Effect of bone defect width and a ferrule on the fracture characteristics of vertically fractured teeth reattached with adhesive resin cement: An in vitro study

Kei KYOGOKU1, Tomoko SOMEYA1, Masaaki KASAHARA1, Koji HASEGAWA1, Shinji TAKEMOTO2 and Masayuki HATTORI1

1 Department of Dental Material Science, Tokyo Dental College, 2-9-18 Kandamisaki-cho, Chiyoda-ku, Tokyo 101-0061, Japan
2 Department of Biomedical Engineering, Iwate Medical University, 1-1-1 Idai-dori, Yahaba-cho, Shiwa-gun, Iwate 028-3694, Japan

Corresponding author, Kei KYOGOKU; E-mail: keikyogoku@gmail.com

This study aimed to clarify the effects of vertical bone defect width and a ferrule on fracture of the fragments of fractured tooth reattached with adhesive resin cement (reattached tooth). The reattached tooth was built up by a fiber post and composite resin core for abutment and formed to the abutment with or without a ferrule. The vertical bone defect was fabricated with a V-shaped defect in different widths. The fracture load was evaluated using a universal testing machine. The vertical bone defect did not affect the fracture load, but a ferrule increased the root fracture load. For the specimens without a ferrule, debonding between the composite resin core and the root at the coronal loading side and fractures at the apical side of the root were found. In conclusion, the ferrule at abutment could affect fracture load and modes, and the bone defect width did not.

Keywords: Vertical root fracture, Bone defect width, Ferrule effect, Adhesive resin cement, Intentional replantation

INTRODUCTION

The number of remaining teeth in elderly persons is closely linked to problems with mastication and occlusion and maintaining the number of remaining teeth contributes to increased healthy life expectancy1). Of the reasons for tooth loss, root fracture is the third most common after periodontal disease and caries2). A vertical root fracture (VRF) in particular occurs most often in the maxillary premolar and molar region, and they are extracted in most cases3-6). On the other hand, often in the maxillary premolar and molar region, and vertical root fracture (VRF) in particular occurs most common after periodontal disease and caries2). A vertical root fracture (VRF) in particular occurs most often in the maxillary premolar and molar region, and they are extracted in most cases3-6). On the other hand, the conservation method of reattachment of vertically fractured fragments with adhesive resin cement (reattached tooth) could be selected when the patient wishes to conserve the fractured tooth7-10). However, many points remain unclear in this method of conservation of VRF teeth, including the durability of roots reattached with resin adhesive cements and the post-treatment effects on the surrounding tissue.

Two methods of reattachment of root fracture fragments are the intraoral method and the extraoral method. The extraoral method is intracanal bonding with adhesive resin cement including an adhesive monomer/catalyst, 4-methacryloxyethyl trimellitate anhydride/methyl methacrylate-tri-n-butyl borane (4-META/MMA-TBB), in which the root fragments are reattached using the adhesive resin cement on the fracture surface, without extraction of the tooth. The extraoral method is intentional replantation extraoral bonding with 4-META/MMA-TBB resin, in which the fractured tooth is extracted, the fracture surfaces are reattached with adhesive resin cement, and the tooth is replanted to the extraction socket4,9). Regarding the prognosis for the reattached tooth with intentional replantation extraoral bonding, there are reports that improvement in periodontal pocket depth and vertical bone resorption was confirmed three years after replantation7), and that the success rate at five years after reattachment was 59%5,9). Static fracture loads of reattached teeth with composite resin core are the same as those of teeth with no VRFs11,12). Reattachment of root fracture fragments using adhesive resin cement is therefore a possible option that can conserve the teeth. When a VRF occurs, during the acute phase, there is absorption of the thin alveolar bone on the buccal side, vertically along the line of the fracture. Over time, bone resorption also occurs laterally, producing a V-shape with the root apex as the vertex13). A vertical bone defect in the region surrounding a VRF tooth has been found in over 90% of cases14,15). The formation of the bone defect induces a concentration of stress on the root, which may increase the risk of repeating root fracture16). However, the effects of a V-shaped bone defect on fracture strength or fracture characteristics of the reattached teeth have yet to be clarified.

Endodontically treated teeth are restored with a metal post or a fiber-reinforced composite (FRC) post and composite resin core before placement of the final prosthetic restorations. In the case of restoration with a metal post, the elastic modulus of the metal post is higher than that of dentin, which makes the teeth prone to root fracture17,18). However, the elastic modulus of an FRC post is similar to that of dentin, so that root fracture is less likely17,19,20). Moreover, it has been reported that fracture lines run continuously from the dentin to the interior of the composite resin of the post.
and core restoration as a result of lateral stress to teeth with composite resin core and FRC posts\(^2\).

A ferrule on the tooth is known to be an important key to ensure the retention of restorations on an endodontically treated tooth\(^2\). In fact, a ferrule with a height of 2 mm or more on a tooth has been reported to increase root fracture resistance\(^2\). Saupe et al. compared static fracture loads in endodontically treated teeth with and without a ferrule, and they found no significant difference in the loads, and over 80% of fractures were root fractures\(^2\). This suggested that the ferrule could retain crown restoration, but not alter the fracture strength of an endodontically treated tooth with a post and core. However, there appear to have been no studies of the effects of ferrules on fractures of reattached teeth.

In the present study, reattached teeth with a vertical bone defect model and a ferrule were replicated to mimic the clinical situation by intentional replantation extraoral bonding. Then, the effects of vertical bone defect width and a ferrule on fracture of reattached teeth were investigated. Reattached teeth bonded by an adhesive resin cement were built up with the composite resin core for abutment and an FRC post, and the abutment was formed with and without a ferrule. The fracture load of reattached teeth was evaluated in a vertical bone defect model with a V-shaped defect along a reattachment site. The null hypothesis of this study was that the defect width of the vertical bone defect model and the presence or absence of a ferrule do not affect fracture of the reattached teeth.

**MATERIALS AND METHODS**

**Preparation of reattached teeth**

Bovine anterior teeth were used in this study. The periodontal ligaments were removed from the tooth roots, and the teeth were sectioned 5 mm to the coronal side of the cement-enamel junction (CEJ). A total of 48 roots with a root canal cavity of less than 3 mm in diameter were extracted. The pulp was extracted with a hand file (H-Files, MANI, Tochigi, Japan), and the tooth was formed into a cylinder shape with an external diameter of 7 mm by a precision machining lathe (TL-550S, TATEYA, Yamagata, Japan). Next, a notch, 2 mm in depth, was cut into both the coronal and apical sides of the tooth root using a diamond disc (NTI Superflex Diamond Disc 0.12/22, Kerr, Brea, CA, USA), and the root was divided along the tooth axis using plaster forceps to reproduce a VRF. The fractured root fragments were bonded using 4-META/MMA-TBB resin cement (Super-Bond C&B, Sun Medical, Shiga, Japan) to produce the reattached teeth with fracture lines on both buccal and palatal sides of the roots. The bonding surfaces were first treated with green activator (10% citric acid) for 10 s and rinsed with distilled water and dried. The resin cement was then mixed according to the manufacturer’s instructions and applied to the fractured surfaces with a clean brush and the fractured root fragments were reattached. The surplus parts of the reattached teeth including the notches were then adjusted using a diamond disc to a total length of 13 mm for non-ferrule specimens and 15 mm for ferrule specimens. The root apex was sealed with adhesive resin cement (Super-Bond C&B). Next, a 3-mm-diameter post hole (non-ferrule: depth 8 mm, ferrule: depth 10 mm) was drilled under water injection using a dental surveyor and a 3.0-mm-diameter drill (ironwork drill, NACHI, Tokyo, Japan). The post cavity formed was treated with 3% NaOCl (ChlorCid J, Ultradent Japan, Tokyo, Japan) and 18% EDTA (Ultradent EDTA 18% Solution, Ultradent Japan) for 30 s each, and then rinsed with distilled water and dried. The post-and-core was built up in the post cavity with a 1.6-mm-diameter FRC post (Fiber Post for i-TFC Luminous, Sun Medical) and composite resin core for abutment (Post Resin for i-TFC Luminous, Sun Medical). The shape of the core restoration was made using core formers (Polyester Cones #80 (taper 6°), AnGer G&A, Balice, Poland). In half of the specimens, the ferrule was formed by a chamfer (taper 6°) along the margin using a diamond point (101LRD, Shofu, Kyoto, Japan). A diagram of the reattached teeth fabricated for this study is shown in Fig. 1.

**Preparation of vertical bone defect model**

An acrylic ring (outer diameter 19 mm, height 20 mm) (EX embedding ring, Refine Tec, Kanagawa, Japan) was filled to the top with auto-cured acrylic resin (Tray Resin II, Shofu), and the reattached tooth root was fixed in the center of the ring using a surveyor. The reattached tooth was set such that the crown margin was positioned 3 mm above the upper edge of the acrylic ring. Before the resin cured, a silicone rubber mold in the shape of the vertical bone defect was pressed into the auto-cured acrylic resin to reproduce a vertical bone defect (Fig. 2). The presence or absence of a ferrule and the form of the bone defect of the various specimens are shown in Table 1. The defects were in a V-shape with a depth of 5 mm and a width of either 3 mm or 5 mm, and the defect region was set over the fracture line (Fig. 3). The specimens with no defect (width 0 mm) were prepared as controls (Fig. 3). Eight specimens were prepared for each combination of defect and ferrule.

**Measurement of fracture load**

Crowns restorations simulating maxillary premolars with a semicircular stopper on the inner slope of the buccal occlusion were cast in copper-zinc alloy (K metal, Ishifuku, Tokyo, Japan). The crowns were luted to the specimens using temporary cement (HY-Bond Temporary Cement [Hard], Shofu) such that the bone defect region on the specimen was to the buccal side. The specimen was then tilted buccally at 30° to the tooth axis and mounted on a universal testing machine (Autograph AG-I 20kN, Shimadzu, Kyoto, Japan). Fracture loads of specimens were measured with a 3-mm diameter steel ball adjusted to apply a load to the semi-circular stopper on the crown at a crosshead speed of 1 mm/min (Fig. 4). The test was set to stop when an instantaneous drop in load value of more than 25% was seen. The maximum
fracture load thus obtained was taken to be the fracture load of the reattached tooth.

Fig. 1 Diagram of reattached teeth restored with a fiber-reinforced composite (FRC) post and composite resin core with presence or absence of ferrule.

Fig. 2 Diagram of reattached tooth embedded with vertical bone defect model. Reattached tooth was fixed in the center of autacured acrylic resin. Defect region was in a V shape with a depth of 5 mm and set over the fracture line at the buccal side.

Table 1 Preparation of specimens

| Code | Ferrule | Defect form               |
|------|---------|---------------------------|
| V0   | Without | Defect absent             |
| Fv0  | With    | Defect absent             |
| V3   | Without | Width 3 mm, Depth 5 mm   |
| Fv3  | With    | Width 3 mm, Depth 5 mm   |
| V5   | Without | Width 5 mm, Depth 5 mm   |
| Fv5  | With    | Width 5 mm, Depth 5 mm   |

Without: specimen without ferrule, With: specimen with ferrule, Defect absent: specimen without defect
Classification of fracture mode
The reattached tooth after the fracture test was carefully removed from the mold. Each of the removed specimens was immersed in 0.2% fuchsin solution (Fuchsin Basic, FUJIFILM Wako Pure Chemical, Osaka, Japan) for 1 min to identify the fracture site and then rinsed and dried. The fracture lines were observed under a stereomicroscope (Stemi508 (ERc5S), Zeiss, Oberkochen, Germany), and the fracture mode was classified. The fracture was classified as “over” if the fracture line remained above the upper margin of the mold made of auto-cured acrylic resin (i.e. above the bone margin) and as “under” if the fracture line extended into the mold (i.e. under the bone margin). All specimens with both over and under types were taken to be under.

Observation of fracture region
Following classification of the fracture mode, some specimens were cut horizontally at 8 mm below the crown margin using a low-speed precision cutting machine (ISOMET1000, Buehler, Lake Bluff, IL, USA). The fracture site on the cut surface was then observed using a field-emission scanning electron microscope (FE-SEM; SU-6600, Hitachi, Tokyo, Japan) following Au-Pd coating to investigate the fracture line below the level of the envisaged bone margin, and the stress concentrated at the apical side of the root.

Statistical analysis
The fracture loads obtained from the fracture tests were analyzed by two-way analysis of variance (ANOVA) with defect width and presence or absence of a ferrule, followed by Tukey’s multiple comparison test. The significance level was set at 5%.

RESULTS
Figure 5 shows the fracture load of the reattached teeth with or without ferrule at different bone defect widths. The fracture loads ranged from 318 N to 1,572 N. The results of the two-way ANOVA are shown in Table 2. There was no significant difference in fracture load among defect widths, but a significant difference was found with the presence or absence of a ferrule (%p<0.01).

The classification of fracture modes following the fracture test is shown in Fig. 6. Both over and under modes of fracture were found in all specimens except Fv5, and all fractures in Fv5 were under mode. Observation by a stereomicroscope showed debonding of the root and the core restoration in all specimens without a ferrule (Fig. 7a). In the specimens with a ferrule, however, some with no debonding of the tooth root and the core restoration were observed (Fig. 7b). Figure 8 shows representative stereomicroscopic and SEM images of the horizontal cross-section at 8 mm below the crown margin of specimens (V3, Fv3, and Fv5) that were subjected to the fracture test. In the specimens without a ferrule (Figs. 8a–c), the fracture at the reattachment site (A), fracture within the dentin (B), and fracture between the dentin and the composite resin core for abutment (C)
Fig. 6 Classification of fracture types. V0 (specimen without defect and ferrule), Fv0 (without defect, with ferrule), V3 (with 3 mm width of defect, without ferrule), Fv3 (with 3 mm width of defect, with ferrule), V5 (with 5 mm width of defect, without ferrule), Fv5 (with 5 mm width of defect, with ferrule). Both over and under types of fracture were found in all specimens except Fv5. All fractures in Fv5 were under.

Fig. 7 Stereomicroscope images of specimens after fracture test. (a) Specimen with debonding of root and core restoration (without ferrule), (b) Specimen with no debonding of root and core restoration (with ferrule)

were seen. In the specimens without a ferrule, multiple fractures were seen within the dentin not just on the buccal side, but also on the palatal side (Fig. 8b). In the specimens with a ferrule (Figs. 8d–g), fractures within the dentin running parallel to the reattachment site (D) were observed on the buccal side. In addition, fractures running continuously from the dentin to the interior of the composite resin core for abutment (E) were confirmed in Fv5.

DISCUSSION

Study design
The present study was carried out to clarify the effects of a vertical bone defect and of a ferrule of abutment on fractures of reattached teeth, and to investigate from mechanical and morphological perspectives whether teeth can be conserved in the event of a VRF if there is a defect in the alveolar bone surrounding the root. When a VRF happens, the tooth is extracted in most cases. However, there are recent studies into methods of reattaching a fractured tooth without extraction, and basic research has been done on the measurement of the fracture loads of reattached teeth and the bonding strength of fractured segments. The fracture load of reattached teeth bonded with adhesive resin cement has been reported to be more than 700 N, which is of a similar order to the value for natural teeth with no VRF. Therefore, the reattached tooth with a VRF could be replanted to the extraction socket from the viewpoint of mechanical strength. However, when the VRF occurs on the root, a narrow vertical fissure progresses in the thin alveolar bone on the buccal side alongside the fracture line with time, and the coronal end of this defect widens to form a V shape. A vertical bone defect of 5 mm or more is found in a very high proportion (91%) of cases of VRF. In this study, therefore, a bone defect was prepared with V-shaped defects having a depth of 5 mm and width of either 3 mm or 5 mm at the coronal end. Since in vitro static load tests have shown that the periodontal ligament has no effect on fracture load,
fracture of the reattached teeth was investigated in the present study without reproducing the periodontal ligament.

**Effect of a bone defect width on fracture of reattached tooth**

In the vertical bone defect with different widths, the defect width had no significant effect on fracture load in reattached teeth. In addition, observation of the fracture mode showed that the “under” type was more common in all specimens. When an occlusal force is applied to the tooth, the stress is concentrated in the bone margin of the non-loading side. Roscoe et al. reported greater buccal deflection of the root with increased distance from the top of the bone to the point of loading. If bone is resorbed in a vertical direction, the center of rotation of the tooth root shifts toward the root apex, and the tooth thus becomes more susceptible to force applied horizontally. Since the bone resorption induced rotation with the defect region as the fulcrum by the principle of leverage, the stress concentration at the apical side of the root became more susceptible to breaking.

In the present study, simulation experiments were conducted with maxillary premolars based on a report that VRFs occur most commonly in the maxillary second premolar. The stress was applied in the buccal direction from the palatal side at an angle of 30° to the tooth axis, so that the bone margin at the non-loading (buccal) side of the root became the fulcrum and resulted in stress concentration. The fulcrum shifted toward the root apex with increased width at the coronal end of the bone defect, thus producing a large strain on the core and the crown side of the root, so that stress concentration also occurred at the apex side of the root (Fig. 9). In this study, the displacement of the root during loading tended to be greater in specimens with a bone defect than in those with no defect. The fracture in Fv5 with the greatest defect width showed that the fracture lines extended deeper than the envisaged bone margin in all specimens. Furthermore, new fractures at the apical side of the root were found in different areas from the root fragments reattached line under SEM (Fig. 8b), although they could not be observed at buccal side above embedded under stereomicroscope. Kono et al. reported that the root with FRC posts and composite resin core did not strengthen the tooth with respect to horizontal stress. This may be because the fracture load of the root with a composite resin core reflects the strength of the root itself, since the root was not strengthened with respect to horizontal stress. Therefore, no significant difference in fracture load could be seen among the bone defect shapes although the displacement of the root during loading was different. The first null hypothesis that differences in defect width do not affect fracture of reattached teeth was therefore rejected.

**Effect of a ferrule of abutment on fracture of reattached tooth**

With a 3-mm-wide defect, specimens with a ferrule showed greater fracture load than those without a ferrule. The ferrule effect is known to increase retention of restorations and increase root fracture resistance. Samran et al. reported that the fracture resistance of teeth with a ferrule was 37% higher than of teeth with no ferrule. Silva et al. reported that a 2-mm ferrule increased the fracture resistance of endodontically treated teeth, regardless of the type of material of the crown or the post. Ichim et al. reported that a ferrule on endodontically treated incisors reduced the distortion of the root, and the stress concentration on the root itself decreased. Although the above are reports on resin abutment of teeth with no VRFs, the results of the present study agree that the reattached teeth with a ferrule also have increased fracture load.

In the present study, the ferrule on the reattached tooth with composite resin core increased the fracture load; however, fractures were found not just in the root dentin, but also in the composite resin core continuously from the root canal dentin to the composite resin core (Fig. 8g). The composite resin core integrated with the root canal dentin has been reported to develop fractures from the dentin to the composite resin core and then to the FRC post in that order resulting from lateral stress. In the present study as well, the ferrule on a tooth with a composite resin core in a large bone defect induced stress concentration at the apical side of the root first, and then the fracture at the composite resin core integrated with the dentin (between the FRC post and the composite resin core for abutment).

In all specimens without a ferrule, debonding between the root and composite resin core was observed during loading to the crown (Fig. 7a). One cause of debonding of the composite resin core from the root is low bonding strength between the dentin and the composite
resin core\textsuperscript{35-38}. The tooth without a ferrule is often found to have debonding at the interface between the root and the core restoration\textsuperscript{29,32}. In addition, restorations with a narrow post cavity in the root canal are prone to low bonding strength between the composite resin core and the dentin because of the smear layer and the residue of the endodontic obturating material\textsuperscript{38}. Cohesive failure of the dentin was found in the present study, not just on the buccal side, but also on the palatal side, in addition to which debonding of the root and the composite resin core was found at the apical side of the root (Fig. 8b). This means that, with no ferrule on the abutment tooth, the stress applied to the crown was concentrated between the root and the core restoration, and debonding occurred first (Fig. 10a). The debonded core restoration then concentrated the stress in the palatal side dentin at the apical side of the root, with the buccal coronal dentin as the center of rotation (Fig. 10b\textsuperscript{16,31}). As a result, fractures in the root and composite resin core occurred if the dentin was poorly bonded to the composite resin core. The present results suggested that the fracture load may be increased in reattached teeth by a ferrule. In addition, since the fracture load was greater in teeth with a ferrule, the second null hypothesis that the ferrule on an endodontically treated root with composite resin core does not affect fracture of reattached teeth was also rejected.

**Clinical implication**

Reattached teeth with a vertical bone defect could have the same fracture resistance in the fracture load test as reattached teeth with no bone defect. If the morphology of the vertical bone defect changed the stress concentration applied to replanted reattached teeth, the fractures extending below the bone margin may increase frequently, along with fractures at the apical side of the root. In addition, since the width of a vertical bone defect increases over time\textsuperscript{18}, the time since the VRF occurred may affect the type of fracture of reattached teeth. At the same time, these results suggested that a ferrule on reattached teeth with a composite resin core could improve fracture resistance. It is therefore important in the treatment of reattached teeth that the fragments of a VRF are to be reattached and the teeth replanted, a ferrule should be preserved. Since some substitute materials such as bovine teeth, auto-cured acrylic resin as a bone substitute, and no material for periodontal ligaments were used, the present study did not completely reproduce the actual clinical situation. Therefore, the limitations of the present study are that the reattached teeth replanted in the bone defect could have an effect on the fracture of reattached teeth, and the ferrule of the reattached teeth could increase the fracture load. Further investigation will be necessary to mimic the oral environment such as human teeth replanted in periodontal ligaments.

**CONCLUSIONS**

This study investigated the effects of vertical bone defect width and a ferrule in the attached tooth on fracture resistance. Within the limitations, the following conclusions were obtained.

1. When reattached teeth were replanted in a mold with a bone defect, no difference in fracture load was found due to differences in defect widths.
2. Fracture load was greater on the reattached tooth with a ferrule than that without a ferrule.
3. In reattached teeth without a ferrule, debonding of the composite resin core and the root at the coronal loading side and fractures at the apical side of the root were found.

**ACKNOWLEDGMENTS**

This study is partially supported by JSPS KAKENHI Grant Numbers JP 21K17000.

**REFERENCES**

1) Friedman PK, Lamster IB. Tooth loss as a predictor of shortened longevity: Exploring the hypothesis. Periodontol 2000 2016; 72: 142-152.
2) Aida J, Ando Y, Akhter R, Aoyama H, Masui M, Morita M. Reasons for permanent tooth extractions in Japan. J Epidemiol 2006; 16: 214-219.
3) Tamse A, Fuss Z, Lustig J, Kaplavi J. An evaluation of endodontically treated vertically fractured teeth. J Endod 1999; 25: 506-508.
4) Testori T, Badino M, Castagnola M. Vertical root fractures in endodontically treated teeth: A clinical survey of 36 cases. J Endod 1993; 19: 87-90.
5) Kahler W. The cracked tooth conundrum: Terminology, classification, diagnosis, and management. Am J Dent 2008; 21: 275-282.
6) Almasri M. Assessment of extracting molars and premolars after root canal treatment: A retrospective study. Saudi Dent
7) Unver S, Onay EO, Unger M. Intentional re-plantation of a vertically fractured tooth repaired with an adhesive resin. Int Endod J 2011; 44: 1069-1078.
8) Okaguchi M, Kuo T, Ho YC. Successful treatment of vertical root fracture through intentional replantation and root fragment bonding with 4-META/MMA-TBB resin. J Formos Med Assoc 2010; 118: 671-678.
9) Hayashi M, Kinomoto Y, Takeshige F, Ebi su S. Prognosis of intentional replantation of vertically fractured roots reconstructed with dentin-bonded resin. J Endod 2004; 30: 145-148.
10) Arikan F, Franko M, Gurkan A. Replantation of a vertically fractured maxillary central incisor after repair with adhesive resin. Int Endod J 2008; 41: 173-179.
11) Ozcopur B, Akman S, Eskitascioglu G, Belli S. The effect of different posts on fracture strength of roots with vertical fracture and re-attached fragments. J Oral Rehabil 2010; 37: 615-623.
12) Doğanay Ylduz E, Arslan H, Ayaz N, Gündoğdu M, Özdoğan A, Gundogdu EC. Effect of Super-Bond C&B and self-adhesive dual-cured resin cement on the fracture resistance of roots with vertical root fracture. J Dent Res Dent Clin Dent Prospect 2019; 13: 153-157.
13) Lustig JP, Tamase A, Fuss Z. Pattern of bone resorption in vertically fractured, endodontically treated teeth. Oral Surg Oral Med Oral Pathol 2000; 90: 224-227.
14) Liao WC, Tsai YL, Wang CY, Chang MC, Huang WL, Lin HJ, et al. Clinical and radiographic characteristics of vertical root fractures in endodontically and nonendodontically treated teeth. J Endod 2017; 43: 687-693.
15) Meister F Jr, Lommel TJ, Gerstein H. Diagnosis and possible causes of vertical root fractures. Oral Surg Oral Med Oral Pathol 1980; 49: 243-253.
16) Reinhardt RA, Krejci RF, Pao YC, Stannard JG. Dentin stresses in post-reconstructed teeth with diminishing bone support. J Dent Res 1983; 62: 1002-1008.
17) Giovani AR, Vansan LP, de Sousa Neto MD, Paulino SM. In vitro fracture resistance of glass-fiber and cast metal posts with different lengths. J Prosthet Dent 2009; 101: 183-188.
18) Hayashi M, Takahashi Y, Imazato S, Ebisu S. Fracture resistance of pulpless teeth restored with post-cores and crowns. Dent Mater 2006; 22: 477-485.
19) Cagidiaco MC, García-Godoy F, Vichi A, Grandini S, Goracci C, Ferrari M. Placement of fiber prefabricated or custom made posts affects the 3-year survival of endodontically treated premolars. Am J Dent 2008; 21: 179-184.
20) Freedman GA. Esthetic post-and-core treatment. Dent Clin North Am 2001; 45: 103-116.
21) Kono T, Yoshinari M, Takemoto S, Hattori M, Kawada E, Oda Y. Mechanical properties of roots combined with prefabricated fiber post. Dent Mater J 2009; 28: 537-543.
22) da Silva NR, Raposo LH, Versluis A, Fernandes-Neto AJ, Soares CJ. The effect of post, core, crown type, and ferrule presence on the biomechanical behavior of endodontically treated bovine anterior teeth. J Prosthet Dent 2010; 104: 306-317.
23) Ferrari M, Vichi A, Fadda GM, Cagidiaco MC, Tay FR, Breschi L, et al. A randomized controlled trial of endodontically treated and restored premolars. J Dent Res 2012; 91: 72s-78s.