Retention and Failure Morphology of Prefabricated Posts

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Purpose: This study evaluated the effect of cement, post material, surface treatment, and shape *(1)* on the retention of posts luted in the root canals of extracted human teeth and *(2)* on the failure morphology. ***Materials and Methods:*** Posts of titanium alloy (ParaPost XH), glass fiber (ParaPost Fiber White), and zirconia (Cerapost) received one of several surface treatments—sandblasting, CoJet treatment, application of Metalprimer II, or sandblasting followed by silane application—and were then luted in the prepared root canal of human incisors and canines (n = 10). Following water storage at 37°C for 7 days, retention was determined by extraction of the posts. Failure morphology of extracted posts was analyzed and quantified stereomicroscopically. ***Results:*** Type of luting cement, post material, and shape of post influenced the retention and failure morphology of the posts. Because of limited adherence of the cement to the root canal, surface treatments did not always have a positive effect on retention. ***Conclusion:*** Choice of luting cement was critical for all three types of posts. Parallel posts showed superior retention to tapered posts. *Int J Prosthodont 2004;17:307–312.*

Failures of posts and cores include loss of retention, fracture of the root, and fracture of the post or core. Loss of retention of posts is the most frequent type of failure[1–3] and often results in the development of caries in the root canal. Retention of posts is influenced by numerous factors related to the post, cement, and interaction of cement-post and cement-dentin.[3–8]

The influence of the post on retention has been demonstrated in several studies, and parameters such as length, diameter, design, surface structure, material, and surface treatment have been found to affect retention. Studies have shown that increased length and diameter result not only in superior retention, but also in increased risk of root perforation or fracture.[8–13] The influence of post design and surface structure on retention has been demonstrated in several studies, and in vitro and in vivo studies report superior retention of parallel-sided posts compared to tapered posts.[3,4,14,15]

Prefabricated posts of different materials have been introduced to the market. Two groups of prefabricated posts exist: metallic posts, such as titanium alloy, and nonmetallic posts, such as glass fiber–reinforced resin composite or zirconia, which are intended to be adhesively bonded to the root canal.[16–20] Retention of titanium alloy and zirconia posts has been investigated in a number of studies.[5,19–23] However, data on some of the new types of posts, eg, glass fiber–reinforced resin composite posts, are scarce.

The effect of the cement on retention of posts is influenced by the strength of the cement and adherence of the cement to the post and dentin walls. Several studies show superior retention of posts luted with resin cement compared to zinc phosphate cement.[20,21,24–27] Unlike zinc phosphate and conventional resin cements, adhesive resin cement systems have the ability to adhere to dentin and the post with a reinforcing effect.[28]

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Table 1 Prefabricated Posts and Cements Investigated

Material	Composition (according to manufacturer)
Posts	
ParaPost XH, Coltène/Whaledent	90% titanium, 6% aluminum, 4% vanadium
ParaPost Fiber White, Coltène/Whaledent	42% glass fiber, 29% resin, 29% filler
Cerapost, Brasseler	94.9% ZrO_2, 5.1% Y_2O_3
Cements	
DeTrey Zinc, Dentsply/DeTrey	Zinc oxide, magnesium oxide, phosphoric acid
ParaPost Cement, Coltène/Whaledent	bis-GMA, bis-EMA, TEGDMA, BPO, silanized barium glass, amorphous silica
ParaPost Cement Primer, Coltène/Whaledent	HEMA, BPO, maleic acid, glycerol mono- and dimethacrylate, methacrylized polyalkenoate, ethanol, water
Panavia F, Kuraray	Silanized barium glass, silanized silica, sodium fluoride, BPO, photosensitizer, MDP, hydrophobic and hydrophilic dimethacrylate, bisphenol A polyethoxy dimethacrylate
ED Primer, Kuraray	MDP, HEMA, N-methacryl 5-aminosalicylic acid, sodium benzene sulfinate, N,N-diethanol-p-toluidine, water

bis-GMA = bisphenol-A-glycidyldimethacrylate; bis-EMA = bisphenol-A-diethoxymethacrylate; TEGDMA = triethylene glycol dimethacrylate; BPO = benzoyl peroxide; HEMA = hydroxyethyl methacrylate; MDP = 10-methacryloyloxydecyl dihydrogen phosphate.

In an attempt to maximize the adherence of resin cement to posts, different types of surface treatments have been investigated. Sandblasting with alumina particles is used for many types of restorations and results in increased roughness of the surface and increased surface area.[22,29] Coating with primers, such as silane and so-called metal primers, creates chemical adhesion between the resin cement and restoration.[30,31] A third type of surface treatment, CoJet (3M/ESPE), uses silicate-coated alumina particles for sandblasting, thereby welding a silicate layer onto the surface by means of the high spot heat produced by the blasting pressure followed by silanization. CoJet treatment has been found to enhance the bond strength of resin cement to the treated surface.[32,33] Most studies of the effect of surface treatment on adherence of resin cement to posts have used bond strength measurements, not posts luted in root canals.[22,29–33] Furthermore, the studies include only a few types of posts or surface treatments.

It was hypothesized that the retention of prefabricated posts luted in human teeth and the failure morphology would be influenced by the type of cement and by the material, shape, and surface treatment of the post. The aim of this in vitro study was to evaluate the effect of cement, post material, surface treatment, and shape on the retention of posts luted in the root canals of extracted human teeth and on the failure morphology.

Materials and Methods

Three types of prefabricated posts—titanium alloy (ParaPost XH), glass fiber–reinforced resin composite (ParaPost Fiber White), and zirconia (Cerapost)—and three types of cement—zinc phosphate cement (DeTrey Zinc), conventional bis-GMA–based resin cement (ParaPost Cement), and adhesive MDP-containing resin cement (Panavia F)—were used (Table 1).

Extracted human maxillary incisors and canines were kept in an antimicrobial preservative (0.5% chloramine T) after extraction. On each tooth, the crown was removed by horizontal sectioning to leave 13 mm of root. The roots were randomly distributed into 29 experimental groups, each consisting of 10 roots. The roots assigned to receive ParaPost XH or ParaPost Fiber White posts were prepared with the ParaPost drill system (Coltène/Whaledent) to a final diameter of 1.25 mm. Roots planned to receive parallel-sided Ceraposts (Ceraposts used "upside down") were prepared by the ParaPost drill system to a final diameter of 1.4 mm, and roots assigned to receive tapered Ceraposts (Ceraposts used as intended) were prepared with the matching tapered drill and roughened by the corresponding roughening instrument (Komet 050) according to the manufacturer's instructions. For all roots, the length of the prepared root canal was 5 mm. After preparation, the canal was rinsed with deionized water for 2 minutes.

ParaPost XH posts (size 5, 1.25-mm diameter), ParaPost Fiber White posts (size 5, 1.25-mm diameter), and Cerapost posts (No. 050, 1.4-mm diameter) were surface treated according to one of the treatments shown in Table 2. Sandblasting was performed with an extraoral sandblasting device (Basic Duo, Renfert) at 4 bars for 15 seconds using 50-µm alumina particles. The nozzle was held perpendicular to the post surface at a distance of 20 mm. The posts were ultrasonically cleaned in deionized water for 2 minutes after sandblasting. In some experimental groups, sandblasting was supplemented by silane coating according to the manufacturer's instructions. Metalprimer II was applied to the post surface according to the manufacturer's instructions. CoJet treatment consisted of air abrasion with an intraoral sandblasting device (Dento-Prep, Rønvig) at 4 bars for 15 seconds using 30-µm silicate-coated particles, followed by silane coating with ESPE-Sil (3M/ESPE) according to the manufacturer's instructions.

Table 2 Post Surface Treatments Investigated

Treatment	Composition	Post
None	–	ParaPost XH, ParaPost Fiber White, Cerapost
Sandblasting, BEGO	50-µm alumina particles	ParaPost XH, ParaPost Fiber White, Cerapost
CoJet, 3M/ESPE	30-µm silicate-coated particles, silane	ParaPost XH, ParaPost Fiber White, Cerapost
Metalprimer II, GC	Thiophosphoric methacrylate (MEPS)	ParaPost XH
Sandblasting and silane, BEGO and Pulpdent	50-µm alumina particles, silane	ParaPost Fiber White, Cerapost

Table 3 Effect of Surface Treatment on Investigated Parameters*

Post and surface treatment	ParaPost Cement		Panavia F	
	Retention (N)	PACC (%)	Retention (N)	PACC (%)
ParaPost XH				
Untreated	238 (46)[a,b]	10 (9)[a]	168 (45)[a]	15 (10)[a,b]
Sandblasting	213 (67)[a,b]	73 (27)[d]	239 (66)[a,b]	86 (12)[d,e]
CoJet	187 (78)[a,b]	93 (16)[e]	180 (56)[a]	86 (25)[d,e]
Metalprimer II	271 (90)[b]	24 (15)[b,c]	200 (70)[a,b]	38 (16)[c]
ParaPost Fiber White				
Untreated	245 (60)[c]	92 (12)[b]	137 (31)[a]	100 (0)[b]
Sandblasting	135 (32)[a]	100 (0)[b]	201 (30)[b]	63 (31)[a]
CoJet	146 (50)[a,b]	100 (0)[b]	180 (43)[a,b]	85 (26)[a,b]
Sandblasting, silane	177 (39)[a,b]	94 (10)[b]	164 (66)[a,b]	77 (29)[a,b]
Cerapost				
Untreated	74 (26)[a]	0 (0)[a]	164 (24)[c]	4 (5)[a]
Sandblasting	127 (36)[b]	6 (8)[a]	158 (29)[c]	33 (32)[b]
CoJet	184 (37)[c]	64 (37)[c]	169 (35)[c]	90 (13)[c]
Sandblasting, silane	118 (33)[b]	9 (7)[a]	183 (45)[c]	26 (19)[b]

*Mean (standard deviation) (n = 10). For each post separately and for retention and % of post area covered by resin cement after testing (PACC), respectively, mean values with the same superscript were not statistically significantly different ($P > .050$).

After a possible surface treatment of the post, the root canals were dried with paper points (No. 45, Top Dent); in the case of the two resin cements, the walls of the root canals were treated with the corresponding bonding system according to the manufacturer's directions. The cement was mixed according to the manufacturer's recommended procedure and applied in the root canal, and the post was cemented to a length of 3 mm. Because of splitting or fracture of the nonluted part of the ParaPost Fiber White posts and Ceraposts when high loads were applied, the luted post length had to be limited to 3 mm. Dual-curing Panavia F was light cured for 20 seconds with a conventional curing unit (XL 3000, 3M/ESPE). All specimens were allowed to set for 15 minutes and then stored in water at 37°C for 7 days. The specimens were placed in a jig that fixed the root and nonluted part of the post, respectively, in a universal testing machine (Instron). The posts were then extracted from the roots at a cross-head speed of 1 mm/min. The direction of tensile loading was parallel to the long axis of the luted post. Failure morphology of the extracted posts was studied at 18× magnification with a stereomicroscope (Leitz) fitted with a measuring ocular. The failure morphology was characterized visually by the amount of cement adhering to the post and quantified as the percentage of the post area covered by cement. All procedures were carried out by one operator.

Statistical Analysis

The retention results were analyzed by parametric statistical methods (one-way analysis of variance [ANOVA] and Newman-Keuls' multiple range tests, or Student's *t* test). Because of the lack of homogeneity of the standard deviations, nonparametric Mann-Whitney *U* tests were used to analyze the failure morphology results.

Results

Effect of Surface Treatment

With ParaPost XH, none of the surface treatments significantly increased the retention of the posts compared to untreated posts (Table 3). There were no significant differences in retention between the two resin cements. However, all surface treatments significantly increased the percentage of the post area covered by cement after testing (PACC) compared to untreated posts.

For ParaPost Fiber White, certain surface treatments influenced the retention of the posts compared to untreated posts. When ParaPost Cement was used, all surface treatments resulted in significantly lower retention compared to untreated posts. When Panavia F was used, one surface treatment (sandblasting) resulted in significantly

Table 4 Effect of Cement on Investigated Parameters*

Post (untreated)	ParaPost Cement		Panavia F		DeTrey Zinc	
	Retention (N)	PACC (%)	Retention (N)	PACC (%)	Retention (N)	PACC (%)
ParaPost XH	238 (46)^{d}	10 (9)^{b}	168 (45)^{b,c}	15 (10)^{b}	180 (41)^{b,c}	0 (0)^{a}
ParaPost Fiber White	245 (60)^{d}	92 (12)^{c}	137 (31)^{b}	100 (0)^{c}	198 (38)^{c}	0 (0)^{a}
Cerapost	74 (26)^{a}	0 (0)^{a}	164 (24)^{b,c}	4 (5)^{a,b}	93 (36)^{a}	1 (2)^{a}

*Mean (standard deviation) (n = 10). For retention and % of post area covered by resin cement after testing (PACC), respectively, mean values with the same superscript were not statistically significantly different ($P > .050$).

Table 5 Effect of Post Shape on Investigated Parameters*

Post (untreated)	ParaPost Cement		Panavia F	
	Retention (N)	PACC (%)	Retention (N)	PACC (%)
Cerapost, parallel	74 (26)^{c}	0 (0)^{a}	164 (24)^{d}	4 (5)^{a}
Cerapost, tapered	33 (15)^{a}	0 (0)^{a}	54 (13)^{b}	0 (0)^{a}

*Mean (standard deviation) (n = 10). For retention and % of post area covered by resin cement after testing (PACC), respectively, mean values with the same superscript were not statistically significantly different ($P > .050$).

higher retention compared to untreated posts, whereas the other two surface treatments had no significant effect. Significant differences in retention were found between the two resin cements in two cases. Only with Panavia F did surface treatment affect PACC.

With Cerapost luted with ParaPost Cement, all surface treatments improved retention of the posts compared to untreated posts. When Ceraposts were luted with Panavia F, none of the surface treatments significantly influenced the retention compared to untreated posts. Significant differences in retention were found between the two resin cements. Surface treatment significantly influenced PACC.

Effect of Cement and Post

Type of cement had a significant effect on retention for all three types of untreated posts (Table 4), but only a significant effect on PACC for ParaPost XH and ParaPost Fiber White. Type of post had a significant influence on both retention and PACC.

Effect of Post Shape

Significant differences in retention were found between the two different post shapes of Cerapost (Table 5). For both resin cements, luting of the parallel-sided part of Ceraposts gave significantly higher retention than did luting of the tapered part of the post. There was no significant difference between the PACCs of the two post shapes for either cement.

Discussion

The present study evaluated the effect of cement type, post material, surface treatment, and post shape on retention of posts luted in the root canals of extracted human maxillary incisors and canines. Retention is a complex expression of a multitude of factors such as the bond of the cement to the post and root canal, mechanical properties of the post and cement, and surface structure and shape of the post. It may be assumed that retention is largely determined by the adherence to post or to dentin, depending on which is weaker. Adherence between cement and post is reflected in the amount of cement left on the post after testing. Thus, in the cases in which PACC = 100%, the adherence between cement and dentin failed and retention was determined exclusively by the adherence to dentin. Adherence to dentin was about the same for ParaPost Cement (135 N and 146 N) and Panavia F (137 N) (Table 3). This finding is in contrast with earlier measurements, which found that Panavia F bonds better to dentin than does ParaPost Cement,[34] but it may be explained by the different configuration of the two test methods.

It was previously found that the surface treatments used in the present study significantly increase the shear bond strength of cement to posts,[34] and this was also the case when the bond was assessed by a diametral tensile strength test.[35] In the present study, the surface treatments had only a moderate effect on retention. The explanation for this finding may be that retention is limited by the adherence to dentin, and an increase in the adherence to the post beyond a certain level (approximately 140 N) does not increase retention appreciably. On the other hand, if adherence to the post is poor, retention will be low for this reason.

As discussed above, a high PACC value is an indicator of good adherence, although this is not necessarily reflected in the retention. In fact, significant correlations were found between PACC and earlier published values of shear bond strength for all posts ($P < .001$)[34] and between PACC and values of diametral tensile strength for ParaPost XH and Cerapost ($P < .001$).[35] It was not possible to include diametral tensile strength values for ParaPost Fiber White, as the diametral tensile strength test was invalid with this material.[35]

None of the surface treatments affected retention of ParaPost XH. This finding is seemingly in disagreement with previous studies of bonding,[34,35] but it may be explained by the above considerations concerning the limiting effect of the adherence to dentin.

Surface treatments affected the retention with ParaPost Fiber White. When ParaPost Cement was used, surface treatment of the posts decreased the retention. This finding is in disagreement with a previous study of the effect of surface treatments on bond strength.[34] One possible explanation may be the fact that sandblasting and CoJet treatment of ParaPost Fiber White resulted in marked volume loss, and consequently in poor fit of the post and increased thickness of the cement layer in the root canal. The increased thickness of resin cement may reduce retention. When Panavia F was used, sandblasting increased the retention of the post, whereas the other surface treatments had no effect. The increased thickness of the cement layer caused by sandblasting did not result in reduced retention in the case of Panavia F, possibly because of the higher bond of this cement to dentin.[34]

Regarding Cerapost, there were fundamental differences between surface treatments and the two resin cements. Whereas surface treatment improved the retention when ParaPost Cement was used, it did not affect the retention when Panavia F was used. The positive effect of surface treatment on retention with ParaPost Cement may be explained by the level of the retention values: In three cases, the retention was below 140 N and therefore mainly determined by adherence to the post. The fact that surface treatment of Cerapost did not affect retention with Panavia F may indicate that adherence to the post was so high that adherence to dentin was the main determining factor.

The type of cement significantly influenced the retention of the three posts. The retention of ParaPost XH and ParaPost Fiber White posts was highest when ParaPost Cement was used, whereas the retention of Cerapost posts was highest when Panavia F was used. This finding is in accordance with previous results[34,35] and may be explained by differences in the correspondence of surface energy characteristics of the posts and cements.[36]

In accordance with other studies, the retention of Ceraposts (parallel sided) was generally lower than that of ParaPost XH and ParaPost Fiber White posts.[7,37] The differences in retention between Cerapost and ParaPost XH or ParaPost Fiber White posts may be explained by the differences in macrostructure of the posts: Cerapost is a smooth post, whereas ParaPost XH and ParaPost Fiber White are designed with macroretention patterns.

Regarding the shape of the post, parallel-sided Ceraposts yielded significantly higher retention values than did tapered Ceraposts. This finding corroborates several in vivo and in vitro studies.[3,4,7,8,15]

Conclusions

The hypothesis of this study was confirmed: The retention and failure morphology of prefabricated posts were influenced by the type of cement and by the material, shape, and surface treatment of the post. Based on this study, the following conclusions can be drawn:

- Choice of luting cement was critical for all three types of posts.
- Parallel posts showed superior retention compared with tapered posts.
- The positive effect of several surface treatments on adherence between post and cement was not manifested in improved retention because of limited adherence of the cement to the root canal.

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References

1. Bergman B, Lundquist P, Sjögren U, Sundquist G. Restorative and endodontic results after treatment with cast posts and cores. J Prosthet Dent 1989;61:10–15.
2. Hatzikyriakos AH, Reisis GI, Tsingos N. A 3-year postoperative clinical evaluation of posts and cores beneath existing crowns. J Prosthet Dent 1992;67:454–458.
3. Torbjörner A, Karlsson S, Ödman PA. Survival rate and failure characteristics for two post designs. J Prosthet Dent 1995;73:439–444.
4. Standlee JP, Caputo AA, Hanson EC. Retention of endodontic dowels: Effects of cement, dowel length, diameter, and design. J Prosthet Dent 1978;39:400–405.
5. Chapman KW, Worley JL, von Fraunhofer JA. Retention of prefabricated posts by cements and resins. J Prosthet Dent 1985;54:649–652.
6. Isidor F, Brøndum K, Ravnholt G. The influence of post length and crown ferrule length on the resistance to cyclic loading of bovine teeth with prefabricated titanium posts. Int J Prosthodont 1999;12:78–82.
7. Cohen BI, Pagnillo MK, Newman I, Musikant BL, Deutsch AS. Retention of four endodontic posts cemented with composite resin. Gen Dent 2000;48:320–324.
8. Sorensen JA, Martinoff JT. Clinically significant factors in dowel design. J Prosthet Dent 1984;52:28–35.
9. Johnson JK, Schwartz NL, Blackwell RT. Evaluation and restoration of endodontically treated posterior teeth. J Am Dent Assoc 1976;93:597–605.
10. Trope M, Maltz DO, Tronstad L. Resistance to fracture of restored endodontically treated teeth. Endod Dent Traumatol 1985;1:108–111.
11. 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.

12. Manning KE, Yu DC, Yu HC, Kwan EW. Factors to consider for predictable post and core build-ups of endodontically treated teeth. Part II: Clinical application of basic concepts. J Can Dent Assoc 1995;61:696–707.
13. Sornkul E, Stannard JG. Strength of roots before and after endodontic treatment and restoration. J Endod 1992;18:440–443.
14. Colley IT, Hampson EL, Lehman ML. Retention of post crowns. An assessment of relative efficiency of posts of different shape and sizes. Br Dent J 1968;124:63–69.
15. Isidor F, Brøndum K. Intermittent loading of teeth with tapered, individually cast, or prefabricated, parallel-sided posts. Int J Prosthodont 1992;5:257–261.
16. Ferrari M, Vichi A, Garcia-Godoy F. Clinical evaluation of fiber-reinforced epoxy resin posts and cast post and cores. Am J Dent 2000;13:15B–18B.
17. Mannocci F, Ferrari M, Watson TF. Intermittent loading of teeth restored using quartz fiber, carbon-quartz fiber and zirconium dioxide ceramic root canal posts. J Adhes Dent 1999;1:153–158.
18. Ferrari M, Vichi A, Grandini S, Goracci C. Efficacy of a self-curing adhesive resin cement on luting glass-fiber posts into root canals: An SEM investigation. Int J Prosthodont 2001;14:543–549.
19. O'Keefe KL, Miller BH, Powers JM. In vitro tensile bond strength of adhesive cements to new post materials. Int J Prosthodont 2000;13:47–51.
20. Ferrari M, Mannocci F, Vichi A, Cagidiaco MC, Mjör IA. Bonding to root canal: Structural characteristics of the substrate. Am J Dent 2000;13:255–260.
21. O'Keefe KL, Powers JM, McGuckin RS, Pierpont HP. In vitro bond strength of silica-coated metal posts in roots of teeth. Int J Prosthodont 1992;5:373–376.
22. Miller BH, Nakajima H, Powers JM, Nunn ME. Bond strength between cements and metals used for endodontic posts. Dent Mater 1998;14:312–320.
23. Kern M, Wegner SM. Bonding to zirconia ceramic: Adhesion methods and their durability. Dent Mater 1998;14:64–71.
24. Chapman KW, Worley JL, von Fraunhofer JA. Effect of bonding agents on retention of posts. Gen Dent 1985;33:128–130.
25. Nissan J, Dmitry Y, Assif D. The use of reinforced composite resin cement as compensation for reduced post length. J Prosthet Dent 2001;86:304–308.
26. Utter JD, Wong BH, Miller BH. The effect of cementing procedures on retention of prefabricated metal posts. J Am Dent Assoc 1997;128:1123–1127.
27. Rosin M, Splieth C, Wilkens M, Meyer G. Effect of cement type on retention of a tapered post with a self-cutting double thread. J Dent 2000;28:577–582.
28. Mendoza DB, Eakle SW, Kahl EA, Ho R. Root reinforcement with a resin-bonded preformed post. J Prosthet Dent 1997;78:10–14.
29. Kern M, Thompson VP. Effects of sandblasting and silica-coating procedures on pure titanium. J Dent 1994;22:300–306.
30. Taira Y, Yanagida H, Matsumura H, Yoshida K, Atsuta M, Suzuki S. Adhesive bonding of titanium with a thione-phosphate dual functional primer and self-curing luting agents. Eur J Oral Sci 2000;108:456–460.
31. Taira Y, Yoshida K, Matsumura H, Atsuta M. Phosphate and thiophosphate primers for bonding prosthodontic luting materials to titanium. J Prosthet Dent 1998;79:384–388.
32. Cobb DS, Vargas MA, Fridrich TA, Bouschlicher MR. Metal surface treatment: Characterization and effect on composite-to-metal bond strength. Oper Dent 2000;25:427–433.
33. Frankenberger R, Krämer N, Sindel J. Repair strength of etched vs silica-coated metal-ceramic and all-ceramic restorations. Oper Dent 2000;25:209–215.
34. Sahafi A, Peutzfeldt A, Asmussen E, Gotfredsen K. Bond strength of resin cement to dentin and to surface-treated posts of titanium alloy, glass fiber, and zirconia. J Adhes Dent 2003;5:153–162.
35. Sahafi A, Peutzfeldt A, Asmussen E, Gotfredsen K. Effect of surface treatment of prefabricated posts on bonding of resin cement. Oper Dent 2004;29:60–68.
36. Asmussen E, Attal J-P, Degrange M. Factors affecting the energy of adherence of experimental cements bonded to a nickel-chromium alloy. J Dent Res 1995;74:715–720.
37. Standlee JP, Caputo AA. Effect of surface design on retention of dowels cemented with a resin. J Prosthet Dent 1993;70:403–405.