Effect of Core Diameter and Surface Treatment on the Retention of Resin Composite Cores to Prefabricated Endodontic Posts

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Purpose: With advances in adhesive dentistry and current emphasis on esthetic restorations, dowel systems have been developed to take advantage of these new techniques. Of interest when using these systems is the interaction between core materials and post materials. This investigation compared the tensile retentive force of two resin composite core materials to two metallic and one nonmetallic prefabricated endodontic posts. Two dimensions of core build-up and two post-surface treatments were tested.

Materials and Methods: One hundred twenty posts (stainless steel, titanium alloy, and glass fiber-impregnated resin) were secured in a jig with 4 mm of the post extending into a cylindrical matrix. The matrix formed cylinders with diameters of 3 and 5 mm into which resin composite was inserted. The posts were treated or not treated with a bonding agent. After storage for 24 hours at 100% humidity, five specimens per condition were tested in an Instron testing machine at a crosshead speed of 0.5 mm/min. Failure loads were recorded in kilograms and failure modes were observed under light microscopy (40×). Four-way analysis of variance and multiple comparison testing were used to compare means at the 0.05 level of significance.

Results: The means and standard deviations of tensile loads were calculated. All variables were significant in either main effects or interactions ($p < 0.05$). Fisher's PLSD intervals for post, core, treatment, and diameter were 2.0, 1.6, 1.6, and 1.6 kg, respectively. In most cases, the retentive force recorded for metallic posts was higher than that of glass fiber posts. Titanium posts had higher retentive forces than did the stainless steel posts. For metallic posts, 5-mm cores provided higher forces than 3-mm cores. In the glass fiber group, core diameter was not significant. For core materials, Build-It gave higher results with stainless steel posts, and FluoroCore gave higher results with the titanium ones. The surface treatment results were mixed. In the metallic post groups the adhesive failure data ranged between 80% and 100%, whereas in the glass fiber post groups, adhesive failures ranged between 60% and 70%.

Conclusions: Within the limitations of this study, the metallic post groups always provided higher tensile retentive forces, with the titanium post groups showing higher retentive forces than the stainless steel ones. In the glass fiber post groups, different core diameters did not affect retention values.

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POST AND CORE systems have been used to restore endodontically treated teeth for more than 250 years.[1] The use of prefabricated posts and resin restorative materials to fabricate post and core systems was introduced in the 1960s.[2]

Prefabricated post and core systems are available in a variety of materials. Traditional prefabricated posts are made of metal. The materials of choice are stainless steel, titanium, and titanium alloy. Other metal alloys that have been used are platinum-gold-palladium, chromium-containing alloys, and brass.[3]

There are reports in the literature of poor post retention, potential for post and root fractures, and risk of corrosion associated with conventional metallic dowel systems.[4-7] The modulus of elasticity of the metallic posts is significantly greater than that of dentin ($210 \gg 14.2$ GPa).[8] This difference might create stresses at the root–cement–post interface and the possibility of post separation and failure.[8-10]

Carbon fiber posts were introduced in 1990 by Duret et al.[11] Certain properties, such as biocompatibility and corrosion resistance, make the carbon fiber post a potential replacement for conventional metallic posts in many clinical situations;[12-14] however, the modulus of elasticity of the carbon fiber material is much greater than that of dentin ($120 \gg 14.2$ GPa).[8] Also, as with metallic posts, the use of carbon posts has generally limited esthetic expectations. Their dark underlying color can adversely influence the shade of overlying gingival tissues and prosthetic restorations.[15]

Ceramic posts made of zirconium dioxide partially stabilized by the addition of yttrium oxide were introduced in 1993.[16] These posts are esthetic, radiopaque, biocompatible, and mechanically rigid. They also have a modulus of elasticity higher than that of dentin ($170 \gg 14.2$ GPa),[8] which could result in concentration of occlusal forces in the root.

Recently, research in this field has focused on the development of a biocompatible endodontic post that is capable of optimally satisfying functional and esthetic concerns. The result of this research is the development of a resin-reinforced glass fiber post, an endodontic post with numerous clinical advantages.[15] The primary advantage of the glass fiber post is its modulus of elasticity ($\sim$40 GPa), which more closely approximates that of dentin.[8] The similarity in elasticity may allow post flexion to mimic tooth flexion, so the post acts as a shock absorber, transmitting only a fraction of the stresses placed upon the tooth to the dentinal walls.[15]

Glass fiber posts have a high esthetic potential. They have a universal tooth color and are highly translucent.[17] Elimination of dark metal posts enhances esthetics by preventing metallic discolorations from showing through the labial bone covering roots and overlying attached gingiva. Cormier et al in 2001[18] showed that glass fiber posts were readily retrievable after failure, whereas the metallic and ceramic post systems tested were nonretrievable. The glass fiber endodontic post is fabricated from longitudinal glass fibers embedded in a resin composite matrix. With adhesive bonding, the potential exists for integrating tooth structure, post, core, and restoration into a single unit, instead of an assemblage of heterogeneous materials.[18]

The core material of choice for most dentists today is resin composite. When combined with bonding techniques, this material can provide an essential link in the restoration of endodontically treated teeth. In addition, composites satisfy esthetic demands, a consideration of major importance in the anterior region. Moreover according to studies by Cho et al,[19] Millstein et al,[20] Zalkind et al,[21] and Miyawaki et al,[22] resin composite core materials performed as well as dental amalgam in strength, better than amalgam in bond strength to dentin, and similar to tooth structure in hardness and fracture toughness.

Stress transfer from the restoration to the remaining root structure should ideally be uniform and of low magnitude. The effect that the thickness of different core materials covering the post head (core height) has on the tensile and compressive strengths was evaluated in a study by Chang and Millstein.[23] The results showed that the compressive failure load was affected by the thickness of the core that covers the post head. On the other hand, the thickness of the core covering the post head did not influence the tensile failure load.

The retention between core and prefabricated post materials is critical to post and core longevity. Therefore, retention values for the various materials should be known. To date, there have been no investigations of the influence of core diameter on the tensile retentive strength of composite cores bonded to prefabricated endodontic posts. It would be interesting to determine if larger diameter core build-ups that would correspond to wider teeth (mesiodistally) would have a better long-term prognosis than smaller ones, when restored with prefabricated endodontic posts and resin composite core build-ups.

The objective of this study was to determine the resistance to tensile loading of two composite core materials joined to treated and nontreated metallic and glass fiber posts, using composite resin cores with two different diameters. The hypothesis was that there were no differences in the retentive force between metallic and glass fiber posts when two different core materials and two different core diameters were used with or without the application of a bonding agent.

Materials and Methods

The products, codes, batch numbers, manufacturers, and compositions of post materials, core materials, and the bonding agent used in this study are listed in Table 1. One hundred twenty post and core specimens were prepared in a device that consisted of a cylindrical aluminum base and a polytetrafluoroethylene matrix on top of the base. The matrix was used to form composite cylinders with diameters of 3 and 5 mm. The selected diameters correspond to the minimum and maximum mesiodistal widths of natural anterior maxillary and mandibular teeth measured at the level of the CEJ after crown preparation.[24] A channel for post-placement was prepared in the center of the cylindrical base to a depth allowing 4 mm of the experimental posts to extend above the base into the polytetrafluoroethylene matrix. Experimental specimens were made by placing a post in the base and filling the matrix with composite, resulting in a core height of 4 mm.[23]

Stainless steel, titanium alloy, and glass fiber-impregnated resin endodontic posts were tested (Table 1). The post diameter for all posts used for this investigation was 1.25 mm.[14] Half the posts were treated with a bonding agent (Bond-1) according to the manufacturer's instructions, and the other groups were not surface-treated. Resin composite cores [Build-It (BI) and FluoroCore (FC)] were prepared by mixing the catalyst and base pastes according to the manufacturers' instructions and dispensing the mixture into the cylinder formed by the polytetrafluoroethylene matrix (Fig 1). Two diameters of core materials were used: 3 and 5 mm. Photopolymerization was accomplished with an Elipar Highlight (3M ESPE, St. Paul, MN) curing light. The light output was verified at greater than 450 mW/cm^2 throughout the study with a curing radiometer (Demetron/Kerr, Danbury, CT). The experimental design is shown in Table 2. Five specimens per condition were tested for a total of 120 specimens.

The specimens were stored in distilled water for 24 hours at 37°C in a humidor (100% relative humidity), to simulate conditions in the oral cavity. After storage, each specimen was placed in a fixture (Fig 2) on a testing machine (model 4465, Instron Corp., Canton, MA) and loaded in tension until failure at a crosshead speed of 0.5 mm/min. The fixture allowed the dowel to extend through a hole drilled through an aluminum plate, which was attached to the testing machine. The

Table 1. Products, Codes, Batch Numbers, and Manufacturers of Materials Used in This Study

Product	*Code*	*Batch Number*	*Manufacturer*	*Composition*
ParaPost XP™/SS	SS	MT 50776	Coltene/Whaledent, Mahwah, NJ	SS
ParaPost XP™/Ti	TI	MT 54683	Coltene/Whaledent	$TiAl_6V_4$
FibreKor Post System	FK	68242	Pentron Clinical Technologies, Wallingford, CT	Glass fiber-reinforced resin
Build-It	BI	68860	Pentron Clinical Technologies	Bis-GMA, UDMA (urethane dimethacrylate resin), HDDMA, silane-treated glass fillers, chopped glass fibers, pigments with initiators, stabilizers and UV absorber
FluoroCore	FC		Dentsply/Caulk, Milford, DE	*Catalyst Paste:* benzoyl peroxide, UDMA, barium boron fluoroalumino silicate glass
Catalyst paste		0206061		
Base paste		0202071		*Base Paste:* UDMA, barium boron fluoroalumino silicate glass
Bond-1 Primer/Adhesive	ADH	65390	Pentron Clinical Technologies	Methacrylate monomers in ethanol and/or acetone

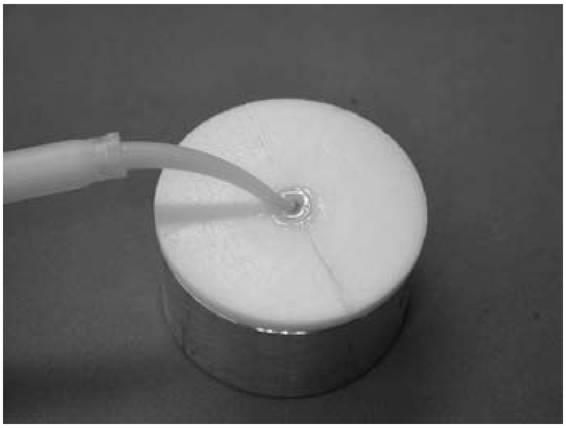

Figure 1. Build-It composite core material is dispensed into the cylinder formed by the polytetrafluoroethylene matrix using the syringe technique, as described by the manufacturer.

post was then grasped with a Jacob's chuck attached to the upper member of the testing machine. This fixture ensured that the post was perpendicular to the aluminum plate and produced tensile loading. Failure loads were recorded in kilograms of force. Failure modes of fracture sites were observed under light microscopy at 40× magnification (Optispec, Micro Enterprises Inc., Norcross, GA) and recorded.

Means and standard deviations of tensile loads were calculated. A four-way analysis of variance (StatView SAS Institute, Cary, NC) was employed to analyze the retentive force data. Fisher's PLSD intervals for post, treatment, core, and diameter were calculated at the 0.05 level of significance for comparisons among means.

Results

The means and standard deviations of the tensile retentive force are presented in Table 2. Analysis of variance results are shown in Table 3. All variables were significant in either main effects or interactions ($p < 0.05$). Fisher's PLSD intervals for post, treatment, core, and diameter were 2.0, 1.6, 1.6, and 1.6 kg, respectively.

Due to the significant interaction effects, the reported results are focused on the following three 2-way interactions: post–core, post–diameter, and treatment–core. However, analysis of the data in Table 2 of the post as a main effect revealed that the titanium post groups in all conditions recorded higher tensile retentive force than did the glass fiber posts.

The results based on the post–core interaction are presented in Table 4 by averaging over treatment and diameter, and indicate that BI groups recorded higher values with stainless steel posts than did FC groups, while FC demonstrated higher values than BI with the titanium post groups. For the glass fiber posts there was no significant difference in the tensile retentive force values when either of the two core materials was used.

Evaluating the results of the post–core diameter interaction by averaging over treatment and core (Table 5), it was concluded that for the metallic post groups, the 5-mm diameter core groups always provided significantly higher values of tensile retentive force than the 3-mm groups. On the other hand, in the case of the glass fiber post groups, the 5-mm diameter core groups did

Table 2. Means (SD) of Tensile Retentive Forces (kg)

			Post Material					
			ParaPost XP™/SS		*ParaPost XP™/Ti*		*FibreKor Post System*	
			Bonded	*Control*	*Bonded*	*Control*	*Bonded*	*Control*
Core material	Build-It	3 mm	27.9* (6.2)	34.4 (7.9)	29.8 (5.0)	41.6 (1.8)	33.5 (1.3)	31.2 (1.2)
		5 mm	43.5 (3.3)	51.6 (7.4)	47.8 (4.5)	49.5 (3.0)	34.7 (2.4)	31.2 (1.1)
	FluoroCore	3 mm	32.7 (5.9)	27.5 (5.9)	43.8 (4.3)	36.9 (6.2)	32.4 (1.1)	29.7 (1.8)
		5 mm	42.1 (5.4)	34.1 (3.6)	55.0 (6.2)	50.8 (5.6)	33.6 (1.1)	32.4 (1.1)

Replications per condition: n = 5. Total number of samples: 120. Fisher's PLSD intervals ($p = 0.05$) for comparisons of means among posts, between core materials, between 3 and 5 mm diameter, and between adhesive versus control were 2.0, 1.6, 1.6, and 1.6 kg, respectively.
*Means (SD).

Figure 2. The specimen is placed in a fixture on the Universal testing machine with the dowel head grasped with a Jacob's chuck.

not produce significantly higher values of tensile retentive force than the 3-mm ones.

The results of the core–treatment interaction by averaging over post and core diameter (Table 6) showed that when BI was used, the tensile retentive force values were higher in the no-treatment condition (control group); however, when FC was used as the core material, higher results were produced when the posts were treated with the bonding agent (bonded groups).

Qualitative analysis of failure modes as observed under light microscopy at 40× magnification showed that, in the metallic post groups, adhesive failures ranged between 80% and 100%, while the composite cohesive failures were between 0 and 20%. In the glass fiber post groups, the adhesive and composite cohesive failure modes ranged between 60% and 70% and between 30% and 40%, respectively. Means of failure mode data for each group is shown in Table 7.

Discussion

Post–core retention was determined by recording the force required to dislodge the post from the core material. The post material, the post design, the mechanical properties of the core material, and the diameter of the core material could possibly have contributed to the results, either individually or by interacting with each other.

There are no reports in the literature comparing the bond strength of stainless steel and titanium posts to composite core materials. The results of this study indicate that the titanium posts bonded better than the stainless steel posts. Titanium alloy ($TiAl_6V_4$) is biocompatible, more corrosion resistant than stainless steel, and

Table 3. Analysis of Variance for Tensile Retentive Force

	DF	*Sum of Squares*	*Mean Square*	*F-Value*	*P-Value*
Post	2	2981	1490	74.7	<0.0001
Treatment (Treat)	1	7	7	0.3	0.5615
Core	1	6	6	0.3	0.5758
Diameter(d)	1	2301	2301	115.3	<0.0001
Post/Treat	2	57	29	1.4	0.2441
Post/Core	2	471	235	11.8	<0.0001
Post/d	2	841	421	21.1	<0.0001
Treat/Core	1	529	529	26.5	<0.0001
Treat/d	1	15	15	0.7	0.3898
Core/d	1	46	46	2.3	0.1340
Post/Treat/Core	2	329	165	8.3	0.0005
Post/Treat/d	2	21	10	0.5	0.5931
Post/Core/d	2	135	68	3.4	0.0377
Treat/Core/d	1	27	27	1.4	0.2482
Post/Treat/Core/d	2	91	46	2.3	0.1076
Residual	96	1916	20		

Table 4. Means (SD) for Interaction Post–Core (Averaging Over Treatment and Core Diameter)

	SS	*TI*	*FK*
BI	39.4 (10.4)	42.2 (8.9)	32.7 (1.7)
FC	34.1 (6.0)	46.6 (8.0)	32.0 (1.7)

Fisher's PLSD intervals ($p = 0.05$) for comparisons of means among posts and between core materials were 2.0 and 1.6 kg, respectively.

Table 6. Means for Interaction Core Material/Treatment (Averaging Over Post and Diameter)

	BI	*FC*
Bonded	36.2 (7.8)	39.9 (8.9)
Control	39.9 (9.1)	35.2 (8.3)

Fisher's PLSD intervals ($p = 0.05$) for comparisons of means between core materials and between adhesive versus control were 1.6 and 1.6 kg, respectively.

creates a stable oxide layer that can increase the bonding potential.[25,26] The different surface characteristics or roughness between these two post types might also explain the superiority of the titanium posts' bonding ability. Future research in this area is indicated.

Another possible reason for the difference in core material retention between the two types of metallic posts could be the lower modulus of elasticity of the titanium posts compared with the stiffer stainless steel ones. Titanium alloy has a relatively low modulus of elasticity that permits elastic deformation of the post within the composite build-up. On the other hand, tensile loading of the rigid stainless steel posts could result in breakage of the core build-up in lower tensile retentive force values.

As stated earlier, the mechanical properties of the composite core materials may have affected the results in this study. The selection of BI as well as the bonding agent was based upon the manufacturers' recommendations for the glass fiber endodontic posts. The second resin composite core material (FC) was selected because of its different composition and also because the mixing and application methods vary when compared with BI. The organic polymer matrix (oligomer) in the case of BI is a compound with the acronym Bis-GMA with the addition of lower-molecular-weight difunctional monomers, while the inorganic filler particles are silane-treated glass fibers and chopped glass fibers. Polymerization is accomplished using free radicals. Because Bis-GMA has reactive double bonds at each end of the molecule, just as the added monomers do, a highly cross-linked polymer is obtained. The oligomer in FC is urethane dimethacrylate and polymerization is accomplished by free radical initiation with a peroxide–amine system. The inorganic filler in this case is barium boron fluoroalumino silicate glass.[27]

If the shear strength of the core material is low, the core material can deteriorate and the post

Table 5. Means for Interaction Post–Core Diameter (Averaging Over Treatment and Core Material)

	SS	*TI*	*FK*
3 mm	30.6 (3.5)	38.0 (6.2)	31.7 (1.6)
5 mm	42.8 (7.2)	50.8 (3.1)	33.0 (1.5)

Fisher's PLSD intervals ($p = 0.05$) for comparisons of means among posts and between 3 and 5 mm core diameter were 2.0 and 1.6 kg, respectively.

Table 7. Means of the Percents of Failure Mode Data

	Adhesive Failure	*Composite Cohesive Failure*	*Post Cohesive Failure*
SS/Bonded/3 mm BI	90	10	0
SS/Control/3 mm BI	96	4	0
SS/Bonded/5 mm BI	86	14	0
SS/Control/5 mm BI	98	2	0
SS/Bonded/3 mm FC	86	14	0
SS/Control/3 mm FC	84	16	0
SS/Bonded/5 mm FC	90	10	0
SS/Control/5 mm FC	96	4	0
TI/Bonded/3 mm BI	82	18	0
TI/Control/3 mm BI	86	14	0
TI/Bonded/5 mm BI	88	12	0
TI/Control/5 mm BI	88	12	0
TI/Bonded/3 mm FC	86	14	0
TI/Control/3 mm FC	86	14	0
TI/Bonded/5 mm FC	84	16	0
TI/Control/5 mm FC	90	10	0
FK/Bonded/3 mm BI	62	38	0
FK/Control/3 mm BI	64	36	0
FK/Bonded/5 mm BI	64	36	0
FK/Control/5 mm BI	70	30	0
FK/Bonded/3 mm FC	60	40	0
FK/Control/3 mm FC	70	30	0
FK/Bonded/5 mm FC	66	34	0
FK/Control/5 mm FC	70	30	0

may be dislodged before breakage of the lateral wall of the core. This may explain the lower tensile force values recorded with BI, when used with titanium posts, whereas FC performed significantly better. Another important factor in evaluating the performance of each core material is the application method used with each material to form specimens. For BI, the syringe technique may have produced less air incorporation, according to Mentink et al.[28] FC was adapted to the dowels with a hand instrument. In the case of the glass fiber posts, this study indicated that higher retentive strength values were obtained with BI core specimens than those with FC cores. A low-viscosity syringable material made of resin like the glass fiber-impregnated resin posts might have bonded better to a similar material; however, FC, which is more viscous and has higher mechanical properties, performed better with the metallic posts.

There have been no previous investigations showing the effect of core diameter on tensile retentive force. The present study showed that a change in core build-up diameter affected the tensile force only in the metallic post groups, whereas with glass fiber post groups, the tensile retentive force values remained the same under both conditions. The finding that 5-mm diameter core specimens performed significantly better than did 3-mm diameter cores in metallic post groups could be explained by the fact that retention in these groups is primarily macromechanical, leading to composite breakage when failure occurs. The smaller the diameter of the core, the easier it is to break under pressure directed from the post toward the lateral wall of the core induced by the vertical deterioration of the core material. The retention in the case of the glass fiber posts is dependent upon the bonded interface between the post and the core materials, which remained the same under both diameter conditions.

Numerous studies[21,23] have reported that the design of the post head strongly influences tensile failure loads. The influence of post design was reflected in the present study by the way in which the composite cores failed. Tensile loading of the metallic dowel specimens with their retentive heads produced lateral stresses within the composite material resulting in the shattering of the core portion of the specimens. On the other hand, the glass fiber posts failed at lower levels of tensile loading, and in most cases, the composite cores were pulled off the post head while some composite material remained on the post head. In these groups, the vertical crack within the core material did not seem to go through the entire composite matrix, preventing complete breakage. This observation was confirmed by viewing specimens after failure under light microscopy. Adhesive failure for the metallic post groups ranged between 80% and 100%, showing that very little composite material remained on post surfaces. On the other hand, in the glass fiber post groups, more composite material remained on the post surface after failure, because the adhesive failure mode ranged between 60% and 70%.

Further research is indicated in order to evaluate the tensile retentive force of post–core systems by employing controls which eliminate the post-surface design factor. Suggestions for future studies could also include different patterns of loading of the post–core systems as well as different testing methods such as a compressive test. In addition, it would be interesting to evaluate the behavior of different fiber-impregnated resin post systems when loaded under tension or compression.

Conclusions

The following conclusions can be drawn from this in vitro study:

1. The titanium post groups recorded higher tensile retentive force than did the glass fiber posts.
2. BI groups recorded higher values with stainless steel posts, while FC demonstrated higher values with the titanium post groups. In the glass fiber post groups, core material did not affect the tensile retentive force.
3. In the metallic post groups, the 5-mm diameter core groups always provided higher tensile retentive forces than the 3-mm ones.
4. In the glass fiber post groups, core diameter did not affect the tensile retentive force.
5. When BI was used, the tensile retentive force values were higher in the no-treatment condition, but when FC was the core material of choice, higher results were produced when the posts were treated with the bonding agent.
6. The failure mode data showed that the adhesive failure rate was higher in the metallic post groups than in the glass fiber post groups.

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References

1. Tylman SD: Theory and Practice of Crown and Bridge Prosthesis (ed 2). St. Louis, MO, Mosby, 1947, pp 1-13
2. Federick DR: An application of the dowel and composite resin core technique. J Prosthet Dent 1974;32:420-424
3. Sivers JE, Johnson WT: Restoration of endodontically treated teeth. Dent Clin North Am 1992;36:631-650
4. Trabert KC, Cooney JP: The endodontically treated tooth. Restorative concepts and techniques. Dent Clin North Am 1984;28:923-951
5. Goodacre CJ, Spolnik KJ: The prosthodontic management of endodontically treated teeth: A literature review. Part I. Success and failure data, treatment concepts. J Prosthodont 1994;3:243-250
6. Silness J, Gustavsen F, Hunsbeth J: Distribution of corrosion products in teeth restored with metal crowns retained by stainless steel posts. Acta Odontal Scand 1979;37:317-321
7. Walton JN, Gardner FM, Agar JR: A survey of crown and fixed partial denture failures: Length of service and reasons for replacement. J Prosthet Dent 1986;56:416-421
8. Stanford JW, Weigel KV, Paffenbarger GC, et al: Compressive properties of hard tooth tissues and some restorative materials. J Am Dent Assoc 1960;60:746-756
9. Trabert KC, Caput AA, Abou-Rass M: Tooth fracture—a comparison of endodontic and restorative treatments. J Endod 1978;4:341-345
10. Kantor MK, Pines MS: A comparative study of restorative techniques for pulpless teeth. J Prosthet Dent 1977;38:405-412
11. Duret B, Duret F, Reynaud M: Long-life physical property preservation and postendodontic rehabilitation with the Composipost. Compend Contin Educ Dent Suppl 1996; 20:S50-S56
12. Purton DG, Payne JA: Comparison of carbon fiber and stainless steel root canal posts. Quintessence Int 1996; 27:93-97
13. Fredriksson M, Astback J, Pamenius M, et al: A retrospective study of 236 patients with teeth restored by carbon fiber-reinforced epoxy resin posts. J Prosthet Dent 1998;80:151-157
14. Dean JP, Jeansonne BG, Sarkar N: In vitro evaluation of carbon fiber post. J Endo 1998;24:807-810
15. Martelli R: Fourth-generation intraradicular posts for the aesthetic restoration of anterior teeth. Pract Periodontics Aesthet Dent 2000;12:579-584
16. Meyenberg KH, Luthy H, Scharer P: Zirconia posts: A new all-ceramic concept for nonvital abutment teeth. J Esthet Dent 1995;7:73-80
17. Nash RW: The use of posts for endodontically treated teeth. Compend Contin Educ Dent 1998;19:1054-1062
18. Cormier CJ, Burns DR, Moon P: In vitro comparison of the fracture resistance and failure mode of fiber, ceramic, and conventional post systems at various stages of restoration. J Prosthodont 2001;10:26-36
19. Cho GC, Kaneko LM, Donovan TE, et al: Diametral and compressive strength of dental core materials. J Prosthet Dent 1999;82:272-276
20. Millstein PL, Ho J, Nathanson D: Retention between a serrated steel dowel and different core materials. J Prosthet Dent 1991;65:480-482
21. Zalkind M, Shkury S, Stern N, et al: Effect of prefabricated metal post-head design on the retention of various core materials. J Oral Rehabil 2000;27:483-487
22. Miyawaki H, Taira M, Toyooka H, et al: Hardness and fracture toughness of commercial core composite resins. Dent Mat J 1993;12:62-68
23. Chang WC, Millstein PL: Effect of design of prefabricated post heads on core materials. J Prosthet Dent 1993;69:475-482
24. Ash MM: Wheeler's Dental Anatomy, Physiology and Occlusion (ed 8). Philadelphia, PA, Saunders, 2003, pp 72-76
25. Jacobi R, Shillingburg HT Jr: Pins, dowels, and other retentive devices in posterior teeth. Dent Clin North Am 1993;37:367-390
26. Palaghias G, Eliades G, Vougiouklakis G: In vivo corrosion behaviour of gold-plated versus titanium dental retention pins. J Prosthet Dent 1992;67:194-198
27. Powers JM: Composite restorative materials. In Craig RG, Powers JM (eds). Restorative Dental Materials (ed 11). St Louis, MO, Mosby, 2002, pp 231-257
28. Mentink AG, Meeuwissen R, Hoppenbrouwers PP, et al: Porosity in resin composite core restorations: The effect of manipulative techniques. Quintessence Int 1995;26:811-815