Effect of the Number of Residual Walls on Fracture Resistances, Failure Patterns, and Photoelasticity of Simulated Premolars Restored with or without Fiber-reinforced Composite Posts

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Abstract

Introduction: This study compared the fracture resistances and the failure patterns of 100 simulated mandibular premolars of a different number of coronal walls (zero to four walls) with or without fiber-reinforced composite (FRC) posts. In addition, the photoelastic stress distribution was analyzed. **Methods:** The fracture resistance was measured at a 45° angle with a crosshead speed of 1 mm/min, and the failure patterns were observed. The photoelastic stress distribution of specimens with or without FRC posts was also evaluated. The fracture resistance was analyzed by analysis of variance and a Duncan's multiple range test ($p < 0.05$). **Results:** In the no post groups, the fracture resistances decreased significantly in groups with two or fewer walls. The FRC post increased fracture resistances significantly, except for the zero-wall group, and optimized the failure patterns. A high stress concentration was observed along the canal space in the no post groups; stress seemed to be distributed in post groups in photoelasticity. **Conclusion:** Within the limitation of the experimental methods of this study, the FRC post was advantageous in lower premolars, especially with two or more walls in terms of the fracture resistance and stress distribution. *(J Endod 2010;36:297–301)*

Key Words

Failure pattern, fiber-reinforced composite post, fracture resistance, photoelasticity, simulated premolar

The combination of reduced structural integrity, moisture, and dentin toughness compromises endodontically treated teeth (ETT), which require special care in restoring (1, 2). Fiber-reinforced composite (FRC) post systems were introduced to develop posts with similar elastic modulus to dentin and to recover the fracture resistance of teeth (3–5). When FRC posts are used, they seldom cause root fractures because of the similar elastic modulus to dentin (3, 6, 7).

Not every ETT needs a crown or a dowel (8). However, even with many studies, no guideline has been proposed as to when a post is required with respect to the amount of tooth structure (9). Guidelines on premolars in particular are lacking. For this reason, there is a need to obtain objective data by measuring the fracture resistance of teeth, taking into account the presence of posts and the amount of remaining tooth structure.

In order to prevent fracture, it is important to evaluate how stress is distributed over the remaining coronal tooth structure-post-root complex under masticatory force. On stress measurement, various methods are available, namely the strain gauge method, the loading test, the finite element, and the photoelastic method (10). Among these, the photoelastic method is a useful technique for evaluating the stresses responsible for structure failure (11) by which the magnitude and direction of stresses at any point can be determined (10). This technique uses transparent models comprised of photoelastic resin.

The previous studies on fracture resistance using natural teeth had limitations of individual variations such as age, the time elapsed after extraction, and storage conditions. In this study, the individual variations were controlled by using simulated premolars fabricated with photoelastic resin.

The aim of this experiment was to evaluate the change of fracture resistances and failure patterns according to the number of coronal walls, with or without FRC posts in mandibular premolars, and to analyze the distribution of stress using photoelasticity. The null hypothesis of this experiment was the presence of FRC posts and the number of residual walls haves no correlation to the fracture resistances of simulated teeth.

Materials and Methods

Preparation of Simulated Premolars

A standardized external configuration of tooth was reproduced by using a mandibular 2nd premolar model (Dental Model; Nissin Dental Products Inc, Kyoto, Japan). An impression of the tooth model was taken with vinyl polysiloxane impression material (Exafine Putty Type; GC Corp, Tokyo, Japan) to fabricate the tooth mold. To reconstruct the internal structure, a cast metal canal was constructed 5 mm longer above and below a tooth model with a 0.06 taper. Two metal pins were used as guiding pins for the putty mold placement into the identical position. The mold was then separated into two parts by cutting at the cementoenamel junction (CEJ) after setting.

A tooth mold and guiding pins were assembled in the frame of a disposable plastic syringe. The liquid resin (epoxy resin) and the hardener (triethylenetetramine) of the photoelastic resin (PLM-1 Liquid; Vishay Micromeasurement, Raleigh, NC) were mixed according to the manufacturer's instructions. The photoelastic resin was injected into

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the mold, and the metal canal was positioned. The resin was allowed to polymerize at room temperature for 24 hours.

Once a total of 100 photoelastic resin teeth were made, they were divided into five groups of 20 each. The designs of the tooth walls were performed as described in a previous study (12). In brief, the control group had four walls, and the four experimental groups had three, two, one, and zero walls, respectively. The walls were removed in the order of distal, mesial, buccal, and lingual aspects. The occlusal-gingival height of the zero-wall group was 2 mm above the CEJ. Each group was divided into two subgroups of 10 each: no post groups and post groups.

Fabrication of Experimental Resin

The experimental resin for restoring the access cavity of simulated teeth was composed of the following: 58.8 wt% Bis-GMA (NK Oligo, EMA-1020; Shin-Nakamura Chemical, Wakayama, Japan), 19.6 wt% diurethane dimethacrylate, 19.6 wt% triethylene glycol dimethacrylate, 1 wt% camphorquinone as a photosensitizer, and 2 wt% 2-dimethylaminoethylmethacylate as an amine initiator. All chemicals were purchased from Sigma-Aldrich, Inc. (Milwaukee, WI) except Bis-GMA.

Endodontic Preparation and Restoration of Simulated Premolars

The root canals of photoelastic resin teeth were shaped with the ProTaper rotary Ni-Ti file (Dentsply Maillefer, Ballaigues, Switzerland) to size F3. The canals were obturated with gutta-percha (Dia-Pro; Dia-Dent, Cheongju, Korea) by a continuous wave technique up to 1 mm below the CEJ and 5 mm above the apices. The post space was prepared using a low-speed drill of glass fiber post (LuxaPost; DMG, Hamburg, Germany) with a 1.5-mm diameter. The post space was prepared to be 15 mm with the buccal cusp tip as a reference. Bond A and Bond B of LuxaBond (LuxaBond Total Etch, DMG) were mixed and applied in the canal. For the post group, the post was cut to 14 mm in length, and a silane coupling agent was applied (Silane, DMG). The posts were cemented by using a dual-cure resin cement (DUOLINK; Bisco, Inc, Schaumburg, IL) and light-cured (Elipar TriLight; 3 M ESPE, Seefeld, Germany) for 40 seconds.

For both the no post and post groups, the access cavity was restored with the experimental resin using an index from the original model. The resin was cured in increments of less than 2 mm. The total polymerization time was 80 seconds in all specimens. The specimens were put in a tightly sealed container at room temperature for 24 hours.

Fracture Resistance

The lingual surface of the buccal cusp was flattened by using a diamond bur so that the load could be applied without slippage. The root portion below the CEJ of the specimen was wrapped twice with polytetrafluoroethylene tape (Nitoflon; Nitto Denko Corp, Fukaya, Japan) to simulate the 0.2-mm thickness of the periodontal ligament (13). The specimens were embedded in acrylic resin (Ortho-jet Acrylic; Lang Dental MFG, Wheeling, VA) up to 2 mm below the CEJ.

To analyze the fracture resistances of the specimens, they were mounted on a universal test machine (ZO20; Zwick, Ulm, Germany) at a 45° angle in order to reproduce typical transverse loading (14). A compressive load was applied with a stainless steel rod of 3.5-mm diameter on the flat surface of the buccal cusp at a crosshead speed of 1 mm/min (15).

Failure Pattern

After the fracture resistance test, the macroscopic fractures of the specimens were observed after ink perfusion to highlight the fracture lines. Fractures were characterized as “restorable” when limited in the coronal portion and “unrestorable” when reaching the root.

Analysis of Photoelastic Stress Distribution

A jig was made with translucent acrylic resin (Ortho-jet Acrylic) for the loading to be applied at an angle of 45° to the long axis of a tooth. The jig and the photoelastic tooth model were fixed in a transparent plastic container, and mineral oil was poured to minimize surface refraction. A load of 5 kg was applied to the buccal cusp of a simulated premolar by a constant loader (Seiki, Tokyo, Japan). Under load, the stress within the model caused the light to be reflected, producing a pattern of colored lines called stress fringes (16, 17). The stresses within the model were recorded photographically in the field of a circular polariscope arrangement using a digital camera (D70S; Nikon, Tokyo, Japan) (16). The stress distributions were interpreted based on the number and proximity of the stress fringes between the no post and post groups (17). The data from the apical portion was excluded in the analysis because of the interaction with the jig.

Statistical Analysis

Data were statistically analyzed with SPSS 12.0 (SPSS 12.0; SPSS GmbH, Munich, Germany). The two-way analysis of variance was used to analyze the fracture resistances with and without posts with respect to the number of residual walls. One-way analysis of variance was used to analyze the fracture resistances according to the number of walls in both the no post and post groups, respectively, with the Duncan’s multiple range test. A t test was performed to find a significant difference between the no post group and the post group of each wall; p was set to 0.05 for all statistical tests.

Results

Fracture Resistance

The fracture resistances of the no post and post groups are shown in Figure 1. The fracture resistances were significantly affected by the number of residual walls and the presence of posts ($p = 0.000$). There was an interaction between the number of walls and the presence of posts by two-way analysis of variance ($p = 0.043$). In the no post groups, the fracture resistances decreased significantly in two or fewer wall groups by one-way analysis of variance ($p < 0.05$). The use of FRC posts increased fracture resistance significantly in each wall group except the zero wall by t test ($p < 0.05$). In post groups, the reinforcing effect of the post was more effective in two or more wall groups by one-way analysis of variance ($p < 0.05$).

Failure Pattern

The percentage of restorable fractures was higher in the post group. As the number of residual walls increased, the teeth tended to be unrestorable (Table 1).

Photoelastic Stress Distribution

In the no post group, high levels of stress were produced in the remaining internal tooth structure along the canal space. As the number of walls decreased to zero, a higher intensity of stress was noted in the lingual side of crown and the CEJ area. In the post group, there was no obvious stress concentration, and, as the residual walls decreased, the stress concentrated on the coronal portion of experimental restorative resin (Fig. 2).

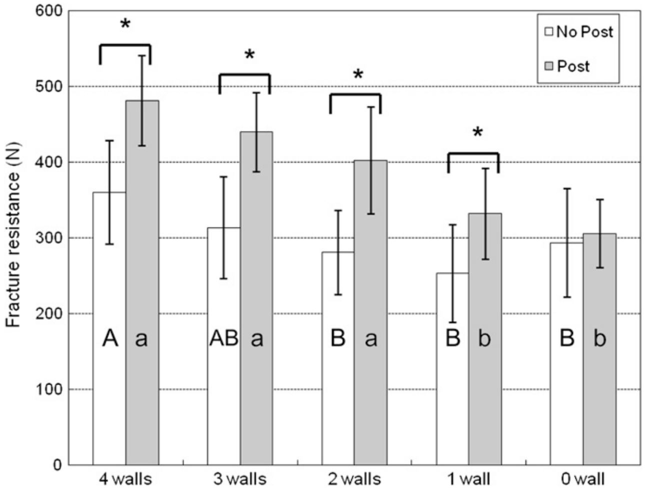

Figure 1. Fracture resistances of endodontically treated teeth with or without post according to the numbers of residual walls. The superscripts with the same letters were not significantly different by one-way analysis of variance at $\alpha = 0.05$. *Significant difference by *t* test.

Discussion

This study was designed to evaluate the fracture resistances and the failure patterns of simulated mandibular premolars composed of differing numbers of residual walls with and without FRC posts. In addition, the stress distribution by photoelastic analysis was examined. The null hypothesis was rejected because the fracture resistances showed significant differences dependent on the number of residual walls and the presence of FRC post.

This study indicates that fracture resistances of simulated lower premolars without posts decreased significantly in groups with two walls or less. The use of FRC posts increased fracture resistance significantly in each wall group, except the zero-wall group. The FRC post showed a better reinforcing effect when the number of remaining walls was two or more. It is noticeable that the mean value of the two-wall group in post groups was even higher than that of the four-wall group in the no post groups. When an ETT is restored with a post, the post can redistribute the stress to increase the fracture resistance (11, 18, 19). However, while preparing for a post space, even a slight amount of remaining tooth structure could be decreased, rendering the tooth weakened (20–22). Therefore, the insertion of FRC posts cannot be assumed to always improve the fracture resistances (12, 23–25). On the other hand, there are studies indicating that FRC posts do improve the fracture resistances (2, 6, 18, 22, 26–29). In a previous study using mandibular molars, fracture resistances were highly dependent on the number of remaining coronal walls, but the presence of post had no effect on fracture resistances (12). However, in this study, the FRC post significantly increased fracture resistances in the one or more wall group.

In failure patterns, post groups showed more restorable fractures than no post groups. The use of FRC post showed positive effects on the failure pattern. As the remaining walls decreased, the more restorable failure pattern appeared. It seemed that the stress was concentrated in the remaining coronal walls in the groups with fewer walls.

A photoelastic study was performed to compare the stress distribution in the no post and post groups. The no post groups showed concentrated stress at the remaining teeth structure along the canal space throughout the teeth. The post seemed to distribute the stress inside the teeth, resulting in higher fracture resistance and a better failure pattern than the no post group.

In this study, resin teeth fabricated with photoelastic resin were used instead of natural human teeth. The current difficulties in obtaining authentic human teeth because of the regulations on research necessitated our use of teeth fabricated with photoelastic resin. In addition, the teeth should be similar in size, shape, and identical number of canals. The storage condition can also be a factor. These problems can be solved by using fabricated teeth. The issue, however, of using resin teeth versus authentic human teeth arises. The structure of resin teeth is different from human teeth because they lack dentin, enamel, and dentinal tubules. According to Kishen and Asundi (11) who investigated the relationship between the stress concentration of photoelastic resin teeth and the fracture pattern of human teeth, the plane of stress concentration in resin teeth restored with post and core exactly coincided with the plane of fracture in human teeth rehabilitated with a post and core. Therefore, the fracture patterns of this study can be regarded to represent those of the human teeth. In addition, photoelastic method was proven to be a valid, reliable, and accurate technique to be used *in vivo* studies on biomechanical behavior of prosthetic devices. In comparison to matching strain gauge data, the stress distributions of photoelasticity showed a high correlation with values obtained at the same areas using strain gauges (30, 31). In terms of fracture resistance, the absolute values are lower in resin teeth than human teeth. However, the values are different even among human teeth specimens depending on the conditions of teeth and experiments. In studies using maxillary incisors restored with fiber posts, the fracture resistance values were as follows: 918.23 N in D'Arcangelo et al's study (18), 333.0 to 520.9 N in Gonclaves et al's study (22), and 210 to 295 N in Naumann et al's report (32). In studies using maxillary premolar, 1,302.5 N in Salameh et al's study (2) and 304 kilograms-force (kgf) in Hayashi et al's study (29) were reported. The trend through the relative comparison according to the number of walls is considered more important. The post group of this study showed the same trend, and the no post group showed a similar trend as in Salameh's research, despite the fact that Salameh's study used human mandibular first and second molar (12). Therefore, this test model seems to be valid and relevant to human teeth. Still, it seems necessary

TABLE 1. Failure Patterns of Simulated Premolars with or without Posts According to the Residual Walls

	No post		Post	
Residual walls (group)	Unrestorable (%)	Restorable (%)	Unrestorable (%)	Restorable (%)
4 walls (1)	50	50	30	70
3 walls (2)	40	60	30	70
2 walls (3)	40	60	30	70
1 wall (4)	20	80	0	100
0 walls (5)	20	80	0	100

Unrestorable failure: a fracture extends to the root of a tooth; restorable failure: a fracture involving the only coronal part of a tooth.

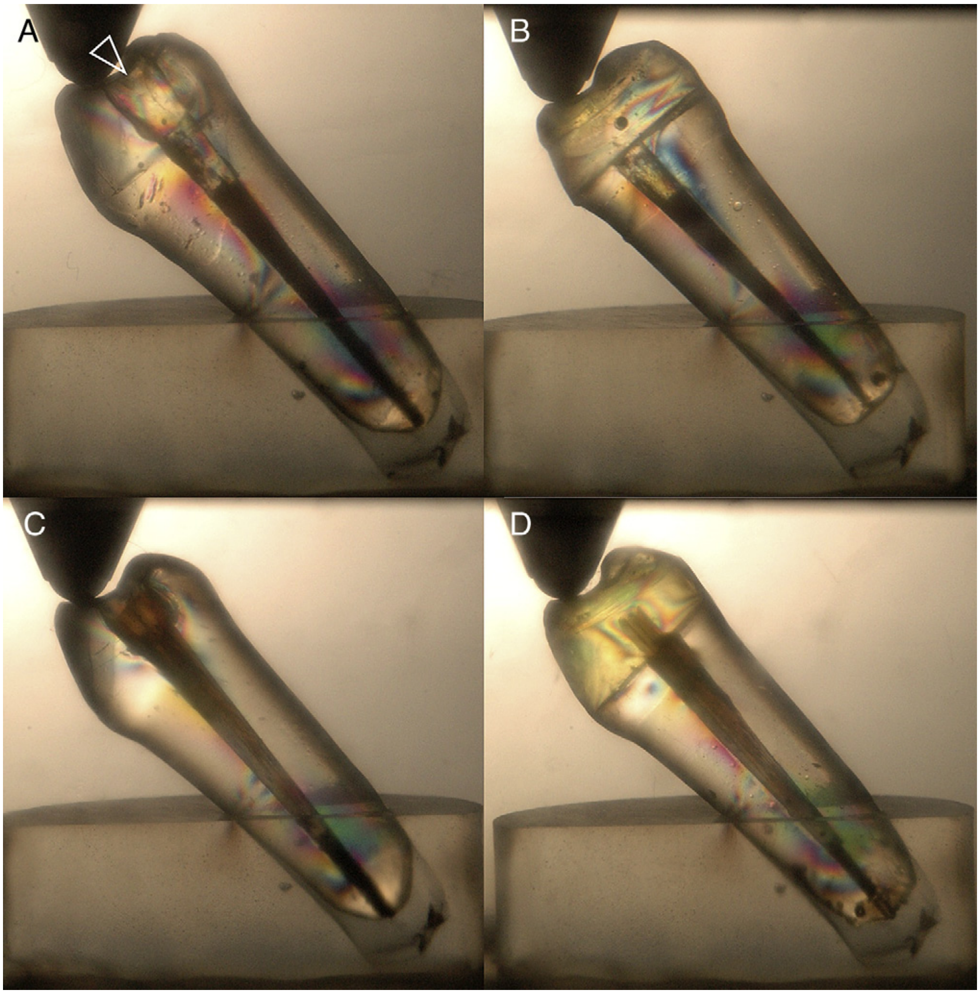

Figure 2. Interference fringes developed in simulated teeth with or without post to show the stress distribution under a vertical load of 5 kg. (*A*) In the three-wall group without a post, the stress fringe was high along the canal space throughout the teeth. (*B*) In the zero-wall group without a post, the stress pattern was concentrated at the coronal and the lingual area of CEJ. (*C*) In the three-wall group with a post, the post seemed to distribute the stress evenly with no obvious stress concentration. (*D*) In the zero-wall group with a post, without obvious stress concentration, except the coronal portion restored with experimental resin; the arrow head (▽) represents the experimental resin used to restore the access cavity in all specimens.

to compare the fracture resistance and fracture patterns of human premolars with these results as a further study to establish a more solid test model.

It is important to understand that this study was an *in vitro* study on teeth analogs without full covering restoration. According to previous studies, restorations with crowns can cancel out the difference among various post systems (33, 34). Therefore, crowns were excluded in this study. However, there are reports that coronal coverage increased the survival of premolars and molars (9, 35). A clinical study with crown coverage of the same design as this experiment is necessary to prove its clinical validity. Furthermore, additional studies using thermocycling or repeated loading to fatigue the specimens would be useful to evaluate the possible breakdown of the bond between the post, resin cement, and the tooth/resin model. Repeated loading and fatigue test are more relevant to clinical situations (13). The photoelasticity model could be revised by using a transparent PDL material with an elastic modulus similar to PDL and the embedding resin with one similar to alveolar bone to simulate the clinical situation better.

Within the limitation of this study, the fracture resistances of simulated premolars restored with experimental resin after endodontic treatment were affected by the number of residual walls and by the presence of posts. The use of FRC post showed a positive failure pattern that could lead to easier retreatment under the experimental methods of this study. Therefore, the use of FRC post was advantageous in lower premolars with two walls or more in terms of the fracture resistance and stress distribution.

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