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Original

Fracture resistance of teeth with oval canal morphology restored using oval and circular posts

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Abstract: The study aimed to evaluate the effects of different post morphologies and placement lengths on the fracture resistance of teeth with oval canal morphology that had been restored with crowns. Extracted mandibular premolars with similar dimensions were decoronated. After the root canal treatment, the teeth were mounted on acrylic blocks. Samples were randomly divided into four groups (*n* = 10 each). In groups C-10 and C-5, 10-mm- and 5-mm-long circular post spaces were created. In groups O-10 and O-5, 10-mm- and 5-mm-long oval post spaces were ultrasonically created. After post cementation, all specimens were restored with composite cores and prepared at height of 6 mm. Thereafter, all teeth were restored with crowns. After thermocycling, all specimens underwent fracture resistance testing. Oval posts and placement at 10-mm depth showed higher fracture resistance than circular posts and placement at 5-mm depth (*P* < 0.001). Increased post length and use of oval posts enhanced the fracture strength of teeth with oval canal morphology. Based on the results of this study, although the fracture resistance of teeth restored with crowns was enhanced by deep fiber post placement, the use of oval fiber post is recommended in cases where deep placement is impossible.
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Introduction

Endodontically treated teeth with access cavity preparation and loss of tooth structure due to caries and endodontic treatment are more vulnerable to fractures than vital teeth (1,2). Although the most effective method to prevent vertical root fractures in pulpless teeth involves minimal tooth cutting in restorative and endodontic procedures (3), restoration of teeth frequently require considerable loss of coronal structure (4). Therefore, posts are often required during restoration to achieve resistance and retention of the core material (5-7). Fiber posts are usually preferred as their elastic modulus is compatible with dentin, and they adhere easily to it with the help of adhesive resins. These properties result in uniform stress distribution along the root structure (8,9).

Because the percentage of oval canals in the dentition is high (10), oval fiber posts have been recently introduced to provide better adaptation to the dentin walls and help avoid the use of circular fiber posts in oval canals (9). Using these posts results in reduced resin cement thickness (11,12), higher open dentin tubule scores (13), and improved post adhesion and retention strength (11,12).

Previous studies have reported that longer fiber posts allow better distribution of stress and prevent root fractures as they have larger bonded areas (14-18). Conversely, other studies have shown that post length has no effect on the strength of endodontically treated teeth (19,20). Therefore, there is a need to determine the proper length of the fiber post required in situations where adaptation to the root structure is improved by the use of oval posts.

The purpose of the present study was to establish effective restorative methods for the reinforcement of pulpless teeth with oval canals and extensive loss of tooth structure. The null hypothesis tested was that there were no differences in the fracture strengths of pulpless mandibular premolars restored with post-core systems of different lengths and shapes and full coverage crowns.

Materials and Methods

Similarly sized extracted human mandibular first premolars (21.7 ± 0.9) were collected and kept in normal saline solution. Teeth with single canals and fully developed apices were included in the present study, while those with root canal treatments, caries, or cracks/fractures were excluded. The teeth were defined as oval if the ratio of the long to short canal diameter was ≥2, measured at a point 5 mm from the apex, as described by Wu et al. (21). Before canal preparation, additional correction of the oval configurations of tooth canals was performed using cone-beam computerized tomography (5G FP; NewTom, Verona, Italy). A total of 40 teeth with ovoid canals were selected for the study. An ultrasonic scaler (Cavitron; Dentsply, York, PA, USA) and curettes were gently used to remove any adherent soft tissues and calculus. This *in vitro* study was approved by the Erciyes University, Faculty of Medicine Ethics Committee (Number: 2016/74).

Root canal treatment

The teeth were sawed perpendicular to the long axis at a point 14 mm from the apex using a slow speed diamond saw (Isomet; Buehler, Lake Bluff, IL, USA) to ensure uniform length. The working length was 1 mm short of the anatomic apex. The root canals were prepared using ProTaper rotary instruments (Dentsply Maillefer, Ballaigues, Switzerland), and the ProTaper F3 was used as the master apical file. Five milliliters of 2.5% NaOCl was used between instrumentation and irrigation, and the final rinse was performed by using 5 mL 17% ethylenediaminetetraacetic acid for 1 min followed by copious irrigation with distilled water. Paper points were used to dry the root canals. Thereafter, the canals were filled with gutta-percha (Diadent Group International, Chongchong Buk Do, Korea) and a resin sealer (AH Plus; Dentsply DeTrey, Konstanz, Germany) using the cold lateral condensation technique. Temporary filling material (Cavit; 3M ESPE, Seefeld, Germany) was used to fill the access cavities. Thereafter, the teeth were stored at 37°C and 100% humidity for 7 days to allow the sealers to set.

Teeth mounting on acrylic blocks

The teeth were individually mounted in self-cure acrylic resin (Elite SC Tray; Zhermack, Rovigo, Italy) to a depth of 2 mm apical to the cementoenamel junction (CEJ) using plastic cylinders with 2 cm diameter and 3 cm length. The samples were cooled in water to prevent the deformation of resin and dehydration of the dentin during acrylic resin polymerization.

Post hole preparation

The samples were randomly divided into four groups of 10 samples each, and the following procedures were performed. Group C-10: The gutta-percha was removed using a #3 Gates Glidden bur (Mani Inc., Utsunomiya, Japan) until a 10 mm post space was achieved. According to the manufacturer's directions for premolar post hole preparation at diameter 1.0 mm apical and 1.8 mm cervical, a preparation drill (#0.5, DT Light-Post; Bisco Inc., Schaumburg, IL, USA) and finishing drill (#2, DT Light-Post; Bisco Inc.) were used for root canal enlargement under continuous water cooling from a handpiece (25 mL/min). The root canal preparation was lubricated using 2.5% NaOCl solution. The drill speed was set at 8,000 rpm, and the depth of the post space preparation was 10 mm. Group C-5: The same procedures were performed as those for group C-10, but the post-space preparations were completed at 5 mm. Group O-10: The gutta-percha was removed using a #3 Gates Glidden bur (Mani Inc.) until a 10 mm post space was achieved. A diamond-coated ultrasonic oval tip with medium (76 μm) grit (Ellipson tip; RTD/Satelec, Merignac, France) was attached to an ultrasonic unit (Satelec P5 Newtron XS; Acteon Group, Mount Laurel, NJ, USA) and used at medium power. According to the manufacturer's directions, the drills and ultrasonic tips were gently used in a gliding movement at a working length of 10 mm with continuous water cooling (25 mL/min), and the post spaces were prepared such that the diameter was 0.6 mm apically and 1.8/1.1 mm cervically. Group O-5: The procedures used were similar to that of group O-10, but the post-space preparations were completed at 5 mm.

Post cementation

The self-adhesive technique for resin cement (RelyX Unicem; 3M ESPE, St. Paul, MN, USA) was used to cement the fiber posts, and a lentulo spiral filler (Dentsply Maillefer) was used to coat the canal walls with cement. Each post was inserted into the canal with a gentle pumping motion to avoid air traps, and excess cement

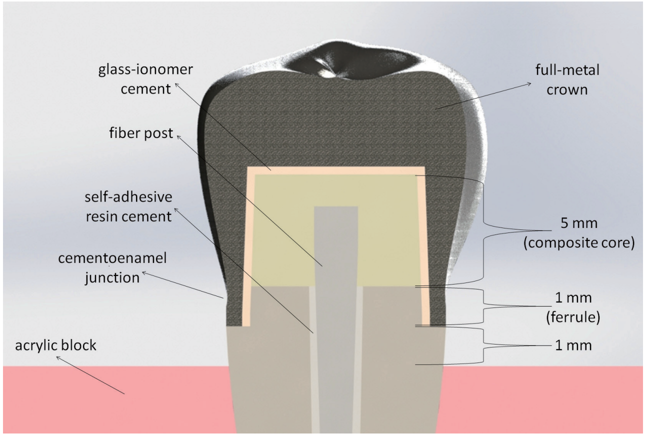

Fig. 1 Restoration details of tested specimens.

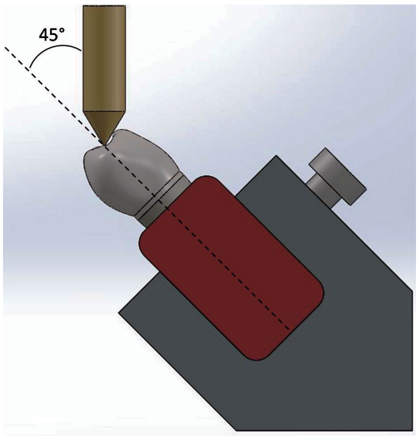

Fig. 2 Schematic view of fracture resistance test in universal testing machine.

squeezed out into the coronal area was cleared away with a brush. Slight finger pressure was applied continuously to secure the post position, and the entire complex was multidirectionally light cured for 2 min.

Core and crown construction

The bonding agent (Clearfil SE Bond; Kuraray Medical Inc., Tokyo, Japan) was applied to the post and residual coronal tooth structure and was light polymerized for 20 s. A composite resin (Filtek Ultimate; 3M ESPE) core was incrementally fabricated in 2 mm layers, and each layer was light polymerized for 40 s. After polymerization, a chamfer margin with a height of 6 mm (including 1 mm ferrule) and a convergence angle of approximately 5° was prepared in all samples, similar to a previous study (22). All teeth were restored with cast metal Ni-Cr (Rubyalloy; rubydent, Istanbul, Turkey) full crowns which were constructed to form a standard first mandibular premolar with 8.5 mm height, 7 mm mesio-distal width, and 7.5 mm bucco-lingual width. Mandibular first premolars have a sharp and long buccal cusp and a short underdeveloped lingual cusp. The crowns were cemented with glass ionomer cement (Ketac-Cem; 3M ESPE) (Fig. 1), and all specimens were stored in 100% humidity at 37°C for 24 h before thermocycling.

Thermocycling and fracture resistance test

Prior to the fracture test, thermocycling was performed 5,000 times (Termalsiklus; Dentall Teknik, Konya, Turkey) between 5°C and 55°C, with 30 s dwell time and 2 s transfer intervals. A universal testing machine (Instron, Canton, MA, USA) was used to apply a 45° oblique load to the center of the cusp of the restored teeth at a crosshead speed of 0.5 mm/min until fracture, and the corresponding load was recorded (Fig. 2). The spread of the fractures were observed using an operating microscope (DV 4; Zeiss, Jena, Germany) at 40× magnification with the aid of trans-illumination. The type of failure modes were recorded as favorable and unfavorable depending on the reparability of the fracture.

Statistical analysis

The Kolmogorov-Smirnov test showed that the fracture resistance data were normally distributed ($P = 0.200$ for all the factors), and the Levene's test indicated homogeneity of variance among the factors ($P = 0.55$). Two-way ANOVA was used to test the effects of post material and post length. No post-hoc tests were used for pairwise comparison as the number of groups was less than 3. A chi-square test was performed to examine the effects of the factors on the fracture types. All statistical analyses were performed using SPSS 20.0 (IBM Corporation Software Group, Armonk, NY, USA).

Results

The two-way ANOVA test showed that different types and lengths of posts significantly affected the fracture resistance of mandibular premolars restored with post cores and crowns ($P < 0.05$) (Table 1). Oval posts (250.81 N ± 98.8) and posts placed at 10 mm length (255.47 N ± 85.1) were more resistant than circular posts (182.03 N ± 50.5) and those placed at 5 mm (177.36 N ± 51.5) (Fig. 3).

The frequencies of fracture types and spread at a 45° oblique load have been illustrated in Fig. 4, and Table 2 shows whether they were favorable or not. Almost all specimens had oblique fractures with fiber posts. Post length and shape did not significantly affect the type of fracture in the specimens, as shown by the chi-square tests ($P > 0.05$).

Table 1 Results of two-way ANOVA

Factors	Sum of squares	*df*	Mean squares	F	*P*
Types of posts	47309.635	1	47309.64	13.151	0.001
Lengths of posts	61016.408	1	61016.41	16.961	<0.001
Types × Lengths of posts	11359.596	1	11359.60	3.158	0.084
Error	129507.504	36	3597.43		
Total	2122654.516	40			

df, degrees of freedom

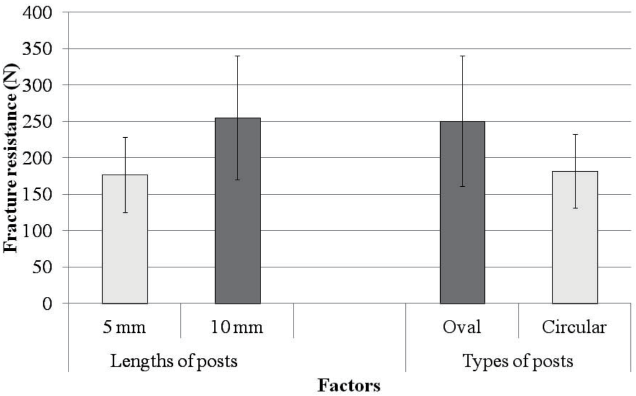

Fig. 3 Box-plot graphs of the tested factors.

Table 2 Statistical evaluation of fracture types in the tested specimens

Fracture types	Factors			
	Lengths of posts		Types of posts	
	5 mm	10 mm	Circular	Oval
Favorable	11	6	7	10
Unfavorable	9	14	13	10
Chi-square test	0.201		0.522	

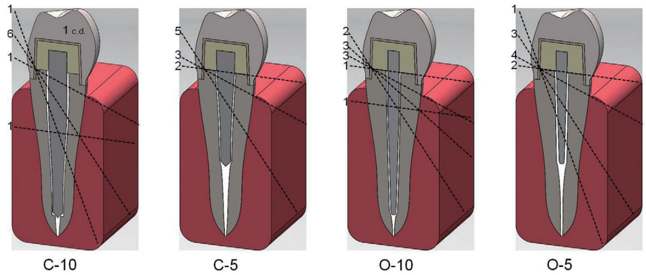

Fig. 4 Failure frequencies of groups (c.d.: crown decementation).

Discussion

This study was designed to investigate the effects of different post shapes and lengths on fracture type and resistance of mandibular premolars with oval canal morphology. Ellipson oval fiber posts (RTD/Satelec) and D.T. Light fiber posts (Bisco Inc.) were used as they have the same Poisson ratio and Young's modulus as quartz fibers (23). Thus, these posts differ only in geometric design. The null hypothesis of this study was rejected as the fracture resistance showed significant differences upon use of different lengths and shapes of post cores with full coverage crowns.

In the present study, circular posts (182.03 N ± 50.5) were less resistant to fracture than oval posts (250.81 N ± 98.8). This result is not consistent with that of a previous study, although similar fracture resistance values were recorded in the oval post group (24). The effects of post space preparations with circular and oval post drills and the placement of oval and circular posts on the fracture strength of roots with oval canals has been evaluated in another study (2), and they found that higher fracture resistance values were recorded in the circular fiber post group than those in the oval fiber post group (2). These differences could be a result of different angles used to apply force on different types of coronal restorations, as well as use of different post materials, dimensions, and lengths. Close adaptation of posts to the canal walls enhances the fracture resistance of restored teeth (25) due to the increased adhesive area and decreased resin cement thickness (26). Krast et al. (24) stated that the removal of inner dentin for post space preparation may weaken the root significantly. Therefore, oval fiber posts were introduced to minimize the need to adapt the post space in root canals with an oval cross section and to ensure greater amount of remaining root dentin than circular fiber posts. Using oval fiber posts in oval canals is therefore appropriate as poor adaptation of a post to the canal wall may result in shrinkage, and the greater resin cement thickness may be detrimental to the long-term clinical performance (17). Although increasing the diameter of a circular post may fix this problem, restorations with larger circular fiber posts have poor fracture resistance because of decreased remaining root dentin (27), leading to increased incidence of vertical root fractures (28). In a previous study, Coniglio et al. (11) investigated the cement thickness upon use of oval and circular posts in premolar root canals. They created three groups as follows: medium grit oval tip + oval posts, fine grit oval tip + oval posts, and Mtwo Post File drill + circular posts. The results of their study showed that the best post adaptation in oval-shaped canals could be achieved by canal preparation with fine grit oval tip and placement of an oval post (11). Moreover, in a previous finite element oval and circular post restoration comparison study (23), the circular fiber posts were found to generate more stress on residual root dentin than oval fiber posts.

In the present study, 10 mm long posts (255.47 N ± 85.1) were more resistant to fracture than 5 mm long posts (177.36 N ± 51.5). The use of longer posts for higher fracture resistance has been recommended as it offers greater rigidity and less root bending (6). Adanir and Belli (16) stated that the use of posts shorter than clinical crowns should be avoided to eliminate clinical failure. However, Cechin et al. (18) concluded that extensive preparation for longer post space was unnecessary as similar fracture resistance could be achieved with crowns restored using 8 and 12 mm long post cores. Moreover, anatomic variations such as mesio-distal widths, proximal concavities, root dilacerations, developmental invaginations, etc. may not permit deep placement of the post. However, oval post systems do not require much preparation as they mimic the natural shape of the canal. The present study showed that although longer oval posts without extensive preparation were beneficial, oval posts should be preferred even when shorter length was necessary.

According to a previous study, failure behavior was divided into restorable and un-restorable modes (29). The restorable failure mode was evaluated as a favorable fracture in the present study and included cervical root fractures and post failures. A fracture line below the cervical third of the root was considered as being unfavorable due to its un-restorable behavior. It has been reported that increasing the post length beyond two thirds of the root length may cause stress concentration in the apical area (30). However, in the present study, there were no differences in the type of fracture observed upon placement of fiber posts of different lengths. The samples had 5 mm post length were cracked deeply and obliquely by the force applied to the functional cusp because of post tip localization at the beginning of the two thirds of the root and force angulation. Therefore, 5 mm fiber posts showed higher unfavorable failure frequency than expected. In another study, evaluation of the stress distribution upon oblique force application in finite element analysis models of teeth with posts placed at 5 mm showed that the stress was mainly concentrated in the middle third of the root (31), and this was consistent with the results of the present study. Additionally, no significant differences in failure modes were observed between oval and circular fiber post usage. This may be due to stress concentration in similar root dentin areas even when different post shapes were used. It was previously reported that variations in the shape of the post did not affect stress distribution in the root dentin (32-34). Conversely, Er et al. (23) reported that stress distribution was lower with oval fiber posts than circular fiber posts. However, this study did not examine the effect of varying lengths of these posts. Thus, further studies that focus on stress distribution in the root dentin upon use of different lengths of oval and circular posts are required.

Since periodontal ligament simulation is limited by the viscoelastic nature of the *in-vivo* complex (35), it was not carried out in the present study. However, thermocycling was used to simulate moisture and temperature changes as they have been previously shown to have significant effects (36,37). In this situation, the periodontal simulation material may have caused uncontrolled tooth movement before the fracture test. Moreover, a previous study stated that periodontal ligament simulation did not show a statistically significant effect on the fracture load or type (4).

The generally accepted ferrule effect (7) of 1 mm was followed for each sample. However, in order to avoid bias, glass ionomer cement was used for luting of the metal crowns. The authors believe that the recorded fracture resistance values were lower than those in previous circular post-core supported crown restoration studies (16,17,24), as the luting agent used was not a resin-based adhesive.

In a recent study, Krastl et al. (24) evaluated the fracture resistance of oval and circular (with small and large diameter) post-restored teeth with composite crowns, and the highest values were recorded in the oval post group, although this difference was not statistically significant. Our results were in accordance with this, but the difference was statistically significant due to the homogenous distribution of the data in the groups. The authors believe that this difference in results may have been due to differences in coronal restoration and experimental design.

Further studies that include adhesive resin cementation with a thermomechanical cycle experimental design would be helpful to understand differences in the mechanical behavior of oval and circular posts. Additionally, since a static laboratory study does not always simulate the dynamic conditions in which the rate, magnitude, and direction of the forces change, long-term clinical evaluation of this correlation should be carried out.

Within the limitations of the present study, increased post length and use of oval posts were found to affect the fracture strength of teeth with oval canal morphology positively. Another advantage of oval posts is that, when used in teeth with oval canal morphology, minimum canal preparation is required to achieve placement of a longer post.

Conflict of interest

This study was executed without the influence of any third party or manufacturer.

References

1. Schwartz RS, Robbins JW (2004) Post placement and restoration of endodontically treated teeth: a literature review. J Endod 30, 289−301.
2. Uzun İ, Arslan H, Doğanay E, Güler B, Keskin C, Çapar ID (2015) Fracture resistance of endodontically treated roots with oval canals restored with oval and circular posts. J Endod 41, 539−543.
3. Reeh ES, Messer HH, Douglas WH (1989) Reduction in tooth stiffness as a result of endodontic and restorative procedures. J Endod 15, 512−516.
4. Pérez-González A, González-Lluch C, Sancho-Bru JL, Rodríguez-Cervantes PJ, Barjau-Escribano A, Forner-Navarro L (2012) Experimental strength of restorations with fibre posts at different stages, with and without using a simulated ligament. J Oral Rehabil 39, 188−197.
5. Robbins JW (1990) Guidelines for the restoration of endodontically treated teeth. J Am Dent Assoc 120, 558, 560, 562, 564, 566 passim.
6. Fernandes AS, Dessai GS (2001) Factors affecting the fracture resistance of post-core reconstructed teeth: a review. Int J Prosthodont 14, 355−363.
7. Al-Omiri MK, Mahmoud AA, Rayyan MR, Abu-Hammad O (2010) Fracture resistance of teeth restored with post-retained restorations: an overview. J Endod 36, 1439−1449.
8. Kremeier K, Fasen L, Klaiber B, Hofmann N (2008) Influence of endodontic post type (glass fiber, quartz fiber or gold) and luting material on push-out bond strength to dentin in vitro. Dent Mater 24, 660−666.
9. Kilic K, Er O, Kilinc HI, Aslan T, Bendes E, Sekerci AE et al. (2013) Infrared thermographic comparison of temperature increases on the root surface during dowel space preparations using circular versus oval fiber dowel systems. J Prosthodont 22, 203−207.
10. Muñoz C, Llena C, Forner L (2011) Oval fiber posts do not improve adaptation to oval-shaped canal walls. J Endod 37, 1386−1389.
11. Coniglio I, Garcia-Godoy F, Magni E, Carvalho CA, Ferrari M (2009) Resin cement thickness in oval-shaped canals: oval vs. circular fiber posts in combination with different tips/drills for post space preparation. Am J Dent 22, 290−294.
12. Coniglio I, Magni E, Cantoro A, Goracci C, Ferrari M (2011) Push-out bond strength of circular and oval-shaped fiber posts. Clin Oral Investig 15, 667−672.
13. Coniglio I, Carvalho CA, Magni E, Cantoro A, Ferrari M (2008) Post space debridement in oval-shaped canals: the use of a new ultrasonic tip with oval section. J Endod 34, 752−755.
14. Asmussen E, Peutzfeldt A, Sahafi A (2005) Finite element analysis of stresses in endodontically treated, dowel-restored teeth. J Prosthet Dent 94, 321−329.
15. Boschian Pest L, Guidotti S, Pietrabissa R, Gagliani M (2006) Stress distribution in a post-restored tooth using the three-dimensional finite element method. J Oral Rehabil 33, 690−697.
16. Adanir N, Belli S (2008) Evaluation of different post lengths' effect on fracture resistance of a glass fiber post system. Eur J Dent 2, 23−28.
17. Büttel L, Krastl G, Lorch H, Naumann M, Zitzmann NU, Weiger R (2009) Influence of post fit and post length on fracture resistance. Int Endod J 42, 47−53.
18. Cecchin D, Farina AP, Guerreiro CA, Carlini-Júnior B (2010) Fracture resistance of roots prosthetically restored with intra-radicular posts of different lengths. J Oral Rehabil 37, 116−122.
19. Scotti R, Valandro LF, Galhano GA, Baldissara P, Bottino MA (2006) Effect of post length on the fatigue resistance of bovine teeth restored with bonded fiber posts: a pilot study. Int J Prosthodont 19, 504−506.
20. 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.
21. Wu MK, R'oris A, Barkis D, Wesselink PR (2000) Prevalence and extent of long oval canals in the apical third. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 89, 739−743.
22. Hou QQ, Gao YM, Sun L (2013) Influence of fiber posts on the fracture resistance of endodontically treated premolars with different dental defects. Int J Oral Sci 5, 167−171.
23. Er O, Kilic K, Esim E, Aslan T, Kilinc HI, Yildirim S (2013) Stress distribution of oval and circular fiber posts in amandibular premolar: a three-dimensional finite element analysis. J Adv Prosthodont 5, 434−439.
24. Krastl G, Lorch H, Zitzmann NU, Addison O, Dietrich T, Weiger R (2014) Do oval posts improve fracture resistance of teeth with oval root canals? Dent Traumatol 30, 232−235.
25. Sorensen JA, Engelman MJ (1990) Effect of post adaptation on fracture resistance of endodontically treated teeth. J Prosthet Dent 64, 419−424.
26. Egilmez F, Ergun G, Cekic-Nagas I, Vallittu PK, Lassila LVJ (2013) Influence of cement thickness on the bond strength of tooth-colored posts to root dentin after thermal cycling. Acta Odontol Scand 71, 175−182.
27. Tjan AHL, Whang SB (1985) Resistance to root fracture of dowel channels with various thicknesses of buccal dentin walls. J Prosthet Dent 53, 496−500.
28. Mireku AS, Romberg E, Fouad AF, Arola D (2010) Vertical fracture of root filled teeth restored with posts: the effects of patient age and dentine thickness. Int Endod J 43, 218−225.
29. Kumagae N, Komada W, Fukui Y, Okada D, Takahashi H, Yoshida K et al. (2012) Influence of the flexural modulus of prefabricated and experimental posts on the fracture strength and failure mode of composite resin cores. Dent Mater J 31, 113−119.
30. Hunter AJ, Feiglin B, Williams JF (1989) Effects of post placement on endodontically treated teeth. J Prosthet Dent 62, 166−172.

31. Chuang SF, Yaman P, Herrero A, Dennison JB, Chang CH (2010) Influence of post material and length on endodontically treated incisors: an in vitro and finite element study. J Prosthet Dent 104, 379–388.
32. Pegoretti A, Fambri L, Zappini G, Bianchetti M (2002) Finite element analysis of a glass fibre reinforced composite endodontic post. Biomaterials 23, 2667–2682.
33. de Castro Albuquerque R, Polleto LT, Fontana RH, Cimini CA (2003) Stress analysis of an upper central incisor restored with different posts. J Oral Rehabil 30, 936–943.
34. Al-Omiri MK, Rayyan MR, Abu-Hammad O (2011) Stress analysis of endodontically treated teeth restored with post-retained crowns: a finite element analysis study. J Am Dent Assoc 142, 289–300.
35. 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.
36. Albashaireh ZS, Ghazal M, Kern M (2010) Effects of endodontic post surface treatment, dentin conditioning, and artificial aging on the retention of glass fiber-reinforced composite resin posts. J Prosthet Dent 103, 31–39.
37. Mazzitelli C, Monticelli F, Toledano M, Ferrari M, Osorio R (2012) Effect of thermal cycling on the bond strength of self-adhesive cements to fiber posts. Clin Oral Investig 16, 909–915.