical performance.

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