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Restoration of endodontically treated teeth

Steven M. Morgano, DMD[a,b,*], Antonio H.C. Rodrigues, DDS, MSD[a,c], Carlos Eduardo Sabrosa, DDS, MSD, DScD[d]

[a] *Department of Restorative Sciences and Biomaterials, Boston University Goldman School of Dental Medicine, 100 East Newton Street, Room G219 Boston, MA 02118-2392, USA*

[b] *Division of Postdoctoral Prosthodontics, Boston University Goldman School of Dental Medicine, 100 East Newton Street, Room G219, Boston, MA 02118-2392, USA*

[c] *Division of Graduate Fixed Prosthodontics, School of Dentistry, Catholic University, Dom José Gaspar 500, Belo Horizonte, MG 30000, Brazil*

[d] *Department of Operative Dentistry, Universidade do Estado do Rio de Janeiro, Av. Ataulfo de Paiva 482 sl. 502, Rio de Janeiro, RJ 22440-030, Brazil*

Endodontic therapy is used routinely in contemporary dentistry, but a satisfactory restorative solution is necessary after the root canal has been treated. There are a variety of materials and techniques advocated for restoring pulpless teeth, and hundreds of studies devoted to this subject have been published in the dental literature. Although knowledge and understanding of the complications associated with pulpless teeth have improved over the last few decades, this topic remains complex and controversial [1]. These restored pulpless teeth are not always trouble free, regardless of the restorative method used; however, a restorative approach that is consistent with contemporary scientific knowledge improves the prognosis [1].

The issue of restoring pulpless teeth is commonly associated with the topic of posts. At one time, a post was regarded as a method of reinforcing a pulpless tooth [2]. Nevertheless, most contemporary studies have suggested that a post weakens the tooth rather than reinforcing it [1,3–6].

* Corresponding author. Division of Postdoctoral Prosthodontics, Boston University Goldman School of Dental Medicine, 100 East Newton Street, Room G219, Boston, MA 02118-2392, USA.

E-mail address: smorgano@bu.edu (S.M. Morgano).

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Increasing the probability of success of single-rooted pulpless teeth restored with posts and cores

Despite its weakening effect on the tooth, a post is indicated when there is inadequate remaining coronal tooth structure to retain a core for an artificial crown, and the majority of single-rooted pulpless teeth are restored with posts and cores. A 10% complication rate was calculated for teeth restored with posts in a comprehensive meta-analysis of clinical studies in fixed prosthodontics [7]. Although it is impossible to determine the reasons for most of these reported complications, misunderstanding by dentists of contemporary biomechanics could be responsible for some of these complications. Dentists seem slow to adapt their treatment approaches to new knowledge [8]. A comprehensive nationwide survey of dentists' philosophies and techniques of restoring endodontically treated teeth reported by Morgano [8] in 1994 indicated major differences in the dentists' beliefs and treatment methods. For example, approximately 50% of the respondents believed in the ability of a post to reinforce a pulpless tooth [8].

Length of the post

A classic retrospective study of the clinical outcomes of restored endodontically treated teeth by Sorensen and Martinoff [4] indicated that longer posts were associated with higher success rates. When the length of the posts equaled the length of the clinical crowns, the failure rate was 2.5%. Posts that were one quarter the length of their respective clinical crowns recorded a failure rate of 25%—a tenfold increase [4]. A study of teeth with vertical root fractures by Fuss et al [9] reported that two-thirds of the posts associated with vertically fractured endodontically treated teeth were extremely short, terminating in the cervical third of the roots. In vitro biomechanical studies also have suggested that better stress distribution occurred with longer posts [10–12].

The ferrule effect

A post in a pulpless tooth can transfer occlusal forces intraradicularly and predispose to vertical fracture of the root [3,5]. If the artificial crown extends apical to the margin of the core and encircles sound tooth structure for 360°, the crown serves as a reinforcing ring or "ferrule" to help protect the root from vertical fracture [6]. A number of studies have reported improved fracture resistance for pulpless teeth restored with a ferrule [13–16]. A recent in vitro study by Isidor et al [17] that evaluated the effects of post length and ferrule length on resistance to dynamic loading of bovine teeth in vitro reported that the mean resistance to failure was greatest for the group restored with a combination of the longest posts (10 mm) and the longest ferrules (2.5 mm).

A ferrule also helps to protect the integrity of the cement seal of the artificial crown. An in vitro study by Libman and Nicholls [18] reported that there was improved resistance to fatigue failure of the cement seal of the crown when the crown margin extended at least 1.5 mm apical to the margin of the core. Torbjörner et al [19] retrospectively evaluated the clinical success and failure characteristics of teeth restored with posts and artificial crowns and reported a higher potential for the fracture of posts when the cemented crowns did not provide a ferrule effect. Also, if the margin of the crown and the margin of the core are at the same cervical level, the retention of the crown depends entirely on the retentive capacity of the post, and the post is more likely to become dislodged.

A contrabevel has been advocated when preparing a tooth for a cast post and core to produce a cast core with a collar of metal that encircles the tooth and serves as a secondary ferrule independent of the ferrule provided by the cast crown [20]. Nevertheless, there seems to be little advantage to this secondary ferrule as a component of the core [21]. A study by Loney et al [22] reported significantly higher mean stresses with collared cores, suggesting that incorporating a ferrule as an integral part of a cast core was undesirable.

Because there is no pulp to expose with a pulpless tooth, many dentists believe they can "over prepare" the coronal portion of a pulpless tooth to provide maximal space for the dental laboratory technician to develop the best esthetic result with the artificial crown. However, current knowledge suggests that dentists should be conservative of coronal tooth structure when preparing pulpless teeth for complete crowns to ensure an adequate ferrule effect. The most commonly accepted guideline for this ferrule is a minimal height of 1.5 to 2 mm of intact tooth structure above the crown margin for 360° around the circumference of the tooth preparation [1]. If insufficient tooth structure remains coronal to the gingival margin to develop this ferrule, surgical crown lengthening [23] or orthodontic extrusion [24] should be considered to expose additional tooth structure. Extraction of the tooth with replacement by conventional or implant-supported prosthodontics is usually a better option whenever an adequate ferrule cannot be obtained [1].

Apical seal

After preparation of a root canal for a post, the only barrier against reinfection of the periapical region is the remaining gutta percha. To avoid violation of the apical seal, the dentist should retain at least 4 to 5 mm of apical gutta percha [25,26]. This minimal amount of gutta percha may limit the length of the post; however, when there is a conflict between the guidelines for the post's length and the length of the apical seal, preservation of an intact apical seal must prevail. Also, once the post space has been prepared, the post should be cemented as soon as is practical because delaying the placement of the post can increase the potential for apical leakage [27].

Design of the post for conservation of radicular tooth structure

Preservation of radicular tooth structure is a vitally important consideration when selecting the design of the post. Posts may be parallel sided or tapered. Two studies of tapered posts reported an increased potential for wedging stresses within the root [28,29]. However, another study suggested no difference in stress distribution between tapered and parallel-sided posts that were designed with adequate length [11]. Custom-made cast posts and cores are potentially more conservative of tooth structure compared with prefabricated posts because the custom cast post is designed to fit the tooth. With a prefabricated post, the dentist must instrument the root to allow it to fit the dimensions of the post. This issue is especially important for teeth with small tapered roots, such as maxillary lateral incisors and mandibular incisors [30]. The thin tapered roots of these incisors can be weakened substantially if instrumented to fit a prefabricated post [30].

With single-rooted teeth, slightly tapered posts are easier to place because most roots are tapered and the root canal had been previously instrumented with tapered endodontic files to form a continuously tapering cone before obturation. Tapered posts help preserve dentin in the apical region of the post, reducing the chances of excessive removal of dentin in this area [31]. A tapered post is less retentive than a parallel-sided post [32], but a clinical study of tapered posts reported no problems with retention when the lengths of the posts were adequate [33].

Overall guidelines for posts in pulpless single-rooted teeth

Custom-made cast posts and cores are the recommended post system for single-rooted teeth when substantial coronal tooth structure is missing. Fig. 1 summarizes the desirable features of a cast post and core for a single-rooted tooth. For the best chances of success, the dentist should remove the gutta percha to the desired depth without removing any additional tooth structure; this should be followed by removal of the endodontic sealer from the walls of the root canal with a rigid engine reamer (Fig. 2). The post should be designed to fit the available space in the prepared canal [6]. The post should be as long as practical, with a slight taper. A minimum of 4 to 5 mm of gutta percha must be preserved. There should be a positive stop for the core on the coronal tooth structure to prevent the post from being forced apically, and the crown should provide a 1.5- to 2-mm or greater ferrule. Commonly, premolars, whether single-rooted or dual-rooted, are restored with a similar protocol. With a dual-rooted maxillary first premolar, one canal is usually chosen for the post, and placement of the post in the palatal canal is generally preferred [34].

Increasing the probability of success of pulpless molars

Sorensen and Martinoff [4] reported an extremely high failure rate for posterior pulpless teeth when these teeth lacked a restoration that covered

Fig. 1. For the highest probability of success, (1) the cast post should follow the natural taper of the instrumented root canal, conserving as much radicular tooth structure as possible; (2) the post should be as long as practical, preserving 4 to 5 mm of apical gutta percha seal; (3) the coronal tooth structure should be prepared to provide a positive apical stop for the core; and (4) the artificial crown should encircle at least 1.5 to 2 mm of sound tooth structure apical to the margin of the core for 360°.

the cusps, and Aquilino and Caplan [35] found a significantly improved success rate for pulpless teeth that were crowned (Fig. 3). These retrospective clinical studies strongly support the placement of a crown or onlay on a pulpless posterior tooth. Premolars usually are restored with crowns supported by cast posts and cores, but molars are most often restored with crowns supported by direct core reconstructions. Materials that have been recommended for use as direct cores include silver amalgam, composite resin, and glass ionomer-based materials [36].

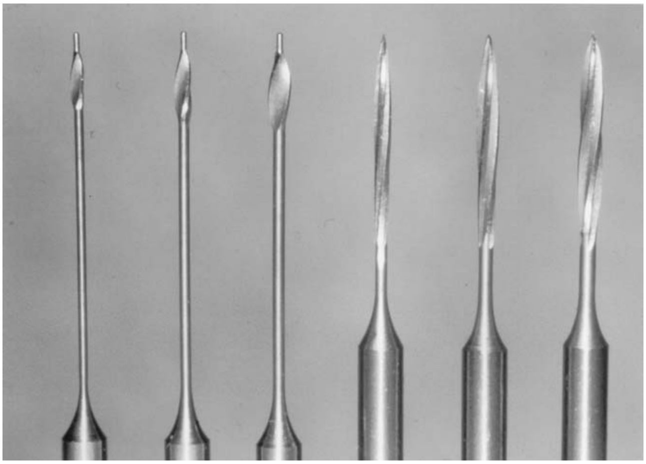

Fig. 2. The gutta percha should be removed to the desired depth with flexible, bud-shaped rotary instruments (Gates Glidden Drills; Moyco Union Broach, York, PA) or with a heated instrument. Residual endodontic sealer should be removed from the walls of the canal with rigid, straight-sided engine reamers (Peeso Reamers; Moyco Union Broach).

Selection of direct core material

When there is substantial residual coronal dentin, the choice of core material is relatively unimportant [1]. However, when only several millimeters of tooth structure remain coronal to the gingival margin, the physical properties of the core reconstruction profoundly influence the long-term prognosis of the restored pulpless tooth [37]. Silver amalgam is the core material of choice when strength is critical [37,38]. When more than half of the coronal tooth structure remains, composite resin in combination with a prefabricated post can be used effectively [1].

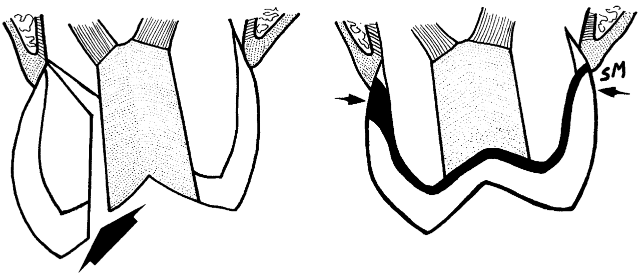

Fig. 3. Access preparation for endodontic treatment of posterior teeth requires substantial removal of coronal tooth structure and destroys the continuity of the occlusal surface. Uncrowned teeth are subject to fracture as a result of normal intraoral occlusal forces (*large arrow*). Placement of an artificial crown restores the continuity of the occlusal surface and encircles the tooth (*small arrows*) to resist fracture.

Glass ionomer materials and several composite core materials contain a fluorosilicate inorganic component that releases trace amounts of fluoride, which may continue for up to 5 years [39,40]. Nevertheless, clinically relevant cariostatic properties have not been established with these fluoride-containing core materials [1]. Glass ionomer-based core materials (including various forms of modified or ''reinforced'' glass ionomer materials) are brittle and incapable of resisting occlusal loads [37]. These materials are indicated only as a method to block undesirable undercuts and should be avoided in situations where the core must resist functional forces [1].

When there is substantial coronal tooth structure above the gingival margin and the molar possesses a deep pulpal chamber, a silver amalgam core reconstruction alone (without a post) has been reported to be highly successful [41,42]. When the residual tooth structure is judged incapable of supporting and retaining the core, a prefabricated post can be used to augment the retention of the core [1]. A prefabricated post with direct core reconstruction, followed by a complete crown, is a common restorative approach for an endodontically treated molar [43].

A custom cast post-and-core system can be used for molars, but problems commonly occur with the development of a path of insertion for the casting, and a two-piece restoration is often required. Also, substantial coronal tooth structure is inevitably removed when a path of insertion is developed for the casting. Prefabricated posts with direct cores are more practical for coronoradicular stabilization of pulpless molars and allow preservation of maximal coronal tooth structure. Although silver amalgam is the most mechanically sound core material, it is difficult to place when there is limited remaining tooth structure above the gingival margin. Silver amalgam has a prolonged setting time compared with composite resin and requires rigid support during the placement, condensation, and setting process. Traditional matrix bands are difficult to apply and may not support condensation pressures required for silver amalgam when much of the coronal tooth structure is missing [44]. A hollowed-out acrylic resin provisional crown can be used as a matrix for the silver amalgam core (Fig. 4) [45–47].

The ferrule effect

The restored molar requires a traditional ferrule in which the margin of the complete crown covers 1.5 to 2 mm of sound tooth structure apical to the margin of the core for 360°. When there is little remaining coronal tooth structure and the furcation is very high, crown lengthening is not usually an option (Fig. 5), and the long-term prognosis of the tooth is poor.

Overall guidelines for restoring pulpless molars

Preservation of coronal and radicular tooth structure improves the probability of success of a restoration for a pulpless molar. Direct cores are

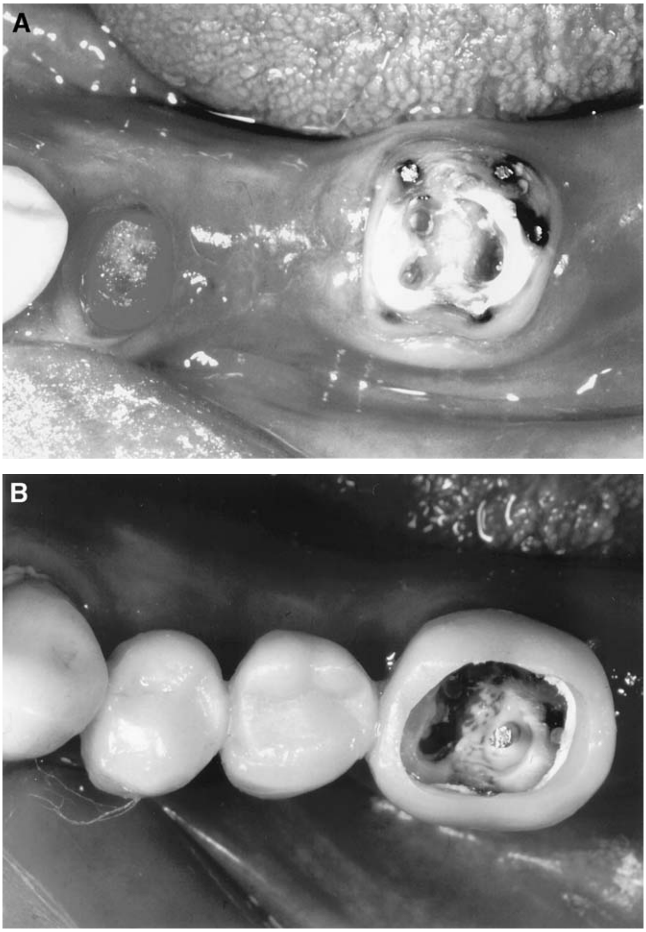

Fig. 4. (*A*) Mandibular molar to be reconstructed with a prefabricated post and a silver amalgam core to serve as an abutment to a fixed partial denture (FPD). (*B*) A narrow-diameter prefabricated post was cemented in the distal root, the molar retainer for the provisional FPD was hollowed out, and the provisional FPD was cemented with temporary cement. (*C*) Silver amalgam was condensed by using the crown shell as a matrix and allowed to set for 24 hours. (*D*) Completed foundation restoration includes a custom-cast post and core for the premolar and a prefabricated post with silver amalgam core for the molar.

potentially more conservative of tooth structure; consequently, they are usually preferred over cast cores. Silver amalgam is the recommended core material under most circumstances. A prefabricated post may be used to improve the retention of the core, and a final restoration that completely covers the cusps is indicated to avoid catastrophic fracture of the tooth.

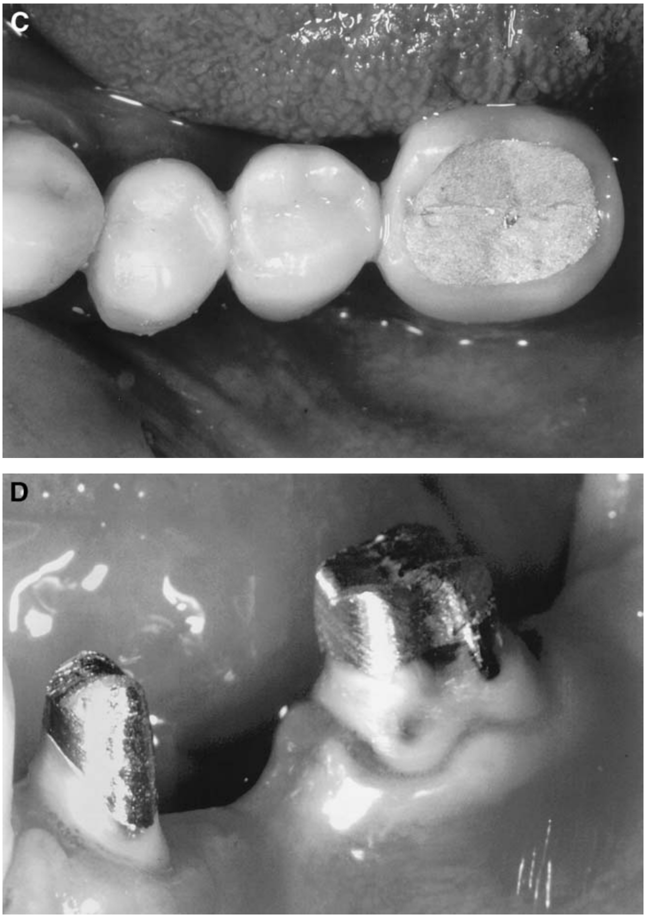

Fig. 4 (*continued*)

Prefabricated posts

There are various types and brands of prefabricated posts (Fig. 6). In a survey of dentists reported in 1994, 40% of general dentists in the United States reported using prefabricated posts most of the time, and the parallel-sided serrated post was the most popular type [8]. Passive posts are most commonly used in the United States [8]. Posts that actively engage radicular tooth structure with threads are more retentive but can predispose the root to fracture [38,48–50]. Retention of a cemented passive post is greatest when the post is parallel sided and has a roughened surface. A narrow-diameter, parallel-sided serrated post can be used effectively in a pulpless molar to augment the retention of the direct core; however, parallel-sided posts are

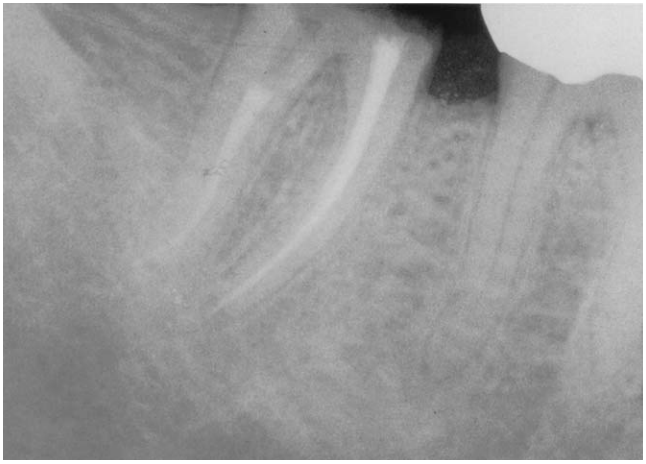

Fig. 5. Endodontically treated mandibular molar with widely spread roots and a high furcation. Prognosis is poor because crown lengthening is not possible to develop a ferrule. Extraction and replacement with an implant-supported crown offers a more favorable prognosis as a definitive restoration.

more difficult to use with single-rooted teeth and dual-rooted premolars because of the natural taper of their roots (Fig. 7) [6].

Fiber reinforced epoxy resin posts

Several brands of fiber-reinforced epoxy resin posts are commercially available. These posts were originally reinforced with carbon fibers, which

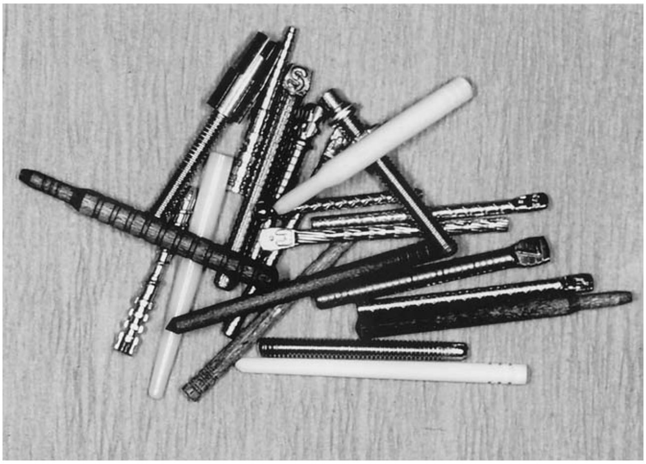

Fig. 6. Examples of commercially available prefabricated posts.

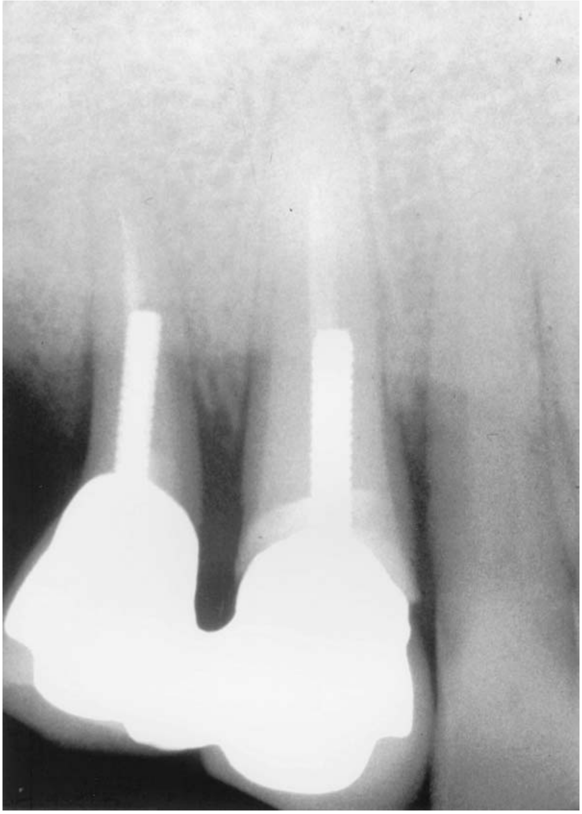

Fig. 7. The use of prefabricated parallel-sided posts of acceptable length in anterior teeth and premolars is difficult because of the natural taper of the roots.

are black [51]. Modifications to these fiber-reinforced posts include coating the post with quartz fibers to mask the black color or replacing the carbon fibers with quartz fibers or glass fibers to improve the esthetic result [52–54]. In vitro studies have indicated that these posts are not as strong as conventional posts, and their strength degrades significantly in vitro after storage in water, thermocycling, and cyclic loading [51–55].

Some investigators have suggested that these fiber-reinforced epoxy resin posts possess inherent flexibility that is similar to the flexibility of natural dentin, allowing the posts to behave similar to the radicular dentin, absorb stresses, and prevent root fractures [56–58]. Nevertheless, an elastic modulus comparable to human dentin as measured in vitro does not ensure that the clinical behavior of the post will be similar to the clinical behavior of radicular dentin. The root is a hollow tube, and the post is a rod within this tube surrounded by a layer of composite resin luting agent. The radically different shape of a root compared with the configuration of the post

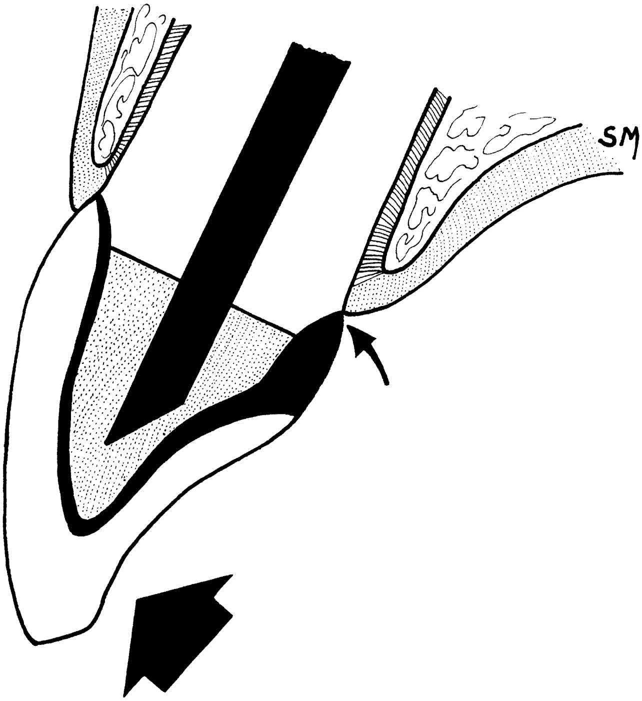

Fig. 8. Anterior tooth restored with a complete crown supported by a fiber-reinforced post and composite core. Normal intraoral forces (*large arrow*) may cause the post to flex, producing micro-movement of the core and failure of the cement seal of the crown (*small arrow*).

combined with the interposed composite resin luting agent suggest that the flexural characteristics of the post do not match that of the root. Another in vitro study indicated that the form of the post itself influenced its rigidity and reported that a smooth, fiber-reinforced epoxy resin post was less flexible than the serrated version of the post [59].

A flexible post can cause failure of the cement seal at the margin of the artificial crown, especially when the ferrule is minimal (Fig. 8). Because the post is bonded to the root and the crown is cemented to the composite core, the crown remains in place, and the problem of leakage at the crown margin is difficult to detect.

Zirconia posts

Posts composed of zirconium oxide, a material that has been used in medicine for orthopedic implants, have also been marketed [60–63]. These all-ceramic posts were originally designed for use with a composite core to improve the esthetic qualities of all-ceramic crowns because it was assumed that a metal post and core would impede light transmission through the ceramic crown. However, a recent study has reported that translucent all-ceramic crowns supported by cast posts and cores made from yellow gold alloy do not appreciably alter the esthetic outcome when the gold core is polished; therefore, the esthetic advantage of these ceramic posts can be questioned [64]. Ceramic materials are tough and have high compressive strengths, but because of their poor tensile strengths they may fracture when subjected to sheer stresses [65]. To compensate for their brittle nature, these posts are made relatively wide, requiring substantial removal of radicular tooth structure. At this time, little is known about the long-term survival of these all-ceramic posts, and they seem to have limited applicability.

Woven-fiber composite materials

The use of cold-glass, plasma-treated, polyethylene woven fibers embedded in conventional resin composite has been advocated for the coronoradicular stabilization of pulpless teeth [66,67]. Nevertheless, a study of woven-fiber composite posts and cores reported that these posts are weaker than cast metal posts and cores [68]. Reinforcement of the woven-fiber composite material with a smaller-diameter prefabricated post improved the mechanical properties significantly, but the strength did not approach that of a cast metal post and core [68]. This material presents disadvantages similar to those of the fiber-reinforced epoxy resin post system—inferior strength combined with undesirable flexibility.

Dental cements

The post is retained in the prepared post channel with dental cement. The primary factors that influence the durability of the bond of the post to the root are compressive strength, tensile strength, and adhesive qualities of the cement. Further considerations concerning the selection of a material to cement posts include the cement's potential for plastic deformation, microleakage, and water imbibition. Also, the cement's handling characteristics during mixing and seating of the post and the nature of the setting reaction of the cement can play a role in the survival of a cemented post in vivo. The currently available dental cements include zinc phosphate, polycarboxylate, glass ionomer, resin-modified glass ionomer, and resin cements. These different classes of cements have advantages and disadvantages, and some should be avoided for use as a cementing medium for endodontic posts. Another relatively new cement, compomer, is rarely advocated for posts.

Zinc phosphate cement has been used for decades to cement dental restorations and has a long history of success. The primary disadvantages of this cement are solubility in oral fluids, especially in the presence of acid, and lack of true adhesion.

Polycarboxylate and glass ionomer cements are also soluble in oral fluids, but they can chemically bond to dentin [69,70]. Polycarboxylate cements have been shown to undergo plastic deformation after cyclic loading, which is a major disadvantage [71]. Glass ionomer cement releases fluoride [72,73], but the ability of this leached fluoride to provide long-term protection against dental caries in dentin has never been proven [74]. Resin-modified glass ionomer cements are stronger than conventional glass ionomer cements and also release fluoride [75,76]. Adhesive resins are essentially insoluble in oral fluids and possess high compressive strengths [77].

A primary disadvantage of conventional glass ionomer cement is its setting reaction. This cement does not reach its maximal strength for many days [78,79]. Therefore, any recontouring of the core with a dental handpiece on the day of cementation of the post can potentially disturb the set of the cement and weaken the immature cement film [1].

Resin-modified glass ionomer cement contains hydrophilic resins that slowly imbibe water, causing the cement film to gradually expand [80,81]. One in vitro study suggested that this expansion of the cement could fracture all-ceramic crowns relatively soon after cementation [82]. However, a more recent study found no potential for fracture of all-ceramic crowns cemented with resin-modified glass ionomer cement after 60 weeks of storage in vitro in 100% humidity [83]. Nevertheless, this cement should be used with caution. If this cement can expand and cause fracture of all-ceramic crowns, it could possibly cause vertical fracture of the roots if used to cement posts (Fig. 9).

Some studies of resin cements have reported significantly higher retentive values for cemented posts [84–87], whereas others have reported conflicting results [88–90]. Reactions between dental resins and eugenol can explain the diametrically opposing results reported in some in vitro studies. The setting reaction of most dental resins is adversely affected by the presence of eugenol, and most endodontic sealers contain eugenol [1]. Also, some commercially available resin cements are technique sensitive and difficult to use for the cementation of posts [89].

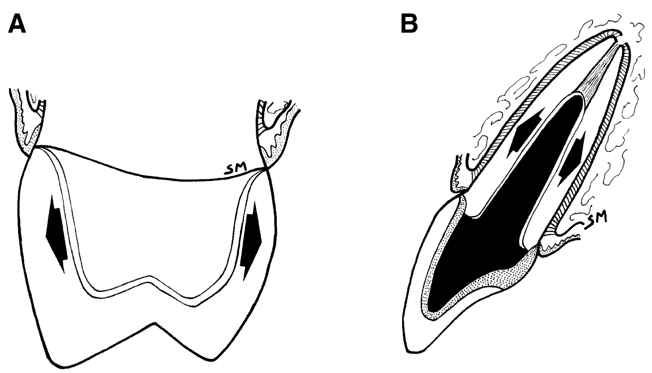

Fig. 9. It has been postulated that delayed expansion of resin-modified glass ionomer cement can fracture an all-ceramic crown (*A*). This expansion also is a concern with posts because root fracture is possible (*B*).

If fundamental biomechanical principles are followed when designing and placing a post, it seems unlikely that the type of cement used for cementation plays a significant role in the overall prognosis of a restored pulpless tooth. Conventional cements, such as zinc phosphate cement, can be used effectively for this purpose.

Problems and complications with posts

The most common complications reported in the literature for posts are dislodgment of the posts, fracture of the roots, and dental caries [7]. Shorter posts are less retentive than longer posts and are more likely to concentrate stresses in the root, increasing the potential for post dislodgement or root fracture (Fig. 10) [9–12]. The ferrule has been shown to substantially reduce stresses within the cervical portion of a tooth restored with a post and complete crown [12–18,91], and this ferrule can also reduce the potential for dislodgment or fracture of the post itself [1,19].

Although there are many factors that can predispose to dental caries, a flexible post or flexible core can generate stresses within the cement seal of the artificial crown, producing leakage at the margin of the crown and eventual caries. Because most crowns are radiopaque, this type of problem is difficult to detect radiographically and may not become apparent until severe destruction of the remaining tooth structure has occurred [92]. A rigid post and core with a relatively long ferrule can help protect against this problem.

Fig. 10. Tooth with a short post and fractured root displaying typical radiographic appearance (*arrow*). Note the thickened periodontal ligament space and widened lamina dura, resembling an upside-down “J”.

Summary

A pulpless tooth has commonly lost substantial tooth structure as a result of previous restorations, dental caries, and the access preparation for endodontic therapy. Consequently, a pulpless tooth requires a restoration that conserves and protects the remaining tooth structure. Although there are many new materials available for the restoration of pulpless teeth, the prognosis of these teeth relies primarily on the application of sound biomechanical principles rather than on the materials used for the restoration.

Posts and cores are commonly required with pulpless teeth. A longer post that preserves 4 to 5 mm of the apical gutta percha seal combined with an artificial crown that provides a ferrule effect offers the best chances of success [17]. Custom-cast posts and cores are generally recommended for anterior teeth and most premolars, and prefabricated posts with direct cores are commonly preferred for molars. Complete crowns or onlays that cover all cusps are recommended for all posterior pulpless teeth regardless of the amount of remaining coronal tooth structure to reduce the chances of fracture of these teeth.

References

[1] Morgano SM, Brackett SE. Foundation restorations in fixed prosthodontics: current knowledge and future needs. J Prosthet Dent 1999;82:643–57.
[2] Kantor ME, Pines MS. A comparative study of restorative techniques for pulpless teeth. J Prosthet Dent 1977;38:405–12.
[3] Guzy GE, Nichols JI. In vitro comparison of intact endodontically treated teeth with and without endo-post reinforcement. J Prosthet Dent 1979;42:39–44.
[4] Sorensen JA, Martinoff JT. Clinically significant factors in dowel design. J Prosthet Dent 1984;52:28–35.
[5] Trope M, Maltz DO, Tronstad L. Resistance to fracture of restored endodontically treated teeth. Endodont Dent Traumatol 1985;1:108–11.
[6] Morgano SM. Restoration of pulpless teeth: application of traditional principles in present and future contexts. J Prosthet Dent 1996;75:375–80.
[7] Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications in fixed prosthodontics. J Prosthet Dent 2003;90:31–41.
[8] Morgano SM, Hashem AF, Fotoohi K, Rose L. A nationwide survey of contemporary philosophies and techniques of restoring endodontically treated teeth. J Prosthet Dent 1994;72:259–67.
[9] Fuss Z, Lustig J, Katz A, Tamse A. An evaluation of endodontically treated vertical root fractured teeth: impact of operative procedures. J Endod 2001;27:46–8.
[10] Standlee JP, Caputo AA. Biomechanics in clinical dentistry. Chicago: Quintessence; 1987. p. 185–203.
[11] Holmes DC, Diaz-Arnold AM, Leary JM. Influence of post dimension on stress distribution in dentin. J Prosthet Dent 1996;75:140–7.
[12] Yang HS, Lang LA, Molina A, Felton DA. The effects of dowel design and load direction on dowel-and-core restorations. J Prosthet Dent 2001;85:558–67.
[13] Barkhordar RA, Radke R, Abbbasi J. Effect of metal collars on resistance of endodontically treated teeth to root fracture. J Prosthet Dent 1989;61:676–8.

[14] Hemmings KW, King PA, Setchell DJ. Resistance to torsional forces of various post and core designs. J Prosthet Dent 1991;66:325–9.
[15] Assif D, Bitenski A, Pilo R, Oren E. Effect of post design on resistance to fracture of endodontically treated teeth with complete crowns. J Prosthet Dent 1993;69:36–40.
[16] Zhi-Yue L, Yu-Xing Z. Effects of post-core design and ferrule on fracture resistance of endodontically treated teeth. J Prosthet Dent 2003;89:368–73.
[17] Isidor F, Brondum K, Ravnholt G. The influence of post length and crown ferrule length on the resistance to cyclic loading of bovine teeth with prefabricated titanium posts. Int J Prosthodont 1999;12:78–82.
[18] Libman WJ, Nicholls JI. Load fatigue of teeth restored with cast posts and cores and complete crowns. Int J Prosthodont 1995;8:155–61.
[19] Torbjörner A, Karlsson S, Ödman PA. Survival rate and failure characteristics for two post designs. J Prosthet Dent 1995;73:439–44.
[20] Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Brackett SE. Fundamentals of fixed prosthodontics. 3rd edition. Chicago: Quintessence; 1997. p. 204.
[21] Sorensen JA, Engleman MJ. Ferrule design and fracture resistance of endodontically treated teeth. J Prosthet Dent 1990;63:529–36.
[22] Loney RW, Kotowicz WE, McDowell GC. Three-dimensional photoelastic stress analysis of the ferrule effect in cast post and cores. J Prosthet Dent 1990;63:506–12.
[23] Smukler H, Chaibi M. Periodontal and dental considerations in clinical crown extension: a rational basis of treatment. Int J Periodontics Restorative Dent 1997;17:464–77.
[24] Kocadereli I, Tasman F, Guner SB. Combined endodontic-orthodontic and prosthodontic treatment of fractured teeth: case report. Austr Dent J 1998;43:28–31.
[25] Mattison GD, Delivanis PD, Thacker RW, Hassel KJ. Effect of post preparation on the apical seal. J Prosthet Dent 1984;51:785–9.
[26] Raiden GC, Gendleman H. Effect of dowel space preparation on the apical seal of root canal fillings. Endod Dent Traumatol 1994;10:109–12.
[27] Fox K, Gutteridge DL. An in vitro study of coronal microleakage in root-canal-treated teeth restored by the post and core technique. Int Endod J 1997;30:361–81.
[28] Trabert KC, Caputo AA, Abou-Rass M. Tooth fracture: a comparison of endodontic and restorative treatments. J Endod 1978;4:341–5.
[29] Cooney JP, Caputo AA, Trabert KC. Retention and stress distribution of tapered-end endodontic posts. J Prosthet Dent 1986;55:540–6.
[30] Gluskin AH, Radke RA, Frost SL, Watanabe LG. The mandibular incisor: rethinking guidelines for post and core design. J Endod 1995;21:33–7.
[31] Raiden G, Costa L, Koss S, Hernandez JL, Acenolaza V. Residual thickness of root in first maxillary premolars with post space preparation. J Endod 1999;25:502–5.
[32] Johnson JK, Sakumura JS. Dowel form and tensile force. J Prosthet Dent 1978;40:645–9.
[33] Weine FS, Wax AH, Wenckus CS. Retrospective study of tapered smooth post systems in place for 10 years or more. J Endod 1991;17:293–7.
[34] Fan P, Nicholls JI, Kois JC. Load fatigue of five restoration modalities in structurally compromised premolars. Int J Prosthodont 1995;82:13–20.
[35] Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent 2002;87:256–63.
[36] Cho GC, Kaneko LM, Donovan TE, White SN. Diametral and compressive strength of dental core materials. J Prosthet Dent 1999;82:272–6.
[37] Kovarik RE, Breeding LC, Caughman WF. Fatigue life of three core materials under simulated chewing conditions. J Prosthet Dent 1992;68:584–90.
[38] Gateau P, Sabek M, Dailey B. Fatigue testing and microscopic evaluation of post and core restorations under artificial crowns. J Prosthet Dent 1999;82:341–7.
[39] Cohen BI, Deutsch AS, Musikant BL. Fluoride release from four reinforced composite resins: a one year study. Oral Health 1995;85:7–8, 10, 13–4.

[40] Cohen BI, Pagnillo MK, Deutsch AS, Musikant BL. A five year study: fluoride release of four reinforced composite resins. Oral Health 1998;88:81–6.
[41] Nayyar A, Walton RE, Leonard LA. An amalgam coronal-radicular dowel and core technique for endodontically treated posterior teeth. J Prosthet Dent 1980;43:511–5.
[42] Nayyar A. Amalgam coronal-radicular buildup for molars and premolars. J Clin Dent 1988;1:41.
[43] Morgano SM, Milot P. Clinical success of cast metal posts and cores. J Prosthet Dent 1993;70:11–6.
[44] Sturtevant CM, Robertson TM, Heymann HO, Sturtevant JR. The art and science of operative dentistry. 3rd edition. St Louis: CV Mosby; 1995. p. 518–23.
[45] Weiner S. Amalgam cores with acrylic resin transitional crowns as a matrix. J Prosthet Dent 1985;54:187–9.
[46] Bonilla ED. Fabrication of an amalgam core using a customized acrylic resin shell. Quintessence Int 1998;29:143–9.
[47] Smidt A, Venezia E. Techniques for immediate core buildup of endodontically treated teeth. Quintessence Int 2003;34:258–68, 87.
[48] Standlee JP, Caputo AA, Holcom J, Trabert KC. The retentive and stress distributing properties of a threaded endodontic dowel. J Prosthet Dent 1980;44:398–404.
[49] Standlee JP, Caputo AA, Holcom J. The Dentatus screw: comparative stress analysis with other endodontic dowel designs. J Oral Rehabil 1982;9:23–33.
[50] Standlee JP, Caputo AA. The retentive and stress distributing properties of split threaded endodontic dowels. J Prosthet Dent 1992;68:436–42.
[51] Sidoli GE, King PA, Setchell DJ. An in vitro evaluation of a carbon fiber-based post and core system. J Prosthet Dent 1997;78:5–9.
[52] Mannocci F, Sherriff M, Watson TF. Three-point bending test of fiber posts. J Endod 2001;27:758–61.
[53] Newman MP, Yaman P, Dennison J, Rafter M, Billy E. Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent 2003;89:360–7.
[54] Drummond JL, Bapna MS. Static and cyclic loading of fiber-reinforced resin. Dent Mater 2003;19:226–31.
[55] Martinez-Insua A, Da Silva L, Rilo B, Santana U. Comparison of the fracture resistances of pulpless teeth restored with a cast post and core or carbon-fiber post with a composite core. J Prosthet Dent 1998;80:527–32.
[56] King PA, Setchell DJ. An in vitro evaluation of a prototype CFRC prefabricated post developed for the restoration of pulpless teeth. J Oral Rehabil 1990;17:599–609.
[57] Fredriksson M, Astback J, Pamenius M, Arvidson K. A retrospective study of 236 patients with teeth restored by carbon fiber-reinforced epoxy resin posts. J Prosthet Dent 1998;80:151–7.
[58] Akkayan B, Gülmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent 2002;87:431–7.
[59] Love RM, Purton DG. The effect of serrations on carbon fibre posts: retention within the root canal, core retention, and post rigidity. Int J Prosthodont 1996;9:484–8.
[60] Pissis P. Fabrication of a metal-free ceramic restoration utilizing monoblock technique. Pract Periodontics Aesthet Dent 1995;7:83–94.
[61] Zalkind M, Hochman N. Esthetic considerations in restoring endodontically treated teeth with posts and cores. J Prosthet Dent 1998;79:702–5.
[62] Zalkind M, Hochman N. Direct core buildup using a preformed crown and prefabricated zirconium oxide post. J Prosthet Dent 1998;80:730–2.
[63] Kakehashi V, Luthy H, Naef R, Wohlwend A, Sharer P. A new all-ceramic post and core system: clinical, technical, and in vitro results. Int J Periodontics Restorative Dent 1998;18: 586–93.
[64] Carossa S, Lombardo S, Pera P, Corsalini M, Rastello ML, Preti PG. Influence of posts and cores on light transmission through different all-ceramic crowns: spectrophotometric and clinical evaluation. Int J Prosthodont 2001;14:9–14.

[65] Ban S, Anusavice KJ. Influence of test method on failure stress of brittle dental materials. J Dent Res 1990;69:1791–9.
[66] Karna JC. A fiber composite laminate endodontic post and core. Am J Dent 1996;9:230–2.
[67] Rudo DN, Karbhari VM. Physical behaviors of fiber reinforcement as applied to tooth stabilization. Dent Clin North Am 1999;43:7–35.
[68] Sirimai S, Riis DN, Morgano SM. An in vitro study of the fracture resistance and incidence of vertical root fracture of pulpless teeth restored with six post-and-core systems. J Prosthet Dent 1999;81:262–9.
[69] Smith DC. A new dental cement. Br Dent J 1968;124:381–4.
[70] Wilson AD, Prosser HJ, Powis DM. Mechanism of adhesion of polyelectrolyte cements to hydroxyapatite. J Dent Res 1983;62:590–2.
[71] Oilo G. Luting cements: a review and comparison. Int Dent J 1991;41:81–8.
[72] Scoville RK, Foremen F, Burgess JO. In vitro fluoride uptake by enamel adjacent to a glass ionomer luting cement. ASDC J Dent Child 1990;57:352–5.
[73] Rezk-Lega F, Ogaard B, Rolla G. Availability of fluoride from glass-ionomer luting cements in human saliva. Scand J Dent Res 1991;99:60–3.
[74] Staninec M, Giles WS, Saiku JM, Hattori M. Caries penetration and cement thickness of three luting agents. Int J Prosthodont 1988;1:259–63.
[75] Musa A, Pearson GJ, Gelbier M. In vitro investigation of fluoride ion release from four resin-modified glass polyalkenoate cements. Biomaterials 1996;17:1019–23.
[76] Chung CK, Millett DT, Creanor SL, Gilmour WH, Foye RH. Fluoride release and cariostatic ability of compomer and resin-modified glass ionomer cement used for orthodontic bonding. J Dent 1998;26:533–8.
[77] Tjan AHL, Li T. Seating and retention of complete crowns with a new adhesive resin cement. J Prosthet Dent 1992;67:478–83.
[78] Mojon P, Hawbolt EB, MacEntee MI, Ma PH. Early bond strength of luting cements to a precious alloy. J Dent Res 1992;71:1633–9.
[79] Matsuya S, Maeda T, Ohta M. IR and NMR analyses of hardening and maturation of glass-ionomer cement. J Dent Res 1996;75:1920–7.
[80] Small IC, Watson TF, Chadwick AV, Sidhu SK. Water sorption in resin-modified glass-ionomer cements: an in vitro comparison with other materials. Biomaterials 1998;19:545–50.
[81] Irie M, Nakai H. Flexural properties and swelling after storage in water of polyacid-modified composite resin (compomer). Dent Mater J 1998;17:77–82.
[82] Sindel J, Frankenberger R, Kramer N, Petschelt A. Crack formation of all-ceramic crowns dependent on different core build-up and luting materials. J Dent 1999;27:175–81.
[83] Snyder MD, Lang BR, Razzoog ME. The efficacy of luting all-ceramic crowns with resin-modified glass ionomer cement. J Am Dent Assoc 2003;134:609–12.
[84] Standlee JP, Caputo AA. Endodontic dowel retention with resinous cements. J Prosthet Dent 1992;68:913–7.
[85] Leary JM, Holmes DC, Johnson WT. Post and core retention with different cements. Gen Dent 1995;43:416–9.
[86] Duncan JP, Pameijer CH. Retention of parallel-sided titanium posts cemented with six luting agents: an in vitro study. J Prosthet Dent 1998;80:423–8.
[87] Junge T, Nicholls JI, Phillips KM, Libman WJ. Load fatigue of compromised teeth: a comparison of 3 luting cements. Int J Prosthodont 1998;11:558–64.
[88] Tjan AHL, Nemetz H. Effect of eugenol-containing endodontic sealer on retention of prefabricated posts luted with an adhesive composite resin cement. Quintessence Int 1992;23:839–44.
[89] Mendoza DB, Eakle WS. Retention of posts cemented with various dentinal bonding cements. J Prosthet Dent 1994;72:591–4.
[90] Schwartz RS, Murchison DF, Walker WA. Effect of eugenol and noneugenol endodontic sealer cements on post retention. J Endodont 1998;24:564–7.

[91] Pierrisnard L, Bohin F, Renault P, Barquins M. Corono-radicular reconstruction of pulpless teeth: a mechanical study using finite element analysis. J Prosthet Dent 2002;88:442–8.
[92] Freeman MA, Nicholls JI, Kydd WL, Harrington GW. Leakage associated with load fatigue-induced preliminary failure of full crowns placed over three different post and core systems. J Endod 1998;24:26–32.