Fabrication of Direct Fiber-Reinforced Posts: A Structural Design Concept

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ABSTRACT

As the clinician continues the quest for optimal functional and esthetic success of a tooth-restorative complex, the current selection of restorative materials and techniques may prove overwhelming. Although no single system provides the ideal restorative solution for every clinical circumstance, understanding of general design criteria and the components for the various post and core systems available allow the clinician to appropriately select the method and materials compatible with the existing tooth structure and desired result. This article provides a discussion of the various post and core systems, the methods and materials inherent in these systems, and general design principles. Using that basic information and clinical experience, the authors offer an alternative procedure for the rehabilitation of the intraradicular anatomy of the post-endodontic channel with a direct composite resin—the fiber-reinforced post and core system.

CLINICAL SIGNIFICANCE

Using improved restorative materials that simulate the physical properties and other characteristics of natural teeth in combination with the proper design principles, the clinician can develop a tooth-restorative complex with optimal functional and esthetic results.

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For over 250 years, clinicians have written about the placement of posts in the roots of teeth to retain restorations.[1,2] As early as 1728, Pierre Fauchard described the use of "tenons," which were metal posts screwed into the roots of teeth to retain bridges.[1,3,4] In the mid-1800s, wood replaced metal as the post material, and the "pivot crown," a wooden post fitted to an artificial crown and to the canal of the root, was popular among dentists.[1,2,5] Often, these wooden posts would absorb fluids and expand, frequently causing root fractures.[4,5] In the late nineteenth century, the "Richmond crown," a single-piece post-retained crown with a porcelain facing, was engineered to function as a bridge retainer.[2,5] During the 1930s, the custom cast post and core was developed to replace the one-piece post crowns. This procedure required casting a post and core as a separate component from the crown.[5] This two-step technique improved marginal adaptation and allowed for a variation in the path of insertion of the crown.[1]

The failure of post-retained crowns has been documented in several clinical studies (Figure 1).[6–11] Many of these studies indicate that the failure rate of restorations on pulp-

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less teeth with post and cores is higher than that for restorations of vital teeth.[6,12,13] Several main causes of failure of post-retained restorations have been identified, including recurrent caries, endodontic failure, periodontal disease, post dislodgement, cement failure, post-core separation, crown-core separation, loss of post retention, core fracture, loss of crown retention, post distortion, post fracture, tooth fracture,[13,16] and root fracture.[13–18] Also, corrosion of metallic posts has been proposed as a cause of root fracture.[13]

Currently, the clinician can choose from a variety of post and core systems for different endodontic and restorative requirements. These systems and methods are well documented in the literature.[19–27] However, no single system provides the perfect restorative solution for every clinical circumstance, and each situation requires an individual evaluation.[19]

The traditional custom cast dowel core provides a better geometric adaptation to excessively flared or elliptical canals and almost always requires minimum tooth structure removal.[1] Custom cast post and cores adapt well to extremely tapered canals or those with a noncircular cross-section or irregular shape, and roots with minimal remaining coronal tooth structure.[19,26] Patterns for custom cast posts can be formed either directly in the mouth or indirectly in the laboratory. Regardless, this method requires two appointment visits and a laboratory fee. Also, because it is cast in an alloy with a modulus of elasticity that can be as high as 10 times greater than that of natural dentin,[28] this possible incompatibility can create stress concentrations in the less rigid root, resulting in post separation or failure. Additionally, the transmission of occlusal forces through the metal core can focus stresses at specific regions of the root, causing root fracture.[28] Furthermore, upon esthetic consideration, the cast metallic post can result in discoloration and shadowing of the gingiva and the cervical aspect of the tooth.[29]

An alternative and currently more popular method is the prefabricated post and core system. Prefabricated post and core systems are classified according to their geometry (shape and configuration) and method of retention. The methods of retention are designated as active or passive. Active posts engage the dentinal walls of the preparation on insertion, whereas passive posts do not engage the dentin but rely on cement for retention.[1,30] The basic post shapes and surface configuration are tapered, serrated; tapered, smooth-sided; tapered, threaded; parallel, serrated; parallel, smooth-sided; and parallel, threaded. Whereas active or threaded posts are more retentive than passive posts, active posts create high stress during placement and increase susceptibility to root fracture when occlusal forces are applied.[31] Parallel-sided serrated posts are the most retentive of the passive prefabricated posts, and the tapered smooth-sided posts are the least retentive of all designs.[5]

Figure 1. Failure of a post-retained system.

Traditional prefabricated metal posts are made of platinum-gold-palladium, brass, nickel-chromium (stainless steel), pure titanium, titanium alloys, and chromium alloys.[5,14] Although stainless steel is stronger, the potential for adverse tissue responses to the nickel has motivated the use of titanium alloy.[32,33] Also, contributing factors to root fracture, such as excessive stiffness (modulus of elasticity)[34–36] and post corrosion,[5] from many of these metal posts have stimulated concerns about their use.

Nonmetallic prefabricated posts have been developed as alternatives, including ceramic (white zirconium oxide), carbon fiber posts, and fiber-reinforced resin posts. Zirconium oxide posts have a high flexural strength, are biocompatible, and are corrosion resistant.[37] However, this material is difficult to cut intraorally with a diamond and to remove from the canal for retreatment.[14] Carbon fiber posts are unidirectional carbon fibers held together with an epoxy resin and ceramic. They exhibit strength and relatively high flexibility and can be retrieved from the canal preparation with ease for retreatment. However, their black color has a negative effect on the final esthetic result of all-ceramic crowns.[32] New advances with second-generation tooth-colored posts, which are identical in design to these conventional carbon fiber posts, may improve this esthetic challenge. There are two methods for the fabrication of the fiber-reinforced resin post system, one using prefabricated posts and the other a direct technique. Prefabricated fiber-reinforced resin posts flex with the tooth structure, are easy to remove if retreatment is required, and have no negative effects on esthetics. However, the adaptation of the prefabricated post to the canal wall is important for retention, and in some cases, the canal must be enlarged to fit the configuration of the selected post, requiring removal of more tooth structure to achieve optimal adaptation. Therefore, these prefabricated posts have optimal adaptation and function in teeth with small circular canals.[38] However, many root canals have irregularly shaped flared canals and the prefabricated system is contraindicated because of the improper adaptation and the required thickness of the resin cement.

A method that can be used for the treatment of irregular canal configurations is the direct fiber-reinforced resin system. Thomas H. Athey, a noted systems analyst, defines a system as any set of components working together for the overall objective of the whole.[1] Only by evaluating the various components and interfaces of the system can the clinician select the proper post and core system for a specific clinical situation.[39] The five components of the post-retained crown system are the internal root dentin surface, intra-radicular post, core buildup, luting cement, and the crown.[40] The system can be analyzed in four regions: at the dentin surface, at the post–tooth interface, within the core, and intra-coronally. Because a failure in any one of these components or interfaces can result in catastrophic failure of the entire system, it is imperative to understand the disparity and complexity of the relation of these interfaces with various restorative materials.[28] When evaluating the interfaces of any system, failures provide design principles that can be used with any post-retained crown system. Therefore, the following design principles should be considered when using any post-retained crown system in the reconstruction of the tooth-restorative complex:

- maximum post retention and core stability[7,14,16,18,36,41–48]
- inherent antirotation of the post and core complex by accentuating the eccentric coronal shape of the root canal[11,45]
- minimal removal of tooth structure[18,36,45,49,50]
- morphologic intra-radicular adaptation[18,45,50]
- optimal esthetics[43]
- inherent resistance to catastrophic root failure [36,49,51]
- lack of corrosiveness[11,17,52,53]
- posts with a similar modulus of elasticity as root dentin, to distribute applied forces evenly along the length of the post[31,54–57]
- restorative materials with flexural and tensile strength characteristics similar to root structure[51,55]
- a system with uninterrupted bonding at all interfaces, resulting

in increased resistance to fatigue and fracture, enhanced retention, and a reduction in microleakage and bacterial infiltration[28,51]

Currently, an increased demand for clinically convenient post and core systems to replace lost tooth structure has provided the clinician with a plethora of simplified "one-visit" post and core restorative options.[11,58] However, in view of the previously mentioned design considerations, it is understandable that clinicians have uncertainties about selection of restorative materials and techniques to achieve optimal results for post and core buildup procedures.[55] Although the quest for the ideal material to restore lost tooth structure continues to be a focus of modern dental research,[59] there are many post and core techniques that are available to the clinician for a variety of clinical procedures, and each clinical situation should be evaluated on an individual basis.[19] This article describes an alternative procedure for the rehabilitation of the intra-radicular anatomy of the post-endodontic channel with a direct composite resin—the fiber-reinforced post and core system.[28]

CONSIDERATIONS FOR THE SELECTION OF RESTORATIVE MATERIALS

According to Anusavice,[60] the selection of dental materials for clinical implementation is based on physicochemical properties, biocompatibility, handling characteristics, esthetics, and economy.[1] Only three of these are related to the functional success of the post and core apparatus: physicochemical properties, biocompatibility, and handling characteristics.[1] Therefore, in the consideration of intermediary materials that are integrated between the post and core apparatus, these three characteristics are essential. However, when using an all-ceramic restoration, the esthetic consideration becomes of utmost importance in creating an optimal esthetic harmony with the surrounding dentition. The shade of this underlying core can determine the final esthetic outcome.[43,51]

As mentioned previously, for optimal functional and esthetic success of this tooth-restorative complex, the following design principles for the fiber-reinforced system should be evaluated and discussed. The insight offered by the integration of the design principles with restorative materials and adhesive techniques have altered post design preparation and resulted in the introduction of a simplified "single-appointment" post and core restorative option. This method of post fabrication uses a bondable reinforcement fiber (e.g., Ribbond, Seattle, Washington; Connect, Kerr Corporation, Orange, California) as the post material, a fourth-generation bonding agent (e.g., OptiBond, Kerr) a dual-cure hybrid composite (e.g., Variolink II, Ivoclar Vivadent, Amherst, New York) as the luting agent, and a dual-cure hybrid composite (e.g., Marathon, Den-Mat, Santa Maria, California) as the core buildup.

The reinforcement material used for the post consists of polyethylene woven fibers that are treated with a cold-gas plasma. This plasma treatment converts the ultrahigh molecular weight fibers from hydrophobic material to hydrophilic. The effect of such treatment is to allow for complete wetting and infusion of the fibers by resin, creating a lower contact angle with the wetting resin and providing a greater bonded surface area to enhance the adhesion to any synthetic restorative material.[43] Also, spectroscopic analysis shows an increase in O – C = O functional groups that allows chemical bonding between the polyethylene fibers and the resin.[61] The reinforcement fibers enhance the mechanical properties of the tooth-restorative complex by increasing flexural and tensile strengths.[62] Several types of weaves are used by various manufacturers, and these can influence strength, stability, and durability. The leno weave of Ribbond reportedly resists shifting and sliding under tension more than a plain weave, minimizing crack propagation by reducing the coalescence of microcracks within the resin matrix into cracks that could lead to failure of the restorative complex. This fiber network also provides an efficient transfer of stress within the internal fiber framework by absorbing the stresses that are applied to the restorative complex and redirecting those forces along the long axis of the remaining root structure.[18,28,63]

The use of the fourth-generation dentin bonding systems reduces the undesirable contraction gap at the dentin–resin interface and represents the second component of the system. The removal of the smear layer and the adhesion of resin at the root canal wall has been shown to decrease microleakage at this interface.[64–66] Therefore, this sealed resin–dentin interface may reduce or eliminate microleakage and bacterial infiltration at the coronal end of the root.[28]

The third component, the dual-cure luting agent, has a physical and, potentially, a chemical interaction with the post material and the dentin that enhances the adhesive interfacial continuity. Conventional luting cements, such as zinc oxysphosphate, only fill in the void between the restorative interfaces without attaching to either surface.[28] However, these bonded interfaces can improve the structural integrity of the remaining radicular dentin and increase the retention and resistance to displacement.[18,28,67] Therefore, the use of a resin luting cement to line and strengthen the canal walls actually reinforces the root and supports the tooth-restorative complex.[16,68]

The core buildup represents the final component of the one-visit option and is an important element in the esthetic reconstruction of the all-ceramic restoration. Because the color of the underlying substrate directly influences the final result,[29] the restorative material should be a tooth-colored dual-cure hybrid composite resin. The translucency of composite resin is preferable to cast gold beneath all-ceramic restorations, with respect to the esthetic influence on the final restoration.[69] Also, when considering the core buildup, the preparation design influences the stability of the crown by preventing crown rotation. The antirotational feature of the post and core complex requires the placement of a 2-mm ferrule around the circumference of the preparation on sound tooth structure.[32,70–72] Clinical studies have demonstrated and confirmed the importance of this coronal tooth "collar" on the mechanical resistance of the endodontically restored tooth complex.[73–78]

The fiber-reinforced composite resin post and core system offers several advantages: a one-appointment technique,[79,80] no laboratory fees, no corrosion, negligible root fracture, no designated orifice size, increased retention resulting from surface irregularities, conserved tooth structure, and no negative effect on esthetics.[62] Disadvantages of the technique include technique sensitivity, the need for a careful adhesive protocol, and the need to maintain an inventory of the reinforcement materials. One study indicated that fiber-reinforced posts may have a greater potential for long-term success than base metal alloys, because of their greater flexibility.[81] However, more research is needed to demonstrate long-term effectiveness.[82]

RESTORATIVE SEQUENCE

After placement of the rubber dam to isolate the area, and upon the completion of endodontic therapy, the gutta-percha and any root canal sealer adhering to the walls of the canal is removed with a heated instrument or a No. 3 Gates-Glidden drill (Figure 2).[82] The depth of the post space is prepared to approximately the height of the final coronal preparation. It is not necessary to eliminate undercuts as in the conventional preparation, because the additional surface area enhances adhesion. The remaining tooth structure is acid-conditioned with a 37.5% gel etchant for 15 to 30 seconds and the post channel is rinsed thoroughly. For a hydrophilic adhesive, the dentin substrate should remain moist, and any excess moisture in the post space is removed with endodontic paper points (Figures 3 and 4). The adhesive is applied in a continuous motion, reapplying every 5 seconds for 20 seconds with a micro-applicator and using saturated endodontic paper points to facilitate placement of the resin to the base of the post space and to remove any excess (Figure 5). The adhesive (e.g., OptiBond, Kerr) is gently air-dried for 5 seconds and light-cured for 20 seconds (Figure 6).

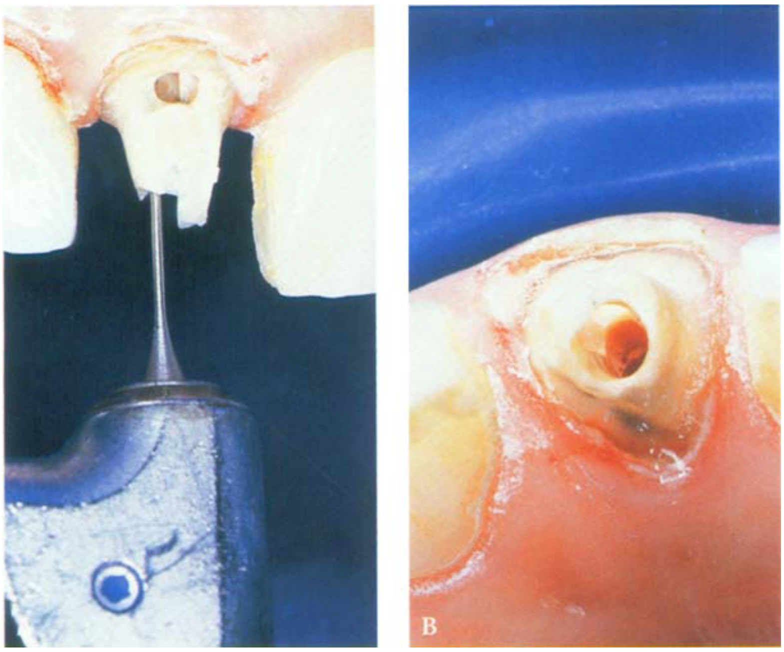

Figure 2. A *and* B*, Removal of gutta-percha with a Gates-Glidden drill.*

If the post space preparation is deeper than 4 mm, a dual-cure adhesive is recommended.

The reinforcement fiber is supplied in various widths, including 1 mm, 2 mm, 3 mm, 4 mm, and 9 mm, depending on the manufacturer. The most frequently used is the 2-mm width; however, a 3-mm width may be used in a larger post space. The appropriate length of the fiber is determined by folding the material once in the canal and folding back on each end, which is approximately six times the height of the anticipated preparation. The plasma-coated fiber ribbon is

Figure 3. Preparation is acid-etched with a 32% semi-gel etchant (Uni-Etch, Bisco, Schaumburg, Illinois).

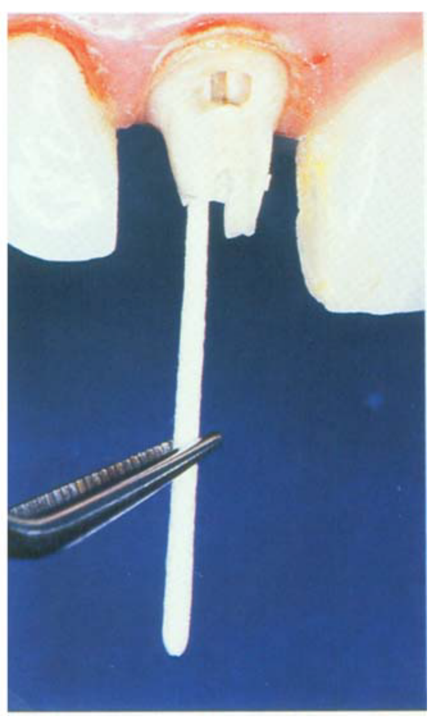

Figure 4. Excess moisture in the post space is removed with endodontic paper points.

Figure 5. The adhesive is applied with saturated endodontic paper points to facilitate placement of the resin to the base of post space and to remove any excess.

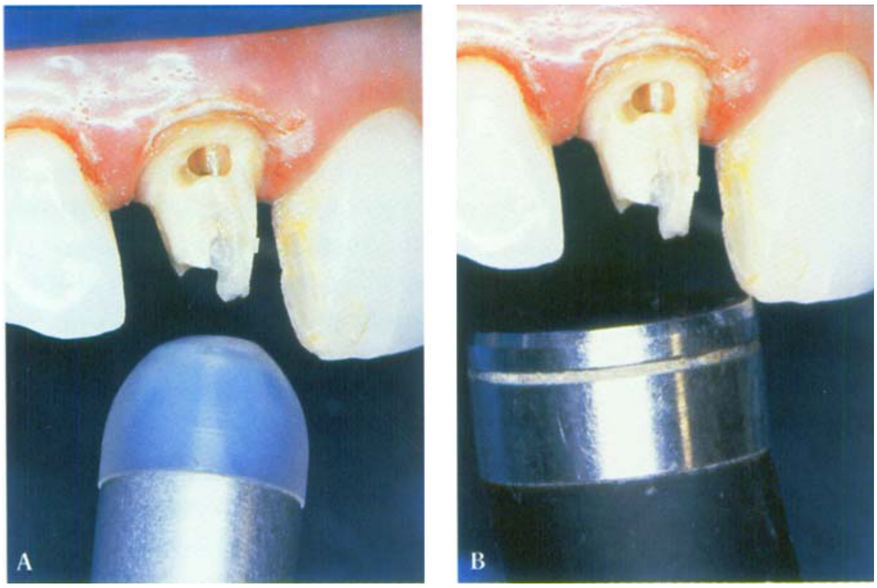

Figure 6. A *and* B, *The adhesive is gently air-dried for 5 seconds and polymerized for 20 seconds.*

measured and coated with an unfilled light-cured resin bonding adhesive or a composite sealant (Figure 7), and the excess is removed with a lint-free 2 × 2 gauze. The resin is light-cured, and the fiber is cut with a supplied shear (Figure 8). A special cotton glove should be worn during handling of the ribbon until the resin has been applied and polymerized. The plasma coating on the fiber should not be contaminated with oils from the fingers or compounds from the latex or vinyl gloves, because this can disturb the plasma coating and decrease the bond strength.[43] Recently, a new poly-

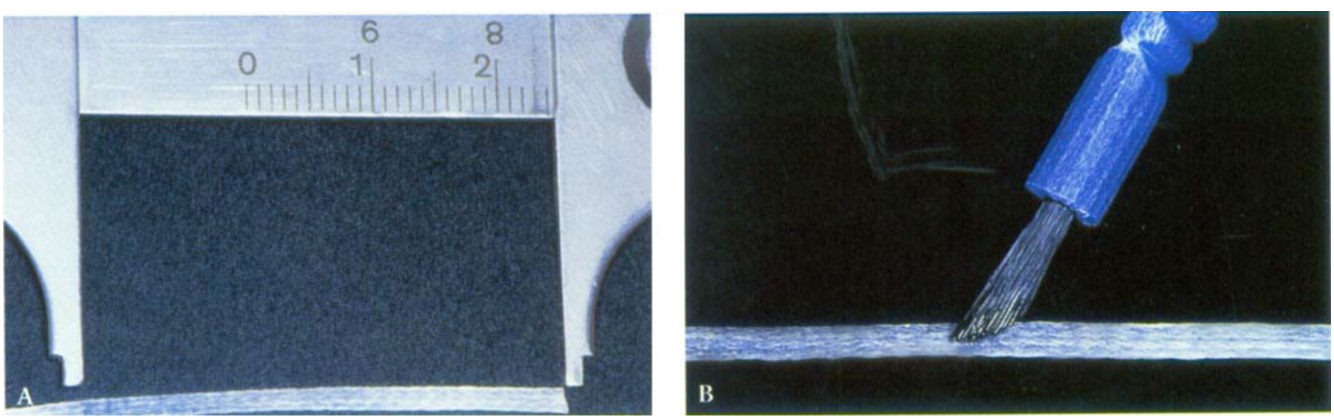

Figure 7. A *and* B, *The appropriate length of the fiber is measured and coated with an unfilled light-cured resin-bonded adhesive.*

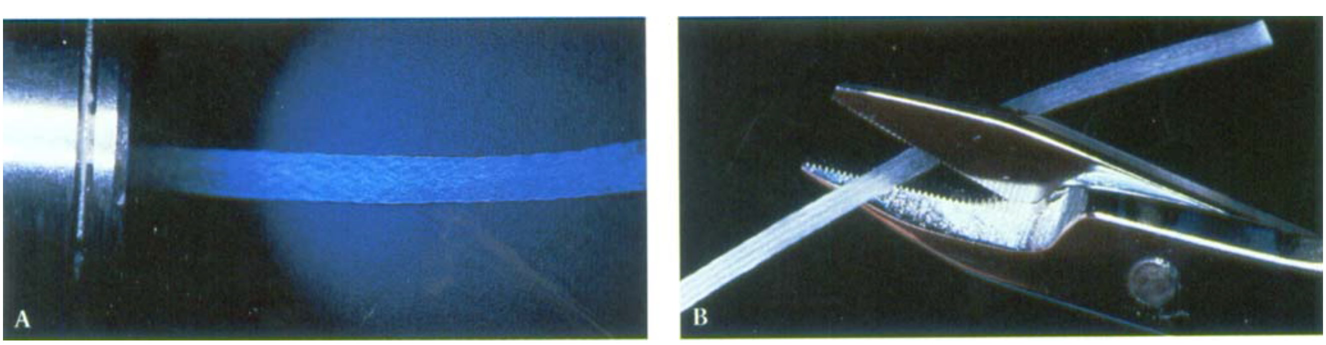

Figure 8. A *and* B, *The resin is polymerized for 20 seconds and cut with a supplied shear.*

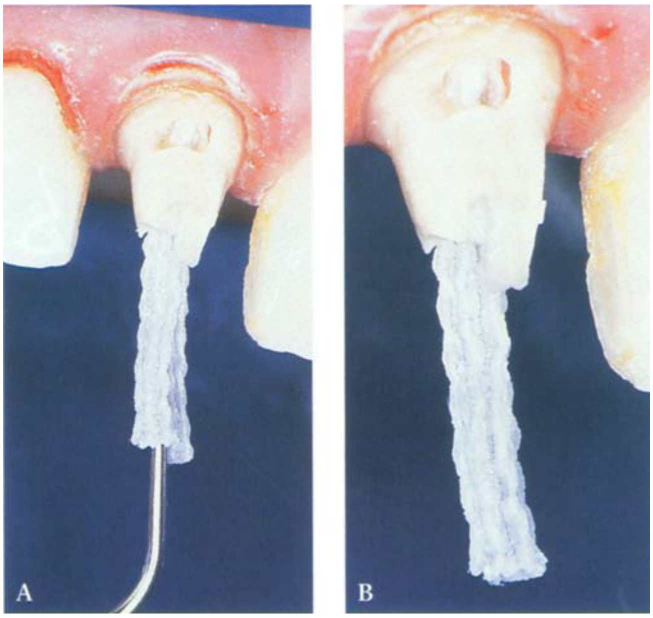

Figure 9. A *and* B, *Rehearsal of the placement of the fiber in the post channel.*

ethylene braid has been introduced (Construct, Kerr), that is impregnated with resin and can be handled by fingers without the use of gloves.

Before placing the adhesive or resin cement, a rehearsal of the placement of the fiber in the post channel is recommended (Figure 9). The fiber is transported to the base of the post space with a modified Luk's gutta-percha condenser, which has a V-shaped groove across the end (Figure 10).

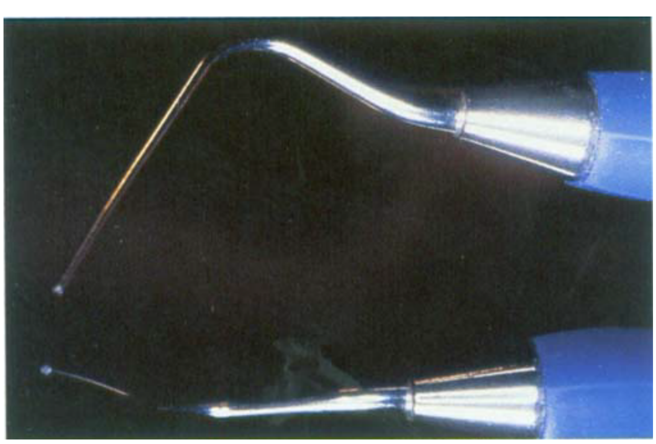

Figure 10. The modified Luk's gutta-percha condenser. Note the V-shaped groove in the mirror image.

A dual-cure composite or resin cement is injected into the post channel with a needle tube syringe (Centrix, Shelton, Connecticut) (Figure 11). The resin material should flow easily, and the working time should be as long as possible. It is important to place the tip at the base of the post space; the resin material is injected as the syringe tip is slowly removed. This technique reduces the possibility of entrapping air bubbles and ensures optimal adaptation of the resin material to the posthole preparation. The fiber is immediately inserted into the posthole with the modified Luk's gutta-percha condenser and the fiber is folded over so that the ends are pointing back into the post channel and between the emerging ends of the fiber.

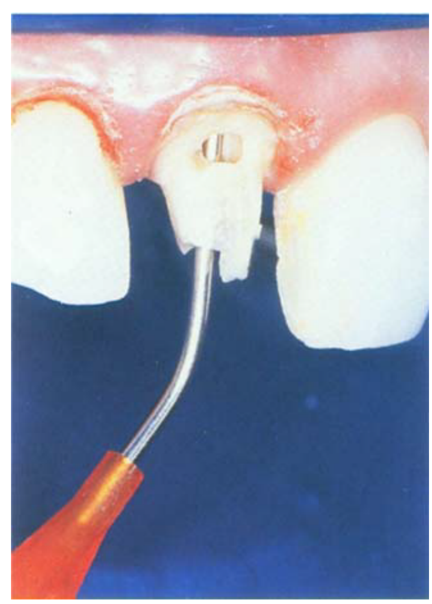

Figure 11. A dual-cure composite or resin cement is injected into the post channel with a needle tube syringe.

The folded ends are arranged into the desired shape of the core and light-cured for 60 seconds (Figure 12).

A dual-cure or light-cured composite is applied freehand or injected with a needle tube syringe over the coronal fibers to an ideal coronal preparation dimension (Figure 13). In the preparation and finishing of the fiber-reinforced resin core, a 2-mm circumferential ferrule is placed on sound tooth structure, which enhances the mechanical retention and resistance of the endodontically restored tooth complex (Figure 14).[32,70–72] The entire preparation is lightly lubricated with glycerin before the final impression is taken.

CONCLUSION

Understanding of general design criteria and evaluation of the components of the various post and core systems available for the reconstruction of the tooth-restorative complex allow the clinician to select an appropriate system for each situation. However, as the industry continues to develop improved methods and materials, the clinician should be encouraged to use the aforementioned general principles as a guide while exploring new products and techniques. As such, this article presents an alternative approach, the fiber-reinforced post and core system, to restore the endodontically compromised tooth. Although this approach has proved successful in specific cases, clearly this technique requires peer research to determine long-term effectiveness. As with most procedures, clinical experience and judgment based on scientific evidence must dictate the final decision for application.[79]

With the emergence of improved restorative materials that have physical properties and characteristics of natural teeth and the use of techniques that incorporate the aforementioned design principles, the clinician can develop a tooth-restorative complex with optimal functional and esthetic results (Figure 15).

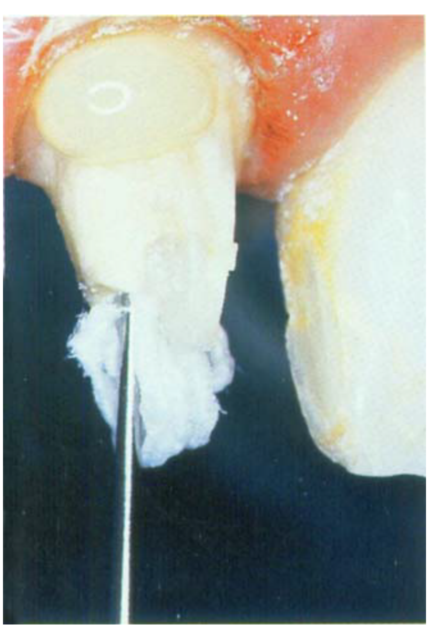

Figure 12. The fiber is immediately inserted into the post hole and the folded ends are arranged into the desired shape of the core.

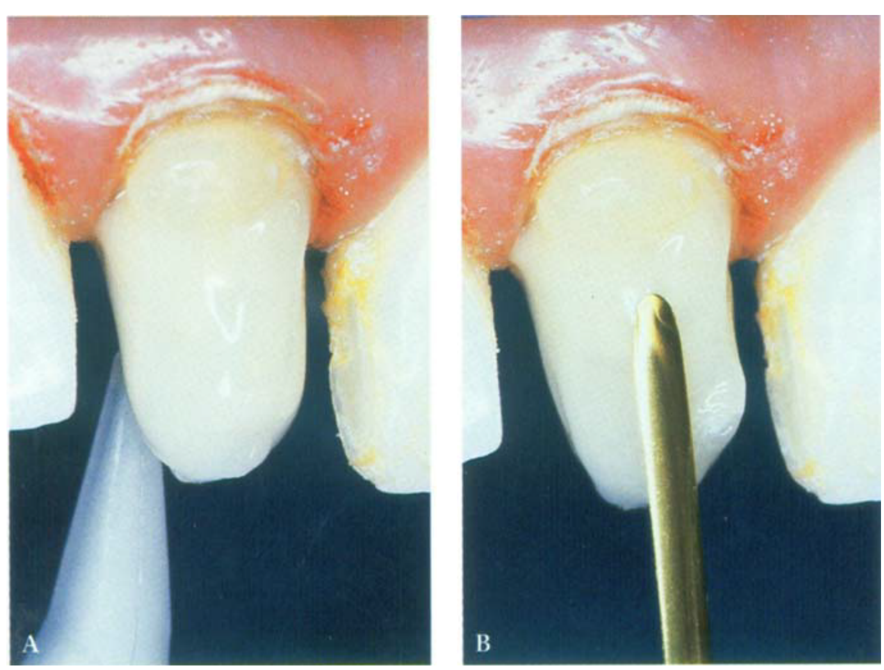

Figure 13. A *and* B, *A dual-cured or light-cured composite is applied, freehand or injected with a Centrix syringe tip (Accudose Low Viscosity Tube, Centrix, Shelton, Connecticut) over the coronal fibers to an ideal coronal preparation dimension.*

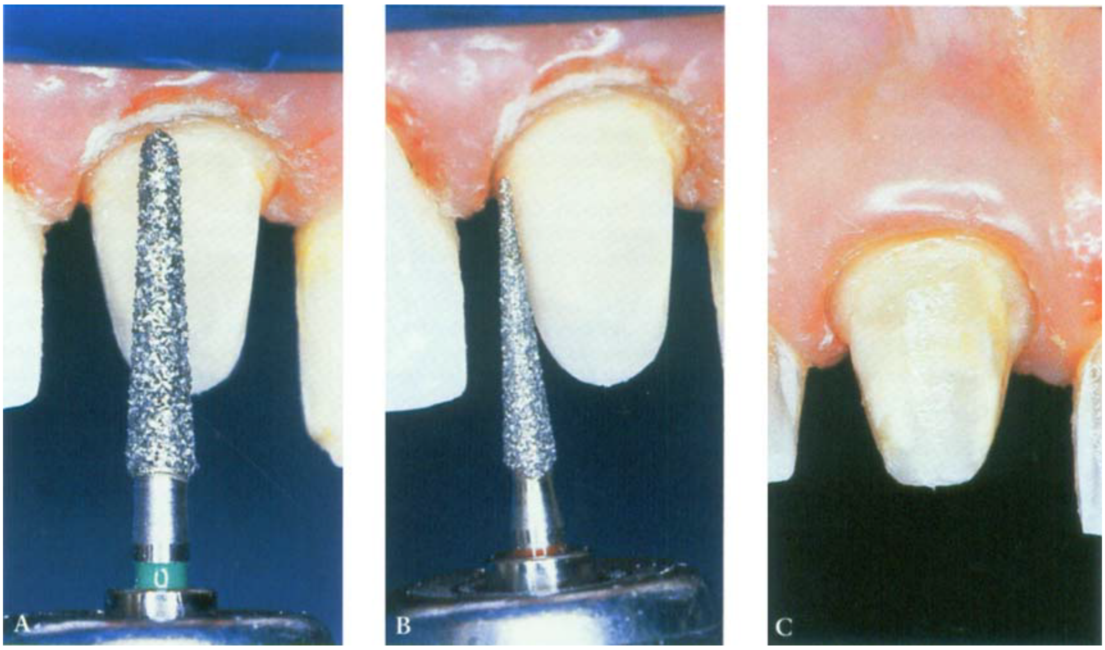

Figure 14. A *and* B, *Preparation and finishing of the fiber-reinforced resin core.* C, *A 1- to 2-mm circumferential ferrule is placed on sound tooth structure, which enhances the mechanical retention and resistance.*

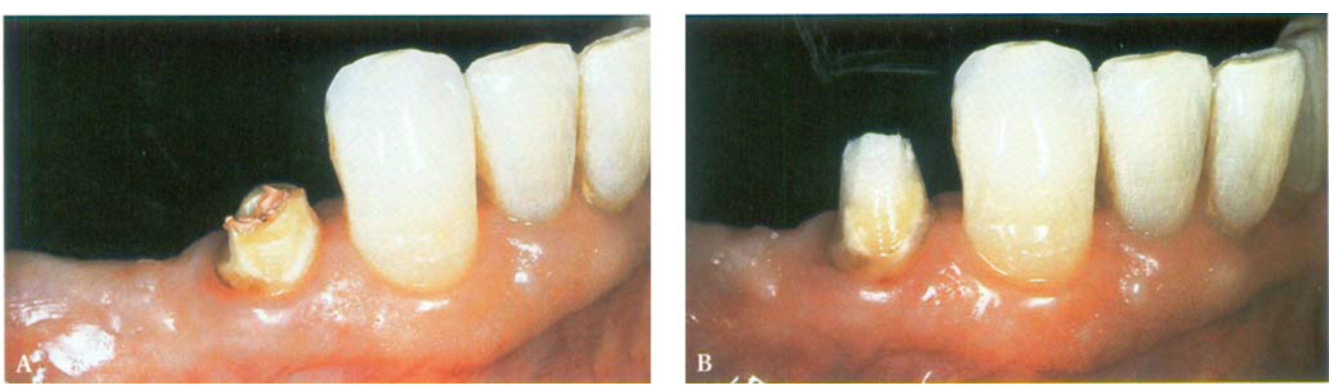

Figure 15. A, B, *and* C, *A sequential development of a posterior tooth restorative complex (4 unit mandibular fixed bridge) with optimal functional and esthetic results.*

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REFERENCES

1. Smith CT, Schuman NJ, Wasson W. Biomechanical criteria for evaluating prefabricated post-and-core systems: a guide for the restorative dentist. Quintessence Int 1998; 29:305–312.

2. Tylman SD. Theory and practice of crown and bridge prosthesis. 2nd Ed. St Louis: CV Mosby, 1947:1–13.

3. Ring ME. Dentistry: an illustrated history. New York: Abradale-Mosby, 1992: 160–179.

4. Ingle JI, Teel S, Wands DH. Restoration of endodontically treated teeth and preparation for overdentures. In: Ingle JL, Bakland LK, eds. Endodontics. 4th Ed. Malvern, PA: Williams & Wilkins, 1994:876–920.

5. Smith CT, Shuman N. Prefabricated post-and-core systems: an overview. Compendium 1998; 19:1013–1020.

6. Roberts DH. The failure of retainers in bridge prostheses. Br Dent J 1970; 128:117–124.

7. Sorenson JA, Martinoff JT. Intracoronal reinforcement and coronal coverage: a study of endodontically treated teeth. J Prosthet Dent 1984; 51:780–784.

8. Bergman B, Lundquist P, Sjogren U, Sundquist G. Restorative and endodontic results after treatment with cast posts and cores. J Prosthet Dent 1989; 61:10–15.

9. Mentink AGB, Meeuswissen R, Kayser AF, Mulder J. Survival rate and failure characteristics of all metal post and core restorations. J Oral Rehabil 1993; 20:455–461.

10. Torbjörner A, Karlsson S, Odman PA. Survival rate and failure characteristics for two post designs. J Prosthet Dent 1995; 73:439–444.

11. 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.

12. Turner CH. Post-retained crown failure: a survey. Dent Update 1982; 9:221–234.

13. Purton DG, Payne JA. Comparison of carbon fiber and stainless steel root canal posts. Quintessence Int 1996; 27:93–97.

14. Asmussen E, Peutzfeldt A, Heitmann T. Stiffness, elastic limit, and strength of newer types of endodontic posts. J Dent 1999, 27:275–278.

15. Zuckerman GR. Practical considerations and technical procedures for post-retained restorations. J Prosthet Dent 1996; 75:135–139.

16. Sirimai S, Riis DN, Morgano SM. An in vitro study of the fracture resistance and the incidence of vertical root fracture of pulpless teeth restored with six post-and-core systems. J Prosthet Dent 1999; 81:262–269.

17. Silness J, Gustavsen F, Hunsbeth J. Distribution of corrosion products in teeth restored with metal crowns retained by stainless steel posts. Acta Odontol Scand 1979; 37:317–321.

18. Freedman G. Bonded post endodontic rehabilitation. Dent Today 1996; 50:52–53.

19. Coleman AJ, Urquiola J. An injection technique for generating direct resin post and core patterns. Quintessence Int 1996; 27:749–752.

20. Kurer PF. The Kurer Anchor System for post crown restoration. J Ont Dent Assoc 1968; 45:57–60.

21. Baraban DJ. A simplified method for making posts and cores. J Prosthet Dent 1970; 24:287–297.

22. Hudis SI, Goldstein GR. Restoration of endodontically treated teeth: a review of the literature. J Prosthet Dent 1986; 55:33–38.

23. Deutsch AS, Musikant BL. The Flexi-Post as a tap in post placement. Gen Dent 1986; 34:146–147.

24. Musikant BL. A new prefabricated post and core system. J Prosthet Dent 1984; 52:631–634.

25. Schneider RL. A one-appointment procedure for cast post and core restorations. J Prosthet Dent 1994; 71:420–422.

26. Rosenstiel SF, Land MF, Fujimoto J. Contemporary fixed prosthodontics. 1st Ed. St. Louis: Mosby, 1988:198–218.

27. Ziebert GJ. Restoration of endodontically treated teeth. In: Malone WFP, Koth DL, Cavazos E, Kaiser DA, Morgano SM, eds. Tylman's theory and practice of fixed prosthodontics. 8th Ed. St. Louis: Ishiyaku-EuroAmerica, 1989:407–418.

28. Freedman G. The carbon fibre post: metal-free, post-endodontic rehabilitation. Oral Health 1996; 86:23–30.

29. Vichi A, Ferrari M, Davidson CL. Influence of ceramic and cement thickness on the masking of various types of opaque posts. J Prosthet Dent 2000; 83:412–417.

30. Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Brackett SE. Fundamentals of fixed prosthodontics. 3rd Ed. Chicago: Quintessence, 1997:194–209.

31. 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.

32. Christensen GJ. Post and cores: state of the art. J Am Dent Assoc 1998; 129: 96–97.

33. Sivers JE, Johnson WJ. Restoration of endodontically treated teeth. Dent Clin North Am 1992; 36:631–648.

34. 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.

35. Dean JP, Jeansonne BG, Sarkar N. In vitro evaluation of a carbon fiber post. J Endod 1998; 24:807–810.

36. Karna JC. A fiber composite laminate endodontic post and core. Am J Dent 1996; 9:230–232.

37. Miller M. Posts: the ratings. In: Reality 2000. 14th Ed. Houston, TX: Reality, 2000:461–474.

38. Rosenstiel SF, Land MF, Fujimoto J. Contemporary fixed prosthodontics. 2nd Ed. St. Louis: Mosby 1995:238–267.

39. Blitz N. Adaptation of a fiber-reinforced restorative system to the rehabilitation of endodontically treated teeth. Pract Periodont Aesthet Dent 1998; 10:191–193.

40. Chalifoux PR. Restoration of endodontically treated teeth: review, classification, and post design. Pract Periodont Aesthet Dent 1998; 10:247–254.

41. Cohen BI, Pagnillo MK, Condos S, Deutsch AS. Four different core materials measured for fracture strength in combination with five different designs of endodontic posts. J Prosthet Dent 1996; 76:487–495.

42. Trope M, Maltz DO, Tronstad L. Resistance to fracture of restored endodontically treated teeth. Endod Dent Traumatol 1985; 1:108–111.

43. Hornbrook DS, Hastings JH. Use of bondable reinforcement fiber for post and core build-up in an endodontically treated tooth: maximizing strength and aesthetics. Pract Periodont Aesthet Dent 1995; 7:33–42.

44. Caputo AA, Standlee JP. Pins and posts: why, when, and how. Dent Clin North Am 1976; 20:299–311.

45. Johnson JK, Schwartz NL, Blackwell RT. Evaluation and restoration of endodontically treated posterior teeth. J Am Dent Assoc 1976; 93:597–605.

46. Standlee JP, Caputo AA, Hanson EC. Retention of endodontic dowels: effects of cement, dowel length, diameter, and design. J Prosthet Dent 1978; 39:401–405.

47. Lui JL. Enhanced post crown retention in resin composite-reinforced, compromised, root-filled teeth: a case report. Quintessence Int 1999; 30:601–606.

48. Gluskin AH, Radke RA, Frost SL, et al. The mandibular incisor: rethinking guidelines for post-and-core design. J Endod 1995; 21:33–37.

49. Sorenson JA, Engleman MJ. Effect of post adaptation on fracture resistance of endodontically treated teeth. J Prosthet Dent 1990; 63:529–536.

50. Perel ML, Muroff FL. Clinical criteria for posts and cores. J Prosthet Dent 1972; 28:405–411.

51. Hunt PR, Gogarnoiu D. Evolution of post and core systems. J Esthet Dent 1996; 8:74–83.

52. Avridson K, Wroblewski R. The migration of metallic ions from screw posts into dentine and surrounding tissues. Scand J Dent Res 1978; 86:200–205.

53. Angmar-Mansson B, Omnell K-A, Rud J. Root fractures due to corrosion 1. Metallurgical aspects. Odontologisk Revy 1969; 20:245–265.

54. Assif D, Oren E, Marshak BL, Aviv I. Photoelastic analysis of stress transfer by endodontically treated teeth to the supporting structure using different restorative techniques. J Prosthet Dent 1989; 61:535–43.

55. Combe EC, Shaglouf AMS, Watts DC, Wilson NHF. Mechanical properties of direct core build-up materials. Dent Mater 1999; 15:158–165.

56. Watts DC. Elastic moduli and visco-elastic relaxation. J Dent 1994; 22:154–158.

57. Isidor F, Odman P, Brondum K. Intermittent loading of teeth restored using prefabricated carbon fiber posts. Int J Prosthodont 1996; 9:131–136.

58. Tjan AHL, Tjan AH, Sun JC. Retention of Luminex post system. Oral Health 1997; 87:31–35.

59. Adair PJ, Grossman DG. The castable ceramic crown. Int J Periodontics Restorative Dent 1984; 4:33–45.

60. Anusavice KJ. Structure of matter and principles of adhesion. In: Anusavice KJ, ed. Phillips science of dental materials. 10th Ed. Philadelphia: WB Saunders, 1996:1–31.

61. Rudo DN, Karbahari VME. Physical behaviors of fiber reinforcement as applied to tooth stabilization. Dent Clin North Am 1999; 43:7–21.

62. Miller M. Composite reinforcement fibers: the ratings. In: Reality 2000. 14th Ed. Houston, TX: Reality, 2000:121–124.

63. Duret B, Reynaud M, Duret F. Un nouveau concept de reconstitution coronradiculaire: le composi post 2. Chir Dent Fr 1990; 542:69–77.

64. Taylor JK, Jeasonne BG, Lemon RR. Coronal leakage effects of smear layer, obturation technique, and sealer. J Endod 1997; 23:508–512.

65. Wennberg A, Orstavik D. Adhesion of root canal sealers to bovine dentine and gutta-percha. Int Endod J 1990; 23:13–19.

66. Tjan AHL, Grant BE, Dunn JR. Microleakage of composite resin cores treated with various dentin bonding agents. J Prosthet Dent 1991; 66:24–29.

67. Freedman G, Novak IM, Serota KS, Glassman GD. Intra-radicular rehabilitation: a clinical approach. Pract Periodont Aesthet Dent 1994; 6:33–39.

68. Lui JL. A technique to reinforce weakened roots with post canals. Endod Dent Traumatol 1987; 3:310–314.

69. Stahl GJ, O'Neal RB. The composite resin dowel and core. J Prosthet Dent 1975; 33:642–648.

70. Christensen GJ. Post, cores, and patient care. J Am Dent Assoc 1993; 124:86–90.

71. Paul SJ, Schärer P. Post-and-core reconstruction for fixed prosthodontic restoration. Pract Periodont Aesthet Dent 1997; 9:513–520.

72. Christensen GJ. When to use fillers, buildups, or post and cores. J Am Dent Assoc 1996; 127:1397–1398.

73. Dietschi D, Romelli M, Goretti A. Adaptation of adhesive posts and cores to dentin after fatigue testing. Int J Prosthodont 1997; 10:498–507.

74. Rosen H, Partida-Rivera M. Iatrogenic fracture of roots reinforced with a cervical collar. Oper Dent 1983; 11:46–50.

75. Barkhordar R, Radke R, Abbasi J. Effect of metal collars on resistance of endodontically treated teeth to root fracture. J Prosthet Dent 1989; 61:676–678.

76. Hemming KW, King PA, Setchell DJ. Resistance to torsional forces of various post and core designs. J Prosthet Dent 1991; 66:325–329.

77. Liban WJ, Nicholls JL. Load fatigue of teeth restored with cast posts and cores and complete crowns. Int J Prosthodont 1995; 8:155–161.

78. Hoag EP, Dwyer TG. A comparative evaluation of three post and core techniques. J Prosthet Dent 1982; 47:177–181.

79. Landwerlen JR, Berry HH. The composite resin post and core. J Prosthet Dent 1972; 28:500–503.

80. Rada R. Placing esthetic bonded direct posts and cores. CDS Rev 1999; April:24–27.

81. Eskitascioglu G, Belli S, Kalkan M. Comparison of two different post and core systems using a finite element stress analysis and a conventional fracture strength test. 4th Joint Meeting of the Continental European and Scandinavian Divisions of the International Association for Dental Research, August 24–27, 2000, Warsaw, Poland.

82. Torbjörner A, Karlsson S, Syverud M, Hensten-Pettersen A. Carbon fiber reinforced root canal posts: mechanical and cytotoxic properties. Eur J Oral Sci 1996; 104:605–611.

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