The Retention of Cast Metal Dowels Fabricated by Direct and Indirect Techniques

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Abstract

Purpose: To explore the effect of fabrication technique, cement type, and cementation procedure on retention of cast metal dowels.
Methods and Materials: Eighty intact single-rooted teeth were selected. The clinical crown was removed at the cementoenamel junction level. Each root was prepared to receive a cast metal dowel of 10-mm length and 1.45 mm in diameter. The 80 specimens were divided into two major groups of 40 based on fabrication technique (direct and indirect). Each group was further divided into four subgroups of ten based on the cement type (zinc phosphate and glass ionomer), and cementation procedure (with and without lentulo spiral). The dowels were subjected to a constantly increasing tensile force, in a universal Instron testing machine, at crosshead speed of 5 mm/min until failure.
Results: The most significant factor to affect retention was the cementation procedure, as cementation with lentulo spiral produced greater retention than cementation without the use of lentulo spiral ($p < 0.05$); however, there seems to be a close interaction between fabrication technique, cement type, and cementation procedure ($p = 0.051$). The least retentive group was the one fabricated by direct technique, cemented with zinc phosphate without the use of lentulo spiral.
Conclusion: Fabrication technique does not affect retention of cast dowels, except when zinc phosphate was the luting agent and placed in the canal space without using a lentulo spiral. The cementation procedure had a significant effect on retention; thus, it is recommended that cementation should be done using the lentulo spiral.

The chief function of a dowel is to improve the retention of extracoronal restorations of nonvital teeth; however, the risk of fracture is increased when endodontically treated teeth are provided with metal dowels.[1] If adequate retention for the core can be derived from natural undercuts in the pulp chamber and canal entrances, then dowels should not be provided.[2] The success of a restorative treatment depends on the ability of cemented cast restorations to resist dislodgment from tooth preparations. Loss of retention is the most frequent cause of dowel failure.[3,4] The interaction of many factors, such as the design of the tooth preparation, fit of the casting, dowel diameter and design, dowel length, luting medium, cementation procedure,[5] surface characteristics,[6] and location in the dental arch,[7] appears to influence the potential for dislodgment.

An individually cast metal dowel is commonly used to enhance retention, preventing dislodgment of a casting not only along a path parallel to the path of insertion of a restoration but also preventing dislodgement along horizontal forces. Dowels with greater retention are more resistant to dislodgement as a result of lateral occlusal stresses.[8]

The importance of adequate dowel length to maximize dowel retention is well recognized. Although the ideal length for dowel retention is controversial,[2] there has been a trend toward maximizing dowel length in all teeth.[9]

Most retention studies have emphasized the fact that dowels should be as close as possible to fitting exactly in the prepared root canal.[10] Therefore, a custom-cast dowel could be preferred over a prefabricated dowel, as it will fit the irregularly shaped canal walls more intimately, and because their shape and structure can resist torsion forces.[11]

Dental cements lute the dowel to radicular dentin, and properties such as compressive strength, tensile strength, and adhesion of the cement to dowel and dentine are commonly described as predictors for the success of a cemented dowel. Other factors, such as potential for plastic deformation, microleakage, water imbibition, behavior of the cement during the setting process, and handling characteristics, can also influence the survival rate of a cemented dowel.[12]

Although various factors affecting retention of dowels have been studied previously, there is a lack of studies about the effect of fabrication techniques (direct and indirect) on the retention of cast dowels. The current investigation aims to study the effect of fabrication technique, in combination with different luting cements and cementation procedures on the retention of cast metal dowels. Moreover, the current study aims at exploring any interaction between fabrication technique, cement type, and cementation technique as major detrimental factors affecting retention of cast metal dowels.

Materials and methods

Eighty recently extracted sound, caries-free, permanent mandibular premolars were selected for this study. The teeth were cleaned of calculus by hand scaling, polished with pumice-water slurry, and stored in saline at room temperature. Buccolingual and mesiodistal radiographs of the teeth were taken. All teeth with more than one root canal, an incomplete apex, and an obstruction within the canal system or internal root resorption were discarded. The structure of the teeth was examined with transillumination (Optilux 500, Demetron-Kerr, Orange, CA) to exclude any teeth with cracks and fractures.

The coronal portion of each tooth was sectioned 1 mm coronal to the cementoenamel junction, perpendicular to the long axes of the tooth with a diamond-coated disk (Superflex, Edenta AG, Dentalprodukte, Au/SG, Switzerland) at high speed, under abundant water cooling. The root face was further flattened with a polishing disc (Super-Snap, Shofu Inc., Kyoto, Japan). Any remaining pulpal tissues were removed from the root canal of each tooth with a barbed broach (Nerve broach, Munich, Germany). Teeth observed to have significantly smaller or larger root canal spaces were excluded from the study to standardize the extent of dentine preparation for the dowels as much as possible. The root length was determined by insertion of a No. 10 file (Dentsply/Maillefer, Ballaigues, Switzerland) into the canal until it appeared through the apex; the file was then drawn back into the canal until it was just visible at the foramen, and the working length was recorded as 0.5 mm shorter than that length. The root surface was the reference point for all measurements. The coronal portion of the root canal was shaped with sizes 2–5 Gates Glidden drills (Dentsply/Maillefer). Instrumentation of the canal continued from the No. 10 file to a No. 20 file with circumferential filing. Preparation of the canal was completed by filing the canals to a size 40. The canals were irrigated with 2% sodium hypochlorite solution after the use of each file and each Gates Glidden drill. New instruments were used for every five specimens.

The canal space was thoroughly dried with medium paper points (Coltene Whaledent, Mahwah, NJ). A calcium hydroxide-based endodontic sealer (Sealapex, Kerr Dental, Orange, CA) was mixed according to the manufacturer's instructions. The sealer was carried to the canal with the lentulo spiral (Dentsply/Maillefer). An appropriate master cone was chosen for every canal, coated with sealer, and inserted into the canal space to the full working length. Accessory gutta percha points were used to complete obturation with lateral condensation using finger spreader. Excess gutta percha was removed with a warm endodontic plugger flush with the root surface. The root canal sealer was allowed to set for more than 2 days.

Wax boxes, 2 cm long, 2 cm wide, and 2 cm high and opened from the top, were prepared. Then self-cure acrylic resin (B.M.S., Cappanoli, Italy) was mixed according to the manufacturer's instruction and poured in the boxes. The tooth was mounted in the middle of the mix with 2 mm of the coronal part of the root appearing above the acrylic resin with the aid of a surveyor (BEGO, Bremen, Germany). The acrylic block was immersed in water for 24 hours.

The mold was fitted onto the base of a customized milling machine (BEGO). Peeso reamer (Dentsply Maillefer) was fitted into the reamer driver, which was fixed to the milling machine and aligned parallel with the long axis of the tooth. A fixed depth of 10 mm and a diameter of 1.45 mm were prepared. The length was controlled and fixed by the milling machine. After dowel space preparation, the canals were irrigated using 2% sodium hypochlorite, and then a cotton pellet was placed at the orifice and covered with temporary filling (Provis, Favodent, Karlsruhe, Germany).

The 80 specimens were further subdivided into eight experimental groups of ten teeth each, based on fabrication technique, cement type, and cementation procedure as follows:

Group 1: Restored with dowels and cores fabricated using indirect technique, cemented with glass ionomer (Medicem, Promedica, Neumunster, Germany) using the lentulo spiral.
Group 2: Restored with dowels and cores fabricated using direct technique, cemented with glass ionomer using the lentulo spiral.
Group 3: Restored with dowels and cores fabricated using indirect technique, cemented with glass ionomer, but without using the lentulo spiral.
Group 4: Restored with dowels and cores fabricated using direct technique, cemented with glass ionomer, but without using the lentulo spiral.
Group 5: Restored with dowels and cores fabricated using indirect technique, cemented with Zinc phosphate (Durelon ESP, Seefeld, Germany) using the lentulo spiral.
Group 6: Restored with dowels and cores fabricated using direct technique, cemented with Zinc phosphate using the lentulo spiral.
Group 7: Restored with dowels and cores fabricated using indirect technique, cemented with Zinc phosphate, but without using the lentulo spiral.
Group 8: Restored with dowels and cores fabricated using direct technique, cemented with Zinc phosphate, but without using the lentulo spiral.

The dowels and cores in groups 1, 3, 5, and 7 were made by indirect technique. An impression was made for the dowel canal space with addition cure silicon impression material (President, Coltene, Furstentum, Liechtenstein). A plastic sectional tray (TeleDyne, Milan, Italy) was loaded with putty impression material. The wash consistency was mixed in a mixed cartridge, and a small nozzle was attached to the tip of the gun. The wash material was injected into the canal space; the material was pushed into the space with a lentulo spiral. A plastic impression dowel was fitted into the canal, and the sectional tray was fitted on the top of the root face. The material was kept after removal for 40 minutes at room temperature before pouring in dental stone (Diastone Rubinit, Pootehno, Spain). The poured impression was separated after 2 hours according to the manufacturer's instructions. A direct inlay wax (Blue regular inlay wax, Heraeus Kulzer, Hanau, Germany) pattern was made, and the core was built and standardized using a custom-made core former.

The dowels and cores in groups 2, 4, 6, and 8 were made by direct technique. The dowel space was recorded using self-cured acrylic resin (DuraLay, Reliance Dental Mfg. Co., Worth, IL). A layer of separator (Reliance Dental Mfg. Co.) was applied into the canal space by special plastic brush (Degussa, Düsseldorf, Germany). The resin was mixed according to the manufacturer's instructions and loaded into the canal using lentulo spiral. A plastic Para-Post (Coltene/Whaledent) was placed in the canal, and the material was allowed to partially set. Additional increments of acrylic resin material were added to build up the core, which was standardized using the core former.

The wax patterns and DuraLay patterns were invested in crystobalite investing material (Bellavest, BEGO). The investment material was mixed in a vacuum-mixing unit (Motava SL, BEGO) following manufacturer's instructions and poured into a casting ring. The specimens were cast using an induction casting machine (BEGO) with beryllium-free nickel-chromium alloy (Remanium, CS, Dentarum, Ispringen, Germany) consisting primarily of Ni (61%), Cr (26%), Mo (11%), and Si (1.5%) and free of Beryllium. After casting, removal, and cleansing, the dowel and cores were sandblasted with aluminum oxide with 50-μm diameter particles. The root canal walls were cleaned with 16% ethylenedimethaminetetreacetic acid by using extra fine interdental brushes for 30 seconds, rinsed with water for 1 minute, and then dried with a compressive air.

In groups 1 to 4, the dowels were cemented with glass ionomer cement. The cement was hand mixed according to manufacturer's instructions and applied either into the canal using a lentulo spiral (groups 1 and 2) or directly applied onto the dowel (groups 3 and 4) prior seating into the canal space.

The dowels in groups 5 to 8 were cemented with zinc phosphate cement. The cement was mixed and handled according to manufacturer's instructions. The cement was either inserted into the canal with a lentulo spiral (groups 5 and 6) or by direct application onto the dowel (groups 7 and 8).

The cast dowel and cores were seated firmly into position with a finger and kept under manual pressure for 2 minutes, until initial setting occurred. After 15 minutes, excess cement was removed with either scalpel blade or a dental explorer.

The specimens were then kept hydrated in normal saline solution and kept under refrigeration for 1 week. After that time, a universal Instron testing machine (Model 4502, Brucks, UK) was used to determine the retention of each cemented dowel. The specimen was placed in a customized, self-aligning apparatus, which was clamped into place with a vise grip. When assembled, the horizontal rod attached to the upper element of the Instron testing machine was passed through the hole, which was made in the core.

The Instron testing machine was calibrated prior to data collection. A shearing dislodging load was applied at crosshead speed of 0.5 mm/min. Each specimen was tested to failure, defined as the "dislodgment of the dowel." The force required to dislodge the dowel from the canal was recorded for every specimen in N.

The data were analyzed using 3-way ANOVA with a significance level of $p < 0.05$. T-independent test was performed to reveal the significant differences between every two independent experimental groups categorized, based on fabrication technique (direct vs. indirect), cement type (glass ionomer vs. zinc phosphate), and cementation procedure (with lentulo spiral vs. without lentulo spiral).

Results

The means and standard deviations of the retention values obtained are summarized in Table 1. The data were treated with 3-way ANOVA at 95% confidence interval. The test revealed that the fabrication technique, direct or indirect, did not have a statistically significant effect on retention (Table 2). The same result was obtained by t-test when used to compare the means

Table 1 Means and standard deviations (N) of the retentive failure shear force recorded for all experimental groups

Fabrication technique	Cement type	Cementation procedure	Mean	Standard deviation
Direct technique	Glass ionomer	With lentulo spiral	169.5	41.4
		Without lentulo spiral	127.5	30.9
		Total (n = 20)	148.5	41.6
	Zinc phosphate	With lentulo spiral	192.2	37.1
		Without lentulo spiral	91.0	29.1
		Total (n = 20)	141.6	61.2
Indirect technique	Glass ionomer	With lentulo spiral	151.5	40.3
		Without lentulo spiral	104.5	36.2
		Total (n = 20)	128.0	44.4
	Zinc phosphate	With lentulo spiral	173.0	33.4
		Without lentulo spiral	129.5	32.6
		Total (n = 20)	151.2	39.1

Table 2 Three-way ANOVA

Variables	Sum of squares	*F*-ratio	*p*
Fabrication technique	588.612	0.470	0.495
Cement type	1336.613	1.068	0.305
Cementation procedure	68269.613	54.544	0.000
Technique + cement	4545.112	3.631	0.061
Technique + procedure	3471.612	2.774	0.100
Cement + procedure	3878.113	3.098	0.083
Technique + cement + procedure	4914.113	3.926	0.051

of the retention for the specimens fabricated by the direct technique ($n = 40$) and those using the indirect technique; however, the only significant difference between the experimental groups according to fabrication technique was between the dowels fabricated by indirect technique, cemented with zinc phosphate without using lentulo spiral and those fabricated by direct technique cemented with zinc phosphate without using lentulo spiral ($p < 0.05$). No other statistically significant differences were found.

The 3-way ANOVA revealed that the cement type was not a statistically significant factor (Table 2). When t-test was used to explore the effect of cement type on retention, a statistically nonsignificant effect was demonstrated. When every two independent groups were tested with t-test, the only statistically significant difference found was between the dowels cemented with glass ionomer and those cemented with zinc phosphate, both groups cemented without using lentulo spiral and fabricated by the direct technique. No other differences were revealed. The 3-way ANOVA revealed that the cementation procedure is a highly significant factor, where cementation with lentulo spiral produced greater values of force required for dislodgement of the dowels (Table 2).

Discussion

Magnitude of retention has been considered an important criterion to assess root canal dowel resistance to dislodgement forces encountered clinically.[13] Thus, dowels that exhibit greater retention values are expected to be less likely to loosen when subjected to occlusal stresses.[14] Although the mode of failure measured in the current investigation may not be directly correlated to the clinical situation, standardized pull-out force testing, where predominantly vertical displacement force is applied, has been used widely to determine the values required to remove the dowel from the root canal.[7] Clinically, occlusal forces are much more complex than forces applied using a simple tensile test. Failure usually occurs if the cement bond fails as a result of gradually increasing tensile and torque forces, and dislodgement of dowels occurs when the cement fatigues, and the bond to dentine is eventually lost.[7]

In vitro experiments using extracted teeth can hardly replicate the clinical behavior of teeth in the mouth when a vital periodontal ligament is present.[11] Previous studies attempted to substitute the periodontal ligament layer with a layer of elastomer to cover the root surface;[15-17] however, since the experimental conditions were similar for all groups and the purpose was to compare the in vitro behavior of experimental groups, the addition of such a layer may not be critically relevant.[18]

To minimize any additional factor that might affect the magnitude of the retention of the cemented dowel, teeth selected for the study were sound, free of cracks, and had a narrow, patent single root canal. Radiographs were taken to ensure that the canal was single, with no obstruction and without internal resorption. Teeth with cracks that could increase the tendency of the root fracture if subjected to tensile force were excluded. Single-rooted teeth with a single patent canal were selected, to minimize anatomical variation between the selected teeth. Teeth were sorted and distributed into groups according to type and size of root canal.

The preparation of teeth was accomplished as close to preparation in the patient's mouth as possible to render the study more clinically relevant. Thus a conventional endodontic treatment was completed for each tooth to achieve a perfect apical seal and simulate the clinical situation.

The prepared roots were vertically aligned and placed into molds of acrylic resin to give them adequate retention to withstand the tensile forces and to prevent unwanted dislodgment of the teeth and to ensure that the force applied was vertical and parallel to the long axis of the teeth, thus preventing any other potential forces other than the tensile one. Rosentiel et al recommend the use of safe-tip instruments such as Peeso reamers and Gates Glidden burs for the removal of the gutta percha.[10] In the current investigation, Peeso reamers were used to remove the gutta percha filling material and the endodontic sealer. This technique was chosen because it provides a standardized root canal preparation and might be more popular among clinicians than the use of heated instruments.[19]

For employing the indirect technique, addition silicone impression material was used to reproduce the details of the root canal space. This material is characterized by the ability to accurately register the margins of the gingival tissues and sulcular area. It also resists distortion and exhibits excellent dimensional stability.[20]

Acrylic resin is the most popular material used with the direct technique, because it has many advantages, including easy manipulation, dimensional stability, a reasonably long setting time, easy adjustment in the mouth as needed, and less working time at the laboratory. These advantages justify the use of self-cure acrylic resin in the current study. Moreover, use of acrylic resin can overcome the technically demanding nature of the indirect technique with its greater number of intermediate steps, which are usually outside dentist control.

A study on dowel retention has concluded that for a dowel to be well retained it must fit the prepared root canal as closely as possible.[21] Turner surveyed dowel crown failures and ascribed poor fit of the dowel within the root canal as the primary cause of dowel failure. It has been found that even where dowels were long, if the fit was poor, they tended to fail.[21]

It was found that fabrication technique (direct or indirect) had no significant effect on the retention of cast metal dowels and cores (Table 2). This result could not be compared with any previous study, as no previous study investigated the influence that fabrication technique may have on the retention of metal cast dowel and core. The indirect technique is considered to be technically demanding, with its extra number of intermediate steps usually outside the dentist's control; however, if a stable impression and accurate material is used and meticulous laboratory procedure followed, it can give results comparable to those obtained by direct technique.

Dowel retention is crucial for the success of the definitive restoration. Hence, retention is one criterion for the selection of the cementing agent.[22] Both zinc phosphate and glass ionomer cements are among the most frequently used cements because of their ease of manipulation, along with the long history of success in luting procedure.[8]

In this investigation, there was no significant difference in retention values between groups cemented with both cements. The current finding agrees with the study of Radke et al[23] who found that there was no significant difference in retention between glass ionomer cement and zinc phosphate cement. The current results also concur with the results reported by Mitchell, who stated that zinc phosphate is a good choice for patients for whom fluoride release is not considered essential and that glass ionomer cement is a good choice for those who need fluoride release.[24]

It has been demonstrated that cementation procedure is a highly significant factor affecting the retention of cast dowels and core. Cementation with a lentulo spiral produced significantly greater values of retention. These results agree with the results obtained by Reel et al[25] and Fakiha et al[26] who demonstrated that insertion of the cement in the dowel space gave greater significant values at retention than placing the cement on the dowel only. The results also agree with the results of a study by Goldstein et al, who concluded that the use of lentulo spiral for cementation procedure of cast dowel and core produces a better retentive effect than placing the cement using endodontic explorer, paper point, or by direct application on the dowel.[27]

This can be justified by taking into account the most critical problem encountered in cementation, which is the air entrapment through the liquid cement to create voids, thereby compromising the physical properties of the cement film.[28] Turner suggests that those voids are responsible for the unexpected low retentive values for dowels.[29]

The lentulo spiral can ensure complete coating of the dowel space walls without inclusion of air bubbles, and results in an even layer of luting cement around the dowel, which will result in increase of the retention in the cement-tooth interface and cement-dowel interface. Therefore, an increase in retention could be expected, and thus more tensile force will be needed for dislodgment of the dowel compared with the dowels cemented without using a lentulo spiral; however, there was a marginally significant ($p = 0.051$) interaction between the fabrication techniques, cement type, and cementation procedure with regard to retention (Table 2). The lowest value of retention recorded was for dowels cemented with zinc phosphate cement without the use of lentulo spiral and fabricated using the direct technique (Table 1). This group was significantly lower than the group cemented with zinc phosphate without lentulo spiral and fabricated by the indirect technique, and was also significantly lower than the group cemented with glass ionomer without lentulo spiral and fabricated by the direct technique. This result may suggest that the retention could be considerably reduced if dowels fabricated using the direct technique are cemented with zinc phosphate without the use of lentulo spiral. There is no clear explanation for this finding, which may necessitate further investigation; however, it could be stated that the fit of the dowel might be a detrimental factor in combination with a particular cement and cementation procedure. The retention could also be correlated with the viscoelastic properties and viscosity of the cement applied within an optimum space around the dowel. As the same findings were not demonstrated with glass ionomer, special care should be exercised when applying zinc phosphate into the canal space, particularly when fit is not optimized. That may also mean that voids could be incorporated easier in the interface of zinc phosphate and dowel than that with glass ionomer cement. This phenomenon should be further investigated.

Clinical recommendations should be made with caution, as the current study did not take into account other clinically important variables such as temperature changes experienced in the oral environment, which may affect the properties of luting cements.[30] Furthermore, forces encountered clinically are more complex than the simply applied vertical force. In the oral environment, forces applied on teeth and restorations include rotational, shearing, and cyclic forces. Therefore, further in vitro tests able to accurately simulate the clinical variables should be employed.

Conclusions

Under the conditions of this study, the following conclusions can be drawn:

(1) Technique of fabrication (direct or indirect) seems to have no effect on the retention of cast metal dowel and core.
(2) Zinc phosphate and hand-mixed conventional glass ionomer cements were not significantly different with regard to retention of cast metal dowel and core.
(3) The cementation procedure has a highly significant effect on the retention of cast metal dowel and core. Cementation using lentulo spiral to insert the cement in the dowel channel produced significantly greater values of retention than those cemented without the use of a lentulo spiral.
(4) There is seemingly a correlation between fabrication techniques, cement type, and cementation procedure in relation to their influence on the retention of cast metal dowel and cores.
(5) The least retentive dowels were those fabricated by direct technique and cemented with zinc phosphate without the use of lentulo spiral.

References

1. Tamse A: Iatrogenic vertical root fractures in endodontically treated teeth. Endod Dent Traumatol 1988;4:190-196
2. Sorensen JA, Martinoff JT: Clinically significant factors in dowel design. J Prosthet Dent 1984;52:28-35
3. Lewis R, Smith BG: A clinical survey of failed post retained crowns. Br Dent J 1988;165:95-101
4. Torbjorner A, Karlsson S, Odman PA: Survival rate and failure characteristics for two post design. J Prosthet Dent 1995;73:439-443

5. Hochman N, Feinzaig I, Zalkind M: Effect of design of pre-fabricated posts and post heads on the retention of various cements and core materials. J Oral Rehab 2003;30:702-707
6. Brown JD, Mitchem JC: Retentive properties of dowel post systems. Oper Dent 1987;12:15-19
7. Cohen BL, Musikant BL, Deutsch AS: Comparison of retentive properties of four post systems. J Prosthet Dent 1992;68:264-268
8. Stockton LW: Factors affecting retention of post systems: a literature review. J Prosthet Dent 1999;81:380-385
9. Karna JC: A fiber composite laminate endodontic post and core. Am J Dent 1996;9:230-232
10. Rosentiel SF, Land MF, Fujimoto J: Contemporary Fixed Prosthodontics (ed 2). St. Louis, MO, Mosby, 2001, pp. 272-276
11. Moragno SM, Milot P: Clinical success of cast metal posts and cores. J Prosthet Dent 1993;70:11-16
12. Dietschi D, Romelli M, Goretti A: Adaptation of adhesive post and cores to dentin after fatigue testing. Int J Prosthodont 1997;10:498-507
13. Grundy JR, Glyn Jones JC: Crowning pulpless teeth. Part 1. Br Dent J 1981;150:307-312
14. Koutayas SO, Kern M: All-ceramic posts and cores: the state of the art. Quintessence Int 1999;30:383-392
15. Tjan AH, Whang SB: Resistance to root fracture of dowel channels with various thicknesses of buccal dentin walls. J Prosthet Dent 1985;53:496-500
16. Saupe WA, Kuldau GA, Smith ML, et al: A comparative study of fracture resistance between morphologic dowel and cores and a resin-reinforced dowel systems in the intraradicular restoration of structurally compromised roots. Quintessence Int 1996;27:483-491
17. Mendoza DB, Eakle WS, Kahl EA, et al: Root reinforcement with a resin-bonded preformed post. Quintessence Int 1997;27:483-491
18. Mezzomo E, Mossa F, Libera SD: Fracture resistance of teeth restored with two different post-and-core designs cemented with two different cements: an in vitro study. Part I. Quintessence Int 2003;34:301-306
19. Hagge MS, Wong RD, Lindemuth JS: Effect of three root canal sealer on the retentive strength of endodontic posts luted with a resin cement. Int End J 2002;35:372-328
20. Button GL, Barnes RF, Moon PC: Surface preparation and the shear bond strength of the casting cement interface. J Prosthet Dent 1985;53:34-38
21. Turner CH: Post retained crown failure: a survey. Dent Update 1982;55:221-234
22. Nergiz J, Schmage, Platzer U, et al: Effect of different surface textures on retentive strength of tapered posts. J Prosthet Dent 1997;78:451-457
23. Radke RA, Bakhordar RA, Podesta RE: Retention of cast endodontic posts: comparison of cementing agents. J Prosthet Dent 1988;59:318-320
24. Mitchell CA: Selection of materials for post cementation. Dent Update 2000;27:350-354
25. Reel DC, Hinton T, Riggs G, et al: The effect of cementation method on the retention of anatomic cast post and cores. J Prosthet Dent 1989;62:162-165
26. Fakiha Z, Al-Aujan A, Al-Shamrani S: Retention of cast post cemented with zinc phosphate cement using different cementing techniques. J Prosthodont 2001;10:37-41
27. Goldestein GR, Hudis SL, Weintraub DE: Comparison of four techniques for the cementation of posts. J Prosthet Dent 1986;55:209-211
28. Assif D, Bitenski A, Pilo R, et al: Effect of post design on resistance to fracture of endodontically treated teeth with complete crowns. J Prosthet Dent 1993;69:36-40
29. Turner CH: Cement distribution during post cementation. J Dent 1981;9:231-239
30. Ertugul HZ, Ismail YH: An in vitro comparison of cast metal dowel retention using luting agents and tensile strength. J Prosthet Dent 2005;93:446-452