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ORIGINAL ARTICLE

In vitro evaluation of the effect of post system and length on the fracture resistance of endodontically treated human anterior teeth

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Abstract
Objectives The aim of this study was to evaluate the effect of post system and length on the fracture resistance of endodontically treated human anterior teeth.
Material and method Seventy-five extracted human incisors were endodontically treated, out of which 60 were decoronated 2 mm above the cementoenamel junction and divided into two experimental groups based on the type of post system to be used: glass fiber post (GFP) and Ribbond fiber post groups (RFP). Endodontically treated human anterior teeth in which no post was placed served as control group. Each group was divided into two subgroups according to the length of post space: 5 and 10 mm and all the samples were restored with metal crowns. The fracture resistance was measured by applying loads at an angle of 130° to the long axis of teeth in an Instron universal testing machine.
Results The results revealed that GFP group at 10-mm post space length showed the significantly highest fracture resistance (740.2133 N) among all groups and subgroups. Decrease in post length resulted in the decrease in fracture resistance in GFP group (425.1867 N), whereas in group RFP 5-mm subgroup (299.6200 N) showed significantly higher fracture resistance than 10-mm subgroup (216.9300 N) but lesser than the control (437.8733 N) in both the subgroups.
Conclusion Glass fiber posts efficiently increase the fracture resistance of an endodontically treated tooth but the determination of optimal post length is also essential.
Clinical relevance The present investigation highlights the significance of using glass fiber posts in the restoration of endodontically treated teeth. Endodontically treated teeth restored with glass fiber posts showed increased fracture strength and favorable mode of fracture, and are therefore highly recommended to achieve better clinical outcomes.

Keywords Glass fiber post · Ribbond · Post space

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Introduction

The restoration of endodontically treated teeth is a major concern in dentistry. These teeth present a higher risk of biomechanical failure than the vital teeth [1, 2]. Excessive removal of tooth structure during mechanical instrumentation of the root canal system, mechanical pressures during obturation, lack of cuspal protection, and large restorations can weaken the tooth resulting in complete or incomplete fractures [3–5]. The decreased moisture content in the calcified tissue along with weaker collagen intermolecular links [6] also results in the increase in brittleness of the teeth [7, 8]. Thus, various researchers and clinicians recommended reinforcing pulpless teeth by the use of post systems [9, 10].

In endodontically treated teeth with severe loss of coronal tooth structure, retention of the coronal restoration is often compromised. A well planned and maintained coronal restoration capable of enduring various physical, mechanical, and chemical stresses carry out the important task of preventing microleakage from the oral cavity into the periapical tissue. So, in restoration of endodontically treated teeth with significant loss of tooth structure, the post and cores are needed to improve the retention and strength of the coronal restoration [8].

At present the importance of using post systems with biomechanical properties similar to teeth [11, 12] is widely emphasized. The major objective is a monobloc restoration, i.e., achievement of a single biomechanical complex by adhesion between the tooth structure and reconstruction material for better stress distribution [13]. So, a variety of nonmetallic fiber posts such as prefabricated glass fiber posts had been introduced having modulus of elasticity similar to that of dentin. Apart from the prefabricated fiber posts, fiber-reinforced composites such as Ribbond (polyethylene fiber-reinforced composite) are also available in the form of a ribbon which can also be used as customized intracanal posts. The required length of the material can be cut from the ribbon and can be packed inside the root canal using the adhesive resin cements to act as customized post. Various other factors such as post length, diameter, and design also have a significant effect on the distribution of stress along the root and thereby affect the strength and resistance of the tooth [14–18]. An increase in the success rate of endodontically treated teeth has been noted when the length of the post is equal to or greater than the crown length [19, 20]. But in clinical situations, it is not always feasible to select post system based on the above-stated factors.

So this study was undertaken to determine the reinforcing capability of two fiber post systems, i.e., glass fiber posts and polyethylene fiber-reinforced post system. The investigation was carried out to answer the following two questions: (1) whether polyethylene fiber-reinforced composites provide a good alternative to glass fiber posts while restoring an endodontically treated teeth and (2) whether any of the two materials have advantage of use at shorter post lengths. The fracture strength and mode of fracture of the endodontically treated teeth restored with different post systems and post lengths were evaluated. The null hypothesis tested was that there was no effect of post system and post length on the fracture strength of the endodontically treated teeth.

Material and methods

This study was conducted on 75 extracted human maxillary central incisors. The teeth were collected irrespective of the age, sex, and side of the arch. All the teeth were without coronal/root caries, coronal/root filings, root cracks and with a minimum of 13 mm of root length with a mesiodistal and buccopalatal dimensions varying between 6–8 mm. The selected teeth were cleaned for any root deposits with the help of ultrasonic scaler (ARTP3II, Bonart, Taiwan). To avoid dehydration, the teeth were stored in normal saline solution at room temperature until used for study. The root canal preparation of all the selected teeth was done with K-files (Mani, Japan) using conventional step-back method. Repeated recapitulation and irrigation with 2% sodium hypochlorite and normal saline was done to avoid any clogging of the canals. Each tooth was instrumented to ISO # 60 master apical file (for standardization) to achieve final contour of root canals. After drying the canals with absorbent paper points (Dentsply), polymeric resin sealer (Bioseal, Equinox) was mixed and coated into the walls of the canals. Endodontic spreaders (Mani, Japan) were used to condense the gutta-percha cones and for obturation of the canals using lateral condensation technique.

Out of 75 endodontically treated teeth, 15 teeth were kept as control in which no further treatment was done. The remaining 60 teeth were decoronated at 2 mm from the most incisal point on the cement–enamel junction perpendicular to the long axis of the teeth, with the help of diamond disk at high speed mounted on straight hand piece using a micro motor (NSK, Japan). The 60 teeth were randomly divided into two experimental groups (n=30) based upon the type of post system used: glass fiber post (GFP; Fibrapost no. 2, Produits Dentaires S.A.), Ribbond fiber post (RFP; Ribbond Inc). Each group had two subgroups (n=15) depending upon the length of the post space, i.e., 10 and 5 mm.

In each group the gutta percha was removed up to the required length with no. 2 and no. 3 peaso (Mani, Japan) reamers. In group GFP, post spaces up to the desired lengths were prepared with specialized drill no. 2 supplied with the glass fiber post kit (Fibrapost, Produits Dentaires S.A.) of diameter 0.85 at tip and 1.30 mm at 11 mm. The canals were then irrigated with normal saline solution to remove any debris. All the posts were cemented with dual cure resin cement (Monocem, Shofu Dental). The prepared root canals were irrigated with distilled water and dried with absorbent points (Dentsply). The posts were seated into the canals with normal finger pressure and excess cement was removed. It was then light-cured for 40 s to achieve complete polymerization. The posts were then submitted to a new adhesive treatment for fabrication of the coronal portion of the post with composite resin.

In group RFP, the post spaces up to the desired length were prepared by a specialized drill having 1.3-mm diameter for the entire length. The desired length of the Ribbond fiber (2 mm) (Ribbond Inc.) was cut by doubling the length of post space and adding to it the core length required (Fig. 1a). Two pieces of desired length were cut and placed in a light protected container. The post space was treated with dual-cure resin (Monocem, Shofu dental) to control polymerization in the deepest part of the canal. The Ribbond pieces were then coated with the dual-cure resin and the excessive resin was removed with a hand instrument

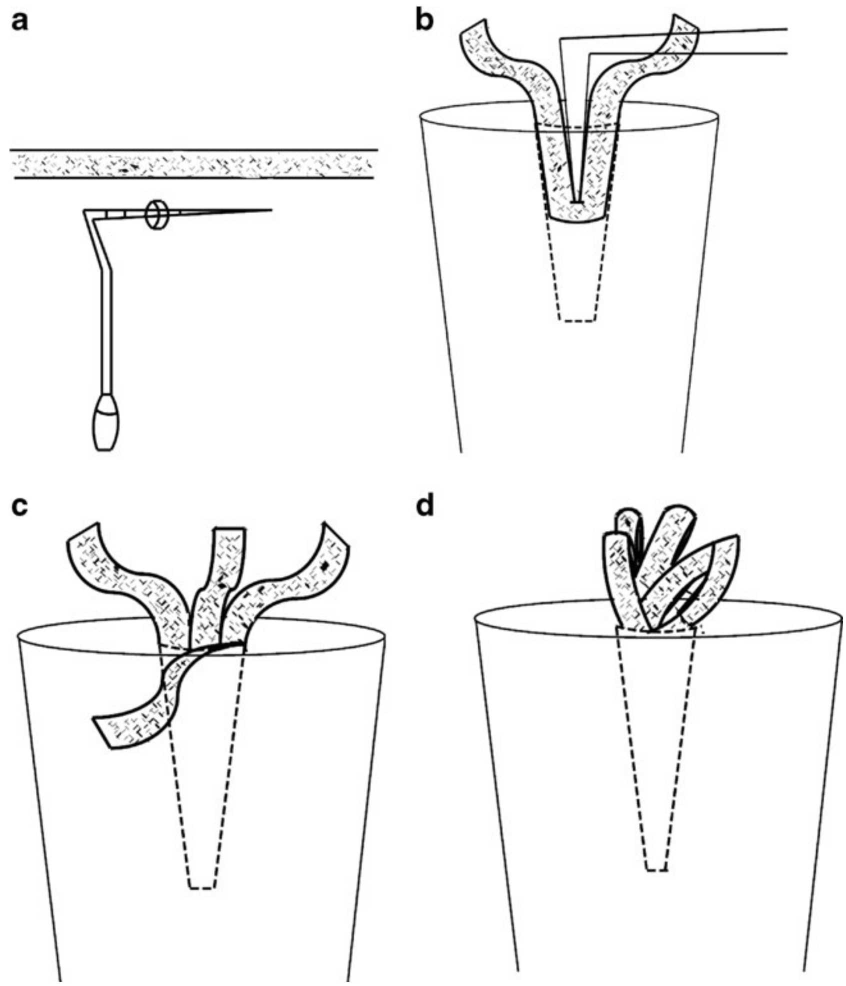

Fig. 1 **a** Determination of the length of Ribbond required. **b** V-shaped piece of Ribbond inserted into the canal. **c** Second piece of Ribbond inserted at right angle to the first piece. **d** Protruding ends of Ribbond are inserted back into the canal

moving in the direction of the fibers. The adhesive-coated piece of fiber was folded in the shape of V and condensed inside the canal using endodontic pluggers (Fig. 1b). A second piece of Ribbond was then taken and placed into the post space at right angles to the first V-shaped piece of Ribbond (Fig. 1c). The free ends of the ribbon protruding from the canal were folded over and tucked back into the canal (Fig. 1d). Finally, the folded ends were twisted and condensed in the shape of a post. The entire fiber resin post was then light-cured for 40 s. The posts were then submitted to a new adhesive treatment for fabrication of the coronal portion of the post with composite resin.

Sixty acrylic resin cylinders were fabricated by mixing the self-cure acrylic resin and pouring it into plastic pipes of 6-cm height and 1.5-cm diameter. All the samples were coated with silicon-based impression material (Impregum, 3 M ESPE) before insertion to give the effect of periodontal ligament. Samples were embedded in acrylic resin (Rapid Repair, Pyrax Polymers) exposing 3 mm of the root surface just apical to the buccal cervical line (to simulate alveolar bone) and held under digital pressure until the material set. Excess material was removed with the help of a B.P knife.

Light-cured composite resin (Nexcomp, Meta Bio-Med) was used for the core fabrication. Post length more than 3 mm was cut with the help of a diamond disk. Samples were washed and dried. Etching of the samples was done for 15 s. The samples were washed and dried with oil-free compressed air. Bonding of exposed post and cut dentine surfaces were done with the dentin bonding agent (Meta P & Bond, Meta Biomed). The preformed polyester matrix (Coltene Whaledent) was filled with the composite resin and placed on the sample. It was then light-cured for 40 s. The matrix was peeled off after curing was completed, with the help of a scalpel. It was finished to the final core height of 6 mm above proximal cervical line, the buccolingual and mesiodistal dimensions corresponding to that of the tooth, with the help of composite finishing instruments. After the fabrication and cementation of post and core, the final finishing of crown preparation was done with super fine diamond points (Shofu Dental).

All the samples were finally restored with cast crowns. The wax pattern was given the final crown shape and height of 8 mm. The patterns were then sprued and invested with phosphate-bonded investment and cast in Ni–Cr alloy (Bego, Germany), using lost wax technique. The cast

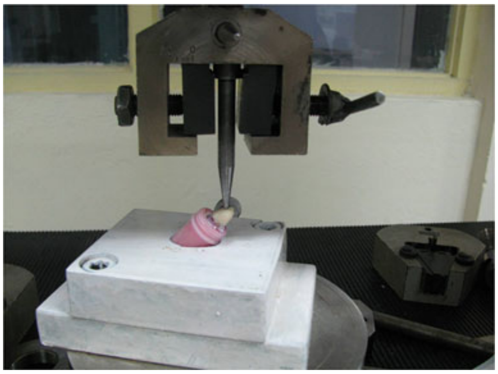

Fig. 2 Loading of the specimens in the Instron universal testing machine

crowns thus obtained were finished and polished. Tooth-colored cold-cure acrylic resin layer was applied on the crown castings. A small step was prepared with carborundum disk at a distance of 3 mm from the incisal edge as a standardized point for load application on the palatal aspect. After pre-cement trial and necessary adjustment, the crowns were cemented with dual-cure resin cement (Monocem, Shofu dental) following the manufacturer's instructions. The samples were stored in normal saline, until tested.

For holding the specimens during testing, the stainless steel metal jig and an attachment clutch were custom made of the desired dimensions according to the testing machine used in the study. Metal jig had the provision for holding acrylic resin blocks, that oriented the sample at an angle of 135° to the load application tip of the attachment clutch.

The whole assembly was fitted in the digital Instron universal testing machine (LR 100 K, UK; maximum capacity, 100 kN). The load was applied on the palatal surface of the cast crown, on a step 3 mm from its most incisal edge, at an angle of 130° to the long axis of the root, at a cross-head speed of 0.5 mm/min until fracture occurred (Fig. 2).

Each sample was then carefully inspected to record the mode of failure. The fracture mode was determined using the classification proposed by Zhi-Yue and Yu-Xing (2003):

1. Resin core or post fracture
2. Cervical root fracture
3. Mid root fracture
4. Apical root fracture
5. Vertical root fracture

The resin core/post fracture was considered as favorable mode of fracture whereas all other fracture modes involving root were considered as unfavorable.

Statistical analysis

The Statistical Package for Social Sciences (SPSS) computer software version 11.0 (SPSS, Inc., Chicago, IL, USA) was used to conduct data analysis. Descriptive statistics including means, standard deviations, and frequency distribution were calculated for each group. Results from the four test groups were compared and analyzed using one-way ANOVA test and the post-hoc least significant difference test to demonstrate differences between pairs of groups. Probability values of $P<0.05$ were set as the reference for statistically significant results.

Results

Fracture resistance

The “Results” revealed that there was significant difference in the fracture resistance of all the groups and among the subgroups. GFP group at 10-mm post space length showed the significantly highest fracture resistance (740.21 N) among all groups and subgroups (Table 1). Decrease in post space length to 5 mm resulted in the decrease in fracture resistance in GFP group (425.19 N), whereas in group RFP 5-mm subgroup showed significantly higher fracture resistance (299.62 N) than the 10-mm subgroup (216.93 N) but lesser than the control (437.87 N) in both the subgroups.

Fracture modes

The fracture mode analysis revealed that specimens in group GFP subgroup 10 mm showed dominance of favorable fractures with 80% of the fractures occurring as core/post fractures. In the 5-mm subgroup in GFP and both the subgroups in group RFP showed dominance of unfavorable fractures mostly in the form of cervical root fractures (Figs. 3 and 4). Table 2 shows the fracture mode distribution of the specimens tested.

Table 1 Mean value of fracture resistance of different groups and subgroups in newtons

Group	Post space length	N	Mean	Std. deviation	Minimum	Maximum
Control		15	437.8733a	32.81070	376.70	495.70
Glass fiber (GFP)	10 mm	15	740.2133b	29.87442	653.30	771.20
	5 mm	15	425.1867a	42.73448	378.60	484
Ribbond (RFP)	10 mm	15	216.9300c	53.39861	172.20	234.50
	5 mm	15	299.6200d	53.42050	212.30	314.90

Different letters indicate the significant difference ($p<0.05$) verified by Mann–Whitney and post-hoc Bonferroni tests

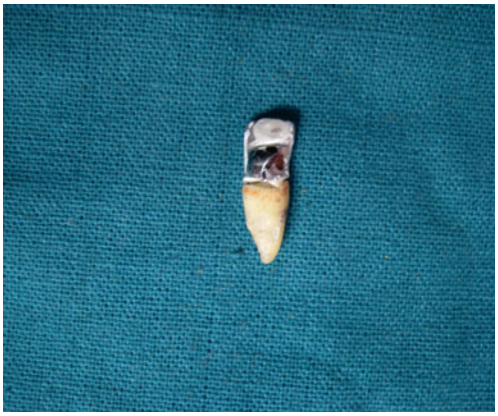

Fig. 3 Irreparable cervical root fracture in a tested sample

Discussion

The results from this study did not support the null hypothesis and there was an effect of both the post system and post length on the fracture strength of endodontically treated teeth. The results clearly indicated the inability of polyethylene fiber-reinforced posts to strengthen an endodontically treated tooth. There was a definite correlation found between post system and post length on the fracture resistance of endodontically treated teeth. The GFP group showed higher fracture resistance as compared to the RFP group at both 10- and 5-mm post space lengths.

In this study, extracted human teeth were used for the preparation of specimens. Human teeth have been commonly used for the in vitro testing of the post restorations [21–24]. Apart from the human teeth, some authors have used either bovine teeth [25–27] or resin teeth [28, 29]. Bovine teeth are comparable to human teeth in modulus of elasticity, tensile strength, and bonding characteristics but they suffer from an unacceptably high size discrepancy relative to human teeth [30]. Resin material teeth can be standardized in terms of size but do not properly simulate the elastic and bonding properties

Fig. 4 Fracture line in a tested sample

Table 2 Fracture mode distribution of the specimens tested

Group		Post/ core fracture	Cervical root fracture	Mid root fracture	Apical root fracture	Vertical root fracture
GFP	10 mm	12	3	–	–	–
	5 mm	3	9	2	1	–
RFP	10 mm	1	10	3	1	–
	5 mm	–	12	3	–	–

of the natural human teeth [30]. Their adhesion to the post is unrealistic and not similar to clinical situations [31, 32]. All teeth in this study received endodontic treatment. This was done keeping in mind that teeth receiving post anchored restorations are always endodontically treated [10] resulting in a small but not negligible loss of tooth structure [30]. As this could influence the outcome, an endodontic treatment is mandatory to obtain reliable result.

The resin cement was used for luting various post systems. Resin cements reduce potential stress as their elasticity approaches to that of dentin [33–36]. The periodontal ligament simulation was done by coating the roots of the specimens with polyether impression material. This allowed limited freedom of movement [37]. The PDL simulation is essential as it was found by Soares et al. that the presence of simulated PDL significantly affected the result of fracture testing [38]. It is believed that the use of a rigid material to embed the extracted teeth may lead to distorted load values and possibly affect the mode of failure of the specimens [39]. All the specimens in this study were given the full metal crowns. According to Martelli et al., the presence of a prosthetic restoration generate a different bio mechanical effect [40].

The testing of the specimens was done by applying compressive load in a universal testing machine at an angle of 130° to the long axis and standardized palatal steps were fabricated to mark the level of loading on each metal crown. The loading angle of teeth with post restoration can strongly affect the fracture resistance [41, 42]. Guzy and Nicholls reported that for incisor teeth, a loading angle of 130° was chosen to simulate a contact angle found in class 1 occlusions between maxillary and mandibular anterior teeth [37]. Several other authors also had found this angle to be the most clinically comparable angle of loading in anterior teeth [43, 44].

The highest fracture resistance of GFP 10-mm subgroup can be explained by the concept of monobloc formation by the fiber posts, i.e., achievement of a single biomechanical complex by adhesion between the tooth structure and reconstruction material capable of resisting greater forces [13]. As the post length was reduced in 5-mm subgroup, the reinforcing effect of glass fiber posts diminished and became even lesser than the control group. Similarly RFP group showed significantly lower fracture resistance values compared to GFP and control groups at all post lengths. The results of

GFP group at 5 mm and RFP at all post space lengths showed that the placement of post negatively affected the strength of an endodontically treated tooth and decreased its fracture resistance.

The fracture mode analysis showed the dominance of core/post fractures in glass fiber group at 10-mm post space length. This can be explained by low modulus of elasticity of glass fiber posts which is closest to that of dentin (modulus of elasticity of glass fiber, 16 GPa). This allowed the restored root strain to occur as it did in the sound teeth with the stress distribution along the restored tooth structures [45]. These types of fractures are considered as favorable fractures as teeth with such type of failures are restorable and allow retreatment. The GFP group at 5 mm and RFP group both at the 10- and 5-mm post space lengths showed the dominance of root fractures. These types of fractures are considered as unfavorable as retreatment is not possible in these types of failures jeopardizing the integrity of the tooth. The reason for cervical root fracture in glass fiber post group at shorter post length and RFP group can be explained by the fact that at shorter post lengths as the mass volume of posts decreases, the absorption of forces by the post system decreases to a considerable degree and they more efficiently transfer the forces to less rigid tooth dentin endangering the tooth structure to more root/catastrophic fractures [46].

Therefore, it can be stated that longer post lengths favors the concept of coronoradicular reinforcement by the use of post system [9, 47], but as the post length is reduced, this concept is not followed and the post placement further worsened the strength of already weakened endodontically treated tooth [48–50]. The concepts laid by various authors regarding the determination of minimum post length while restoring an endodontically treated teeth are extremely important and should be followed for better clinical outcomes.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

1. The use of polyethylene fiber reinforced composites as customized intracanal posts is questionable and needs further research.
2. Glass fiber posts can efficiently increase the fracture resistance of an endodontically treated tooth but the determination of optimal post length is also essential.

Conflict of interest The authors declare that they have no conflict of interest.

Reference

1. Caputo AA, Standlee JP (1976) Pins and posts why, when and how? Dent Clin N Am 20:299–331
2. Sorenson JA, Martinoff JT (1984) Clinically significant factors in dowel design. J Prosthet Dent 52:28–35
3. Rosen H (1982) Cracked tooth syndrome. J Prosthet Dent 47:36–43
4. Trope M, Maltz DO, Tronstad L (1985) Resistance to fracture of restored endodontically treated teeth. Endod Dent Traumatol 1:108
5. Lynch CD, Burke FM (2002) Incomplete tooth fracture following root-canal treatment: a case report. Int Endod J 35:642–0646
6. Rivera E, Yamauchi G, Chandler G, Bergenholtz G (1988) Dentin collagen cross-links of root-filled and normal teeth. J Endod 14:195
7. Helfer AR, Melnick S, Schilder H (1972) Determination of moisture content of vital and pulpless teeth. Oral Surg Oral Med Oral Pathol 34:661–670
8. Gutmann JL (1992) The dentin–root complex: anatomic and biologic considerations in restoring endodontically treated teeth. J Prosthet Dent 67:458–467
9. Standlee JP, Caputo AA, Hanson EC (1978) Retention of endodontic dowels: effects of cement, dowel length, diameter, and design. J Prosthet Dent 39:401
10. Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Brackett SE (1997) Preparations for extensively damaged teeth. In: Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Brackett SE (eds) Fundamentals of fixed prosthodontics. Quintessence, Chicago, pp 181–209
11. Tjan AH, Grant BE, Dungn JR (1991) Microleakage of composite resin cores treated with various dentin bonding systems. J Prosthet Dent 66:24–29
12. Yang HS, Lang LA, Molina A, Felton DA (2001) The effects of dowel design and load direction on dowel-and-core restorations. J Prosthet Dent 85:558–567
13. Tay FR (2007) Monoblocks in root canals: a hypothetical or a tangible goal. J Endod 33:391–396
14. Standlee JP, Caputo AA, Collard EW, Pollack MH (1972) Analysis of stress distribution by endodontic posts. Oral Surg Oral Med Oral Pathol 33:952–960
15. King PA, Setchell DJ (1990) An in vitro evaluation of a prototype CFRC prefabricated post developed for the restoration of pulpless teeth. J Oral Rehabil 17:599–609
16. Purton DG, Love RM (1996) Rigidity and retention of carbon fiber versus stainless steel root canal posts. Int Endod J 29:262–265
17. Fernandes AS, Dessai GS (2001) Factors affecting the fracture resistance of post-core reconstructed teeth: a review. Int J Prosthodont 14:355–363
18. Nissan J, Dmitry Y, Assif D (2001) the use of reinforced composite resin cement as compensation for reduced post length. J Prosthet Dent 86:304–308
19. Sokol DJ (1984) Elective use of current core post concepts. J Prosthet Dent 52:231–234
20. Standlee JP, Caputo AA, Holcomb J, Trabert KC (1980) The retentive and stress distributing properties of a threaded endodontic dowel. J Prosthet Dent 44:398–404
21. Lovdahl PE, Nicholls JI (1979) Pin-retained amalgam cores vs. cast-gold dowel-cores. J Prosthet Dent 43:307–312
22. Reagan SE, Fruits TJ, Van Brunt CL, Ward CK (1999) Effects of cyclic loading on selected post-and-core systems. Quintessence Int 30:61–67
23. Sirimai S, Riis DN, Sm M (1999) 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 81:262–269

24. Heydecke G, Butz F, Strub JR (1999) The effect of various post/core buildup designs on the fracture resistance of crown restored incisors. Dtsch Zahnarztl Z 54:637–640
25. Isidor F, Brøndum K (1992) Intermittent loading of teeth with tapered, individually cast or prefabricated, parallel-sided posts. Int J Prosthodont 5:257–261
26. Isidor F, Brøndum K, Ravnholt G (1999) 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 12:78–82
27. Santos-Filho PC, Castro CG, Silva GR, Campos RE, Soares CJ (2008) Effects of post system and length on the strain and fracture resistance of root filled bovine teeth. Int Endod J 41:493–501
28. Lauer H-C, Ottl P, Weigl P (1994) Mechanical resistance of different post-and-core systems [in German with English summary]. Dtsch Zahnarztl Z 49:985–989
29. Schmeissner H (1983) Comparison of the fracture loads of smooth and screw retained post and core reconstructions [in German with English summary]. Dtsch Zahnarztl Z 38:163–166
30. Butz F, Lennon AM, Heydecke G, Strub JR (2001) Survival rate and fracture strength of endodontically treated maxillary incisors with moderate defects restored with different post and core systems. An in-vitro study. Int J Prosthodont 14:58–64
31. Mendoza DB, Eakle WS, Kahl EA, Ho R (1997) Root reinforcement with a resin-bonded preformed post. J Prosthet Dent 78:10–14
32. O'Keefe KL, Miller BH, Powers JM (2000) In vitro tensile bond strength of adhesive cements to new post materials. Int J Prosthodont 13:47–53
33. Eakle WS, Staninec M, Lacy AM (1992) Effect of bonded amalgam on the fracture resistance of teeth. J Prosthet Dent 68:257–260
34. Suh B, Cincione F (1992) All-Bond 2: the fourth generation bonding system. Esthet Dent Update 3:61–66
35. Leinfelder KF (1993) Current developments in dentin bonding systems: major progress found in today's products. Oral Health 8:7–8
36. Junge T, Nicholls JI, Phillips KM, Libman WK (1998) Load fatigue of compromised teeth: a comparison of three luting cements. Int J Prosthodont 11:558–564
37. Guzy GE, Nicholls JI (1979) In vitro comparison of intact endodontically treated teeth with and without endo-post reinforcement. J Prosthet Dent 42:39
38. Soares CJ, Pizi EC, Fonseca RB, Martins LR (2005) Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. Pesquisa Odontolo´gica Brasileira 19, 11–6. In vitro study. Swed Dent J 7:205–214
39. Newman MP, Yaman P, Dennison J, Rafter M, Billy E (2003) Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent 89:360–367
40. Martelli H Jr, Pellizzer EP, Rosa BT, Lopes MB, Gonini A Jr (2008) Fracture resistance of structurally compromised root filled bovine teeth restored with accessory glass fiber posts. Int Endod J 41:685–692
41. Hayashi M, Takahashi Y, Imazato S, Ebisu S (2005) Fracture resistance of pulpless teeth restored with post-cores and crowns. Dent Mater 16:17–21
42. Loney RW, Korowicz WE, McDowell GC (1990) Three-dimensional photoelastic stress analysis of the ferrule effect in cast post and cores. J Prosthet Dent 63:506–512
43. EshelmanJr EG, Sayegh FS (1983) Dowel materials and root fracture. J Prosthet Dent 50:342–344
44. Patel A, Gutteridge DL (1996) An in vitro investigation of cast post and partial core design. J Dent 24:281–287
45. Zarone F, Sorrentino R, Apicella D et al (2006) Evaluation of the biomechanical behaviour of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. Dent Mater 22:1035–1044
46. Giovani AR, Vansan LP, de Sousa Neto MD, Paulino SM (2009) In vitro fracture resistance of glass-fiber and cast metal posts with different lengths. J Prosthet Dent 101:183–188
47. Shillingburg HT, Kessler JC, Wilson EL (1982) Root dimensions and dowel size. Calif Dent Assoc J 10:43
48. Mannocci F, Ferrari M, Watson TF (1999) Intermittent loading of teeth restored using quartz fiber, carbon-quartz fiber, and zirconium dioxide ceramic root canal posts. J Adhes Dent 1:153–158
49. Akkayan B, Gulmez T (2002) Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent 87:431–437
50. Naumann M, Blankenstein F, Dietrich T (2005) Survival of glass fiber reinforced composite post restorations after 2 years—an observational clinical study. J Dent 33:305–312