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Effect of Ferrule and Bonding on the Compressive Fracture Resistance of Post and Core Restorations

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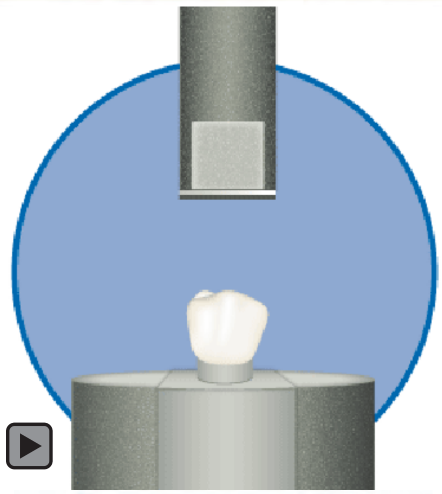

Abstract

Aim: The purpose of this study was to compare the fracture resistance of endodontically treated teeth restored with different post and core systems in combination with complete metal crowns in teeth with no coronal structure.

Methods and Materials: Fifty extracted mandibular premolars were divided into five groups. The coronal portion of each tooth was removed at the cementoenamel junction (CEJ) in all groups except Group 1. In this group the teeth were sectioned 1 mm above the CEJ to create a ferrule. After root canal preparations, cast posts were placed in the first four groups. Prefabricated glass fiber posts and composite cores were placed in the fifth group. An opaque porcelain layer was applied to the metal post surfaces in the third group and an alloy primer was applied to the posts in the fourth group before using Panavia F2 resin cement. No bonding agent or surface treatments were used for the first and second groups. A Ni-Cr full cast crown for each sample was prepared and cemented. A compressive load was applied at an angle of 45 degrees to the crown with a universal testing machine. After 500,000 mechanical cycles at 1.5Hz, the maximum load at fracture (N) was recorded.

Results: Significantly higher fracture resistance values (216.87 N) and survival rates (75%) were demonstrated for non-ferrule teeth restored with opaque layered posts than for other non-ferrule groups. The prefabricated post group showed the most favorable fracture pattern in all test groups (P=0.04).

Conclusion: Either a ferrule preparation or bonding with the use of an opaque porcelain layer can increase the fracture resistance of teeth with little remaining tooth structure that are restored with cast crowns following endodontic therapy.

Clinical Significance: Bonding cast posts to the tooth structure has a significant effect on compensating for the lack of a ferrule on endodontically treated teeth.

Keywords: Post and core, compressive strength, survival, bonding, fiber

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Introduction

In vitro and *in vivo* studies have demonstrated a post does not reinforce endodontically treated teeth, and a ferrule or encircling band of cast metal around the coronal surface of the tooth can improve the integrity of the endodontically treated tooth.[1-5] The purpose of a ferrule is to improve the structural integrity of a pulpless tooth. It is done by counteracting the functional lever forces, the wedging effect of tapering posts, and the lateral forces exerted during placement of the post.[1] The ferrule effect has been studied by several investigators.[6-9] To achieve the full benefit of the ferrule it should be a minimum of 1–2 mm in height, have parallel dentin walls, completely encircle the tooth, ends on sound tooth structure, and avoid encroachment on the attachment apparatus of the tooth.[10]

Clinicians often find situations where very little ferrule can be developed because of limited remaining coronal tooth structure.[1] In these situations there are few alternatives to restoring these teeth with a post and core foundation. Advances in adhesive dentistry have resulted in the recent introduction of modern surface treatment methods and bondable materials. As a result, new treatment options have emerged.[11-14] Use of bonded endodontic posts could improve the distribution of forces along the root surface and, consequently, reinforce the remaining tooth structure.[15-19] Research is evolving toward the development of post and core systems that are strong, corrosion resistant, and biocompatible.[20,21] Prefabricated posts enable dentists to restore endodontically treated teeth successfully at minimal cost without the need for a laboratory procedure. Among prefabricated non-metal posts,

glass-fiber reinforced posts are easily bonded to tooth structure and have a modulus of elasticity similar to dentin.[22] This property may induce less stress concentration in a tooth and might decrease the incidence of catastrophic root fractures.[23] Freedman[24] reported the types of failure associated with esthetic fiber-reinforced resin posts are primarily post-core fractures that could potentially allow retreatment of the tooth.

Saupe et al.[8] compared the fracture resistance of cast gold-alloy posts and cores with a resin reinforced post system of structurally compromised root. The results indicated resistance to the masticatory load of resin-reinforced post and core system was greater than a cast post and core restoration. These investigators also reported no statistically significant differences in the strength between ferrule and non ferrule groups were found when post and core restorations were bonded into the roots.[8]

The purpose of this study was to evaluate the effects of ferrule and post-surface preparation on the fracture resistance of endodontically treated teeth. Teeth restored with cast gold-alloy posts and cores and teeth restored with glass-fiber posts-composite resin cores were included in this study. To simulate clinical conditions artificial aging was used to more predictably mimic clinical behavior. The research hypothesis was bonding posts to tooth structure would have a significant effect on fracture resistance as well as the type of failure in teeth with no coronal structure.

Methods and Materials

Forty recently extracted single-rooted first and second mandibular premolars were selected for the study. All external debris was removed with an ultrasonic scaler and the teeth were stored in a 0.5% Chloramine T (Prolabo, Paris, France) in saline solution until required for the study. Each specimen was inspected under proper lighting and magnification to ensure the root surfaces were free of dental caries, defects, and cracks. The teeth were always handled with latex gloves and kept moist with saline solution during all procedures. The selected teeth were closely matched for size. The buccolingual and mesiodistal dimensions of the roots were recorded at three levels with a digital caliper (Mitutoyo America Corp, Aurora, IL, USA) accurate to within 0.01 mm (Figure 1).

The teeth were ranked according to sizes and distributed into five groups using a stratified random-allocation method. The root dimensions (mesiodistal and buccolingual diameter and root length) were assessed with one way analysis of variance (ANOVA, α=.05) with no significant differences among the measurements for the various groups found (Table 1).

The teeth were then sectioned 1 mm coronal to the cementoenamel junction (CEJ) measured along the buccal surfaces with a diamond disk (6918 B; Brasseler USA, Savannah, GA, USA) under water irrigation. The root canal of each tooth was instrumented with a conventional step-back technique to a size No. 45 file (Kerr/Sybron, Basel, Switzerland) at the apical constriction and to a size No. 55 file (Kerr/Sybron) to a distance within 1 mm from the apex. Saline solution was used during instrumentation. The canals were dried with air and paper points (Kerr, Romulus, MI, USA). Each canal was obturated with gutta percha (Kerr, Karlsruhe, Germany) and AH-26 root canal sealer (Dentsply De Trey, Konstanz, Germany) using the lateral condensation technique. Three days after obturation a coronal portion of the gutta percha was removed from the root canals with a reamer (Peeso Reamer size; Dentsply-Maillefer, Ballaigues, Switzerland) leaving 4 mm of the endodontic filling as an apical seal.

The description of experimental groups is shown in Table 2.

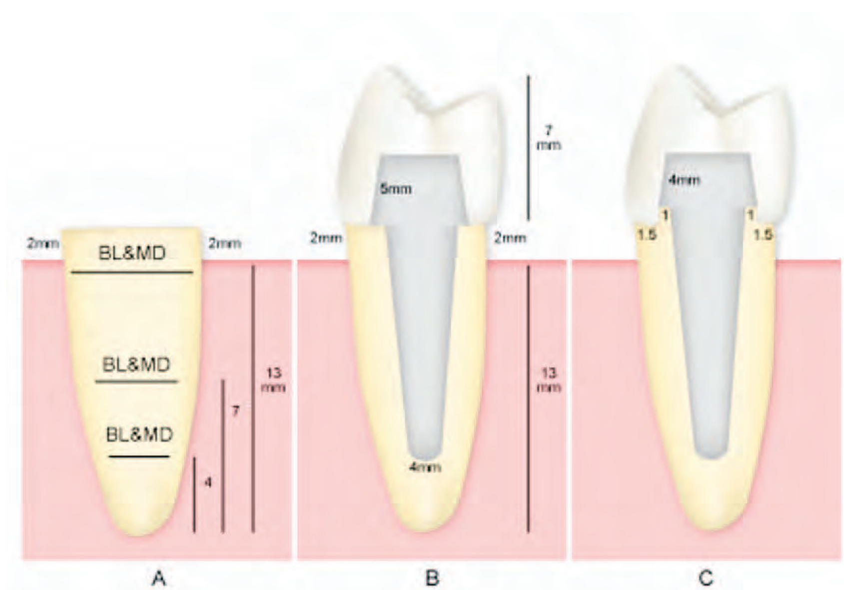

Figure 1. A. View of tooth structure measurements 1 through 5. Schematic representation of post and core foundations. **B.** Groups 1 through 5.

Table 1. One way ANOVA results of tooth dimensions.

Measurement Site	BL13	MD13	BL7	MD7	BL4	MD4	Root Length
P Value	0.85	0.713	0.647	0.366	0.641	0.713	0.819
BL: Buccolingual MD: Mesiodistal							

Table 2. Experimental groups.

Group	Cement	Surface Treatment	Post Type	Ferrule
1	Zinc phosphate	None	Cast post	1 mm
2	Zinc phosphate	None	Cast post	None
3	Panavia F2	Opaque porcelain, HF acid, silane	Cast post	None
4	Panavia F2	Alloy primer	Cast post	None
5	Panavia F2	None	Fiber post	None

The specimens in Group 1 were prepared with a 90 degree shoulder and with 1 mm of coronal dentin above the CEJ. The other four groups were prepared with a 90 degree shoulder and without a coronal dentinal extension (Figure 1). A butt joint configuration was prepared at the tooth core junction in all groups. To ensure similarity, post spaces were prepared in all teeth using special preparation drills for the prefabricated post system (Glassix size; Harald Nordin SA, Chially-Montreux, Switzerland).

A conventional direct technique was used to fabricate the post and core patterns in acrylic resin (Duralay; Reliance, Chicago, IL, USA). The following method was used to make the cores and crowns uniform. A mandibular premolar with normal form and average dimensions was selected and an impression of its coronal portion was made using a putty vinyl polysiloxane impression material (Rapid; Coltene AG, Altstatten, Switzerland). This impression served as an index for preserving the individual coronal dimensions before tooth preparation. Then each tooth was prepared with 1.5 mm axial and occlusal reduction with a subjective convergence angle of 8-10 degrees using water-cooled high-speed instrumentation. Another impression was made of the prepared tooth with putty vinyl polysiloxane impression material (Rapid) to serve as an index for preparing the core portions of the posts.

Five post and core patterns were invested with a phosphate bonded investment (Cera-Fina; Whip Mix, Louisville, KY, USA) and placed in each 4.45 cm ring and cast in Type IV gold alloy (Degubond 4; Degussa, Germany). The cast posts and cores were refined, finished, and abraded with 150 μm aluminum oxide under a 5 bar pressure. The cast patterns were then adjusted to ensure a passive but positive fit to avoid lateral stresses during insertion and cementation.

In Groups 1 and 2 zinc phosphate cement (Harvard; Berlin, Germany) was mixed according to the manufacturer's instructions and used to lute the post and core castings.

In Group 3 a mixture of 0.5 grams of opaque porcelain powder (Ceramco II; Dentsply Burlington, NJ, USA) and 1 cc of distilled water was applied on each post surface with a brush. Then the opaque porcelain layer was fired according to the manufacturer's recommendations. The posts were then conditioned with a 9.6% hydrofluoric acid etch (Porcelain Etch; UltraDent, Jordan, UT, USA) for 40 seconds and silanated (Clearfil porcelain bond activator and Clearfil Linerbond 2V primer; Kuraray, Okayama, Japan) according to manufacturer's guidelines. Primer (ED Primer; Kuraray) was applied for 30 seconds in the canals and on the post surfaces followed by air-drying. Dual-polymerizing resin cement (Panavia F2; Kuraray) was mixed according to the manufacturer's instructions and applied to the surface of each post prior to insertion in the root canal. Excess cement was removed and air isolating medium (Oxyguard II; Kuraray) was applied to all exposed surfaces of the cement. This allowed the anaerobic setting reaction to occur and to ensure complete polymerization of the cement at margins. The specimens were then rinsed and evaluated for defects after completion of cementation.

In Group 4 the cast posts were coated with primer material (Alloy Primer batch #; Kuraray) and allowed to dry. Post spaces were rinsed and dried then the posts were cemented with Panavia F2 resin cement as done with Group 3.

The teeth in Group 5 were prepared similar to those in the non-ferrule groups. These teeth were restored with prefabricated fiber-glass, parallel-sided posts with a tapered end (Glassix; Harald Nordin SA, Chially-Montreux, Switzerland). The cementation procedure was the same as was done in Group 3. The excess coronal length of each post was carefully sectioned by using an annular saw with a continuous water coolant. The composite resin (Nulite F; Laverton, Australia) was then placed using the polyvinyl siloxane index and an incremental filling technique. The core material contained high levels of inorganic filler for sufficient strength. Five increments of the composite resin were applied and cured for 40 seconds with a light cuirng unit (800 mW/cm^2).

An impression (Rapid; Coltene AG) of the coronal portion of each prepared tooth was made using copper rings. Preheated liquid wax (Pico Sculpting wax; Renfert GmbH, Hilzingen, Germany) was inserted in the vinyl polysiloxane crown matrix and was seated directly on the die along the long axis. After cooling, the excess wax and the crown matrix were removed. The same procedure was conducted for all specimens. The finish lines for all specimens were placed at the level of the CEJ. A groove was also placed on the occlusal surface of the crown 2 mm from the facial cusp tip for the compressive loading test. Crowns were cast with nickel chrome alloy (Verabond 2, Albadent, Cordelia, CA, USA) and adjusted on the teeth.

Zinc phosphate cement was mixed and applied in the crowns. The crowns were gently seated on the teeth and held with light finger pressure until the cement reached its initial set (5 minutes). All completed specimens were stored in distilled water at room temperature for a maximum period of two weeks before the testing procedure.

Root surfaces were marked 2 mm below the CEJ and wrapped in two layers of 0.1 mm foil (Adapta System; Bego, Bremen, Germany), prior to being embedded in clear acrylic resin (Technovoit 4000; Heraeus Kulzer, Wehrheim, Germany). This procedure permitted embedding of the roots with the crown margin 2 mm above the level of the acrylic resin, simulating the position of the alveolar bone in natural teeth. Roots of the specimens were mounted in the acrylic resin blocks with plastic rings 2 cm in diameter. After the first signs of polymerization, the teeth and the foil spacers were removed from the resin blocks and the root surfaces. An injection type of vinyl polysiloxane impression material (Rapid; Coltene AG) was delivered with a dispenser gun (3M) through the mixing tip in to the acrylic resin simulated alveolus. The teeth were then reinserted into the block and the impression material was allowed to polymerize. The excess silicone material was removed with a scalpel blade to provide a flat surface 2 mm below the facial CEJ of each tooth. The thin layer of silicone material simulated the periodontal ligament. Then, each specimen was positioned in the mounting device with a special mounting jig and aligned at a 45 degree angle with respect to the long axis of the tooth. This angle of loading was chosen to simulate a contact angle in Class I occlusion between maxillary and mandibular premolar teeth. Loading was conducted at 60 N and 1.5 Hz, similar to the mean rate of mastication of 1-2 Hz, for 500,000 cycles.[22] The number of intact specimens after the fatigue loading was recorded and expressed in percentages.

Table 3. Mean fracture resistance values, mode of failures, and survival times in test groups.

	Mean (± SD)	Survival Time (cycles)	Favorable Fracture**	Catastrophic Fracture***
Group 1	155.00N±78.032[a*]	443750.00±31171.78	1 (12.5%)	7 (87.5%)
Group 2	28.75N±18.46[b]	318750.00±58106.86	2 (25%)	6 (75%)
Group 3	209.00N±99.78[a]	393750.00±65214.49	2 (25%)	6 (75%)
Group 4	70.87N±34.45[b]	387500.00±42158.55	2 (25%)	6 (75%)
Group 5	33.75N±18.59[b]	268750.00±66106.86	6 (75%)	2 (25%)

* Identical letters indicated that values are not significantly different at P<.05 (one way ANOVA followed by a Tamhane test).
**Above the acrylic resin level
***Below the acrylic resin level

All specimens that did not fracture during the dynamic loading were then loaded until fracture in a universal testing machine (MTS 858; MTS Systems Corp, Edent Prairie, MN, USA) with a crosshead speed of 1mm/minute. The maximal loads at fracture and the mode of failure were recorded. Statistical analyses of fracture resistance were performed using a one way ANOVA and Tamhane Post hoc tests. The one-sample Kolmogorov-Smirnov test was used to justify use of the parametric ANOVA. The fracture mode among the five test groups was compared using Fisher's exact test (with an adjusted P value). A significance level of α=.05 was used for all comparisons. The survival rates were also determined using the Kaplan Meier test for all test groups.

Results

Table 3 shows the mean fracture resistance values for the five test groups. The Kaplan Meier test showed Group 1 presented a higher survival cycle (443750.00 ±31171.78) compared with the group restored with a glass fiber post (268750.00 ±66106.86) and the other groups with no ferrule.

Post hoc tests showed the mean fracture resistance values for Group 1 (teeth with 1 mm ferrule length) were significantly higher when compared with Groups 2 and 5 (P=.01 and P=.02, respectively). Statistical analysis also showed the mean fracture resistance of Group 3 was significantly different than Groups 2 and 5 (P=.039 and P=.047, respectively). No significant difference was found in the fracture resistance between Groups 1 and 3 (P=.936) as shown in Table 3 and Figure 2. Multiple comparison Tamhane tests detected no significant difference in the mean fracture resistance among Groups 2, 4, or 5 ($P_{\text{Group 2/Group 4}}$=.81, $P_{\text{Group 2/Group 5}}$=.92, and $P_{\text{Group 4/Group 5}}$=.94).

Fracture patterns were classified according to location as favorable and unfavorable. The mode of failure was considered unfavorable if the tooth fractured below the surrounding acrylic resin and all other types of failure above the acrylic resin were considered as favorable. Table 3 shows the number of each failure type observed and the survival rates for the five groups. The Fisher's exact test did not detect any significant fracture patterns within groups except for Group 5 (P=.04).

Discussion

Variations among specimens within a group are inherent with these types of studies because of natural variations among the teeth, the heterogeneous nature of tooth structure, and the technical difficulties related to the study of root fracture. However, the use of natural teeth has been considered acceptable in this type of *in vitro* testing of posts.[2,3,8,17] One method to reduce these variations is to select similar teeth of the same dimensions, a task that is subjective and time consuming. The dimensions of the experimental teeth in this study were evaluated statistically to eliminate possible variations in size. In addition

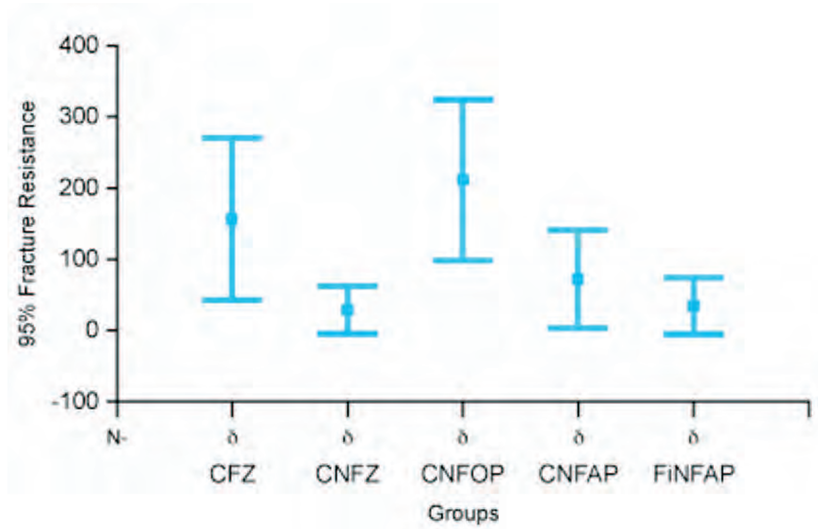

Figure 2. Error bar chart of mean fracture resistance of five experimental groups (± standard error).

all specimens in the present study were restored and tested with standardized complete coverage crowns.

For a restoration to function satisfactory over many years, it has been postulated the luting agent must have sufficient physical strength to resist fracture and long-term cyclic fatigue stresses.[13] Zinc-phosphate cement has been the gold standard luting agent for decades.[14] However, adhesive resin luting agents also have been studied extensively and several investigations have evaluated the retention of posts using these resins.[8,16-19] The adhesive cement used in this study (Panavia F2; Kuraray) consisted of multifunctional phosphoric acid, dimethacrylate-modified monomers, such as Bis-GMA and inorganic fillers of fine glass and silica.[12] This resin cement exhibits high compressive and diametrical tensile strength.[13] The advantages of bonding agents for bonding posts are the absence of wedging effects and less dentin removal (posts could be shorter and thinner) and, therefore, lower fracture susceptibility.[4] It has been postulated this bond allows the formation of a single unit consisting of the tooth, post, core, and crown functioning as a cohesive unit.[19] With respect to the luting agent metal interface, metal surfaces may be altered in a variety of ways to improve adhesion, including airborne-particle abrasion, etching, priming, and silane coating.[18]

In the present study significantly higher fracture resistance was obtained for teeth in Group 3 without a ferrule in which cast gold-alloy posts were treated with an opaque layer of porcelain followed by silane agent and resin cement. This group also had the highest survival time among all other test groups and was comparable to Group 1 representing conventional treatment. This result suggests the improved bond between the metal post and resin cement created by the opaque porcelain layer and silane treatment could compensate for the lack of a ferrule. Similarly, Dumbrigue et al.[3] concluded the fracture resistance of a restored endodontically treated tooth was a function of the strength of the root/remaining, coronal tooth structure available, the post and core, as well as the bond strength between them. It has been demonstrated when coronal tooth structure is absent the resistance to displacement is primarily a function of the bond between the post and core and the root. Hence, improving the bond may offset the lack of a ferrule.[3]

Other studies have reported the bond between resin-based luting agents and metal alloys is made considerably stronger with the use of surface modification by silane coating metal alloys. These procedures are usually expensive and time consuming.[11,13,16,18] The silane coupling agent produces a bond between the silica and the organic matrix of the resin cements (siloxane bonds). Coupling agents also increase the capacity of the cement to flow on the surface to produce micro-mechanical retention.[11] Most silane coupling agents also increase the substrate surface energy and improve the surface wetability to resins.[11]

The significantly higher mean fracture resistance value for Group 1 with a 1 mm ferrule length compared with the other groups without ferrule (except for Group 3) also emphasizes the significant positive effect of a ferrule preparation. Similar to this observation, previous studies have confirmed crowned and endodontically treated teeth are subjected to high stress levels at the cervical region and a cervical ferrule preparation created a positive effect on reducing stress concentration at the core-dentin junction.[5] Sorensen and Engelman[1] found 1 mm of parallel dentin above the shoulder preparation increased the fracture resistance of endodontically treated teeth. Pereira et al.[2] reported an increase in ferrule length significantly increases the fracture resistance of endodontically treated teeth restored with prefabricated posts and cores. However, the forces responsible for failure in their study were considerably higher than the maximal physiologic occlusal forces found intraorally.[2] In another study with a larger sample size (twice the size) and a 2 mm ferrule length, higher survival rates were reported for all groups tested.[15] The survival rates in that study implied post systems were less important when the teeth had adequate ferrule length. However, Gegauff[9] found the combination of simulated surgical crown lengthening procedure and more apical metal-ceramic crown margin placement to provide a 2 mm crown ferrule resulted in a reduction of static failure load for the restored teeth *in vitro*. It is clear researchers have different opinions about the ideal amount of remaining coronal tooth structure.[9]

With regard to the mode of failure, root fracture was predominantly observed for Groups 1 through 4. The only favorable failure mode (above CEJ) was found for Group 5 (teeth with fiber posts and composite resin cores). This finding was significantly different from all other groups (P=.04), although the fracture resistance of this post system was relatively low. It should be noted because of the small sample size in this study, Fisher's exact test with adjusted *P* value was used to analyze the mode of fracture, so it would be difficult to draw definitive conclusions on the observed failure modes.

The findings from the present study are in agreement with the results of other studies in which the investigators concluded composite resin fracture can occur at a lower force than required to cause root fracture.[16,17] Perhaps voids or bubbles within the core or gaps at the post-core interface resulting from incomplete condensation of the material around the posts may affect the integrity and, consequently, the strength of the post and core foundation. Pereira et al.[2] report, despite the lower fracture resistance, the technique of using prefabricated posts and composite resin may be appropriate because there were no root fractures. The authors also concluded teeth with lower resistance also can function successfully and the direct method appeared to protect the root surface.[2]

Most studies use static loading for testing which is not a replication of clinical conditions. Although the fracture threshold of the prefabricated post is lower than root fracture, the relatively short fatigue lifetime would likely require multiple replacements during the lifespan of a patient which may be unacceptable. Although a mechanical fatigue test is better than static loading tests, it is still difficult to compare the results with clinical situations. In the fatigue loading used in this study, the load was a regular and identical force. However, the power of masticatory forces varies clinically. Cyclic loading tests are known to show a large scatter in results, thus, making comparison between groups difficult.[22] Fracture loads for failed specimens during cyclic loading in most studies are considered to be zero. Thus, the failed specimens during the simulation of mastication in this study, which were not available for static loading test, were considered zero in the analysis.

As with any *in vitro* study, it is difficult to extrapolate the results of this study directly to a clinical situation. Ideal situations in the tooth-cement, cement-post interfaces, and the cement layers are not always obtained in clinical practice. Other limitations of this study include the use of finger pressure to maintain the posts and crowns in position, which did not provide a standardized loading force. Also, the ferrule height usually varies around the circumference of the tooth, but this study used a constant height around the periphery of the teeth.

Conclusion

Within the limitations of this *in vitro* study, the following conclusions were drawn:

- Either a ferrule preparation or bonding with the use of an opaque porcelain layer on cast gold post and cores resulted in higher fracture resistance for teeth with little remaining tooth structure receiving cast crowns after endodontic therapy.
- Glass-fiber posts and composite resin cores displayed more favorable fracture patterns compared with cast gold-alloy post and core systems (P=.04), but their mean fracture resistance was considerably lower.

Clinical Significance

This *in vitro* study shows bonding cast gold posts with the use of an opaque porcelain layer to the tooth structure has a significant effect on compensating for the lack of a ferrule on endodontically treated teeth restored with cast post and cores. Furthermore, any resultant fracture of a glass-fiber post can usually be repaired.

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