Photoelastic stress analysis of different prefabricated post-and-core materials

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The purpose of this study was to investigate stress developed by a combination of a stainless steel post or a fiber-reinforced resin post with a silver amalgam core or a composite resin core. Two-dimensional photoelastic models were used to simulate root dentin. Posts (ParaPost XT and ParaPost-FiberWhite) were cemented with a luting agent (RelyX Unicem). Silver amalgam cores and composite resin cores were fabricated on the posts. Complete crowns were fabricated and cemented on the cores. Each model was analyzed with 2 force magnitudes and in 2 directions. Fringe orders were recorded and compared using ANOVA (p=0.05) and the Scheffe’s test. With vertical force, no stress differences occurred among the 4 groups (p=0.159). With a 30-degree force, there was stress differences among the 4 groups (p=0.001). The combination of a fiber-reinforced post and composite resin core could potentially reduce stresses within the radicular dentin when angled loads are applied.

Keywords: Fiber post, Prefabricated-post, Composite-resin core, Amalgam core, Photoelastic

INTRODUCTION

Post-and-core restorations provide coronoradicular stabilization for endodontically treated teeth. Many variables can affect the clinical outcome of teeth restored with posts-and-cores. Among these are the choices of materials and the stress distribution produced during function.

A study by Morgano et al.¹ indicated that 40% of general dentists used prefabricated posts most of the time. Standlee et al.² reported that a parallel-sided post resisted tensile, shear, and torqueing forces better than a tapered post did. Other studies³,⁴ reported similar results. Apart from retention, biomechanics and stress distribution of post designs also have gained interest by investigators by using a photoelastic model⁵-⁸. Henry and Bower⁹ determined the influence of post configuration on stress distribution. Thorsteinsson et al.⁹ compared stress induced by 3 prefabricated threaded post systems. Results indicated that with inclined loading, the Flexi-Post system produced significantly higher stress in the cervical and the middle surfaces than any of the other post designs. Although silver amalgam is the core material of choice⁵-⁸, the use of composite resin and stainless steel posts allows for core construction and tooth preparation in a single visit. Christian et al.¹¹ reported that the silver amalgam core with prefabricated posts was the most resistant to compressive force. However, composite resin cores have also gained acceptance as a core material¹²,¹³. Trope et al.¹⁴ examined the strength of different restorations on endodontically treated teeth and reported that teeth restored with posts constructed from composite resin, combined with the etching and bonding technique, were stronger than teeth restored with metal posts. The disadvantages of composite resins are problems with microleakage and dimensional stability, which may affect marginal adaptation of the overlying crown as shown by Oliva et al.¹⁵.

Root fracture has been observed by clinicians¹⁶-¹⁸. Photoelastic stress analysis has been used to illustrate the stress distribution for various prefabricated post systems¹⁹. This technique is useful for evaluating the stresses responsible for failure of a structure, especially one with irregular form. The model is examined in a field of polarized light with loads applied in a similar manner to those under investigation. Such photoelastic model, under carefully controlled conditions, can indicate internal stress which is similar to those existing in the actual structure regardless of material.

Duret et al.²⁰ introduced a nonmetallic carbon-fiber-reinforced material for the fabrication of posts, and the post was marketed as the Composipost system (RTD, Meylan, France). By exerting uniform tension on the filaments, the carbon fibers impart high strength to the post. A retrospective clinical study by Fredriksson et al.²¹ evaluated the treatment outcome of the Composipost system after 2–3 years in service. They reported that no dislodgement or root or post fractures were observed clinically or on radiographs. Mannocci et al.²² in a clinical study, evaluated 2 experimental groups of endodontically treated premolars in which 109 teeth were restored with silver amalgam and 110 with fiber-reinforced posts and composite resin cores. They reported that no statistically significant difference was found between the proportions of clinically failed teeth in the 2 groups. Grandini et al.²³ presented a 2-year preliminary clinical report on the use of fiber-reinforced posts and direct composite resin cores for restoring endodontically treated teeth. They concluded that in a...
short-term period, direct composite resin restorations represent a viable treatment option. Cagidiaco et al.26 evaluated the 2-year outcome of fiber-reinforced resin posts and composite resin core restorations. A total of 162 teeth were restored. After 23 to 25 months, all patients were evaluated. They concluded that fiber-post retained cores had a satisfactory 2-year clinical outcome.

A retrospective study by Segerstrom et al.25 evaluated the long-term treatment outcomes of the Composipost system. They reported a 35% failure rate for teeth restored with the Composipost system after a mean follow-up time of 6.7 yrs. This failure rate is substantially higher than rates that the literature has reported with metal post systems. Also, 9 teeth failed as a result of dental caries, and these failures were not included when calculating the failure rate.

In a clinical situation, a complete-coverage crown is recommended for endodontically treated teeth26,27. A recent systematic review by Cagidiaco et al.26 aimed to find answers to relevant questions regarding the clinical outcome of endodontically treated teeth restored by fiber-reinforced posts. They reported that 2 randomized controlled trials26,28 indicated a superior performance of fiber posts in the restoration of endodontically treated teeth. The most common type of post failure was post debonding, while root fracture was a rare event for endodontically treated teeth restored with fiber-reinforced posts. Thus, it is of special interest to investigate stress developed by a combination of different post-and-core materials covered by a complete crown. The purpose of this study to observe the relative magnitude of stress and stress distribution induced by 2 different post materials in combination with 2 different core materials by using the photoelastic method.

MATERIALS AND METHODS

The photoelastic material (1454; Measurements Group, Raleigh, NC) was cut into 40 blocks, size 40×20×3.125 mm. Then each block was polished with a buffing wheel (Buffs, Muslin; IDE Interstate Inc., Amityville, NY) and a polishing compound (Luster Shine; National Keystone Products, Cherry Hill, NJ). This photoelastic material has been reported to possess a modulus of elasticity (3.3 GPa) close to that of the fiber-reinforced post, the composite resin core material and human dentin31–35.

The post systems used in this study were ParaPostXT #5 (Coltene Whaledent, New York, NY) and ParaPost-Fiberwhite #5 (Coltene Whaledent, New York, NY). The core materials used in this study were silver amalgam (Dispersalloy, regular set; Dentsply Caulk, Milford, DE) and composite resin (LuxaCore; DMG, Hamburg, Germany). Each post was combined with each core material and each core was covered with a complete crown. There were 4 experimental groups in this study. ParaPostXT post with silver amalgam (PP+Am), ParaPostXT post with LuxaCore (PP+Co), ParaPost-Fiberwhite post with silver amalgam (Fiber+Am), and ParaPost-Fiberwhite post with LuxaCore (Fiber+Co) represented the experimental groups. Ten specimens were used in each experimental group.

The post space was prepared to 8.0 mm in length on each photoelastic block according to the manufacturer’s instruction with the use of the matching drill provided by the manufacturer. Each post was cemented with resin cement (RelyX Unicem; 3M ESPE, St. Paul, MN). The cement was mixed in the Aplicap capsule and dispensed in the post channel by using the elongation tip that was provided by the manufacturer to ensure void-free cementation of the posts. Excess cement was removed, and then polymerized with a halogen light at 600 mW/cm² (Demetron LC; Kerr Corp, Orange, CA) for 5 seconds on both surfaces of the photoelastic block. The tip of the light was positioned 1 mm from the specimen. Polarized light was used to identify residual stress on each photoelastic block.

To standardize the dimensions of the cores, an aluminum plate, 9.5×0.4×1.43 cm, was prepared to provide molds for fabricating the cores. Cores were adapted onto the posts with a diameter of 3 mm and a height of 3 mm. Silver amalgam was placed and condensed in the mold and allowed to set for 24 hours. The composite resin core material was mixed in the cartridge and dispensed by the tip provided by the manufacturer. The composite resin core was condensed and polymerized with the same halogen light at 600 mW/cm² (Demetron LC) for 40 seconds with the tip of light positioned 1 mm from the specimen.

Wax patterns for complete crowns were made on each core. A silver-palladium cast alloy crown (Pallig M; Degudent, DegussaAG Germany) was fabricated by using the lost wax technique and a phosphate bonded investment (Hi-Temp; Whip-Mix Corp., Louisville, Ky.). All casting rings were burned out at 843°C with a 1-hour heat soak time. The alloy was melted with a gas-air torch (Bego, Bremen, Germany), and a broken-arm centrifugal casting machine (Kerr/Sybron, Romulus, MI) was used to cast the crowns. Castings were recovered from the investment that had bench-cooled to room temperature. The castings were then airborne-particle-abraded (Topstar 2; Bego, Bremen, Germany) with 50-µm aluminum oxide at 2 bar (29 psi). All waxing to casting procedures were accomplished by the same investigator.

Each crown was cemented on its core with zinc phosphate cement (Flecks; Mizzy Inc., Cherry Hill, NJ). First, 0.8 g of powder and 12 drops of liquid were placed on the slab. The cement was then mixed incrementally with a total mixing time of 2 minutes. The cement was placed into the casting and the casting was seated on the core with finger pressure. The castings were then positioned under 500 g pressures at the post’s long axis. The cement was allowed to set for 10 minutes. Then excess cement was removed.

A universal testing machine (Instron model-5580; Norwood, MA) was used to apply vertical and angled loads on the crown of each post system. A load cell of 100 kg was used in this study. A puncture probe (Magness Taylor Puncture Probe diameter of 5/16 inch, model 2830-005; Instron) with a rounded-end head was
Fig. 1  Diagram showed vertical loading test.  

Fig. 2  Diagram showed 30 degree angled loading test. 

Fig. 3  Sample of vertical loading on photoelastic model. Yellow=0.25, yellow-red=0.5, yellow-red-blue=1.0  
Fringe values 3a=3  3b=3  3c=1.5  3d=1  
PP.=ParaPost XT; Fiber=ParaPost-FiberWhite; Am.=Amalgam core; Co.=LuxaCore  
(a)  PP+Am: high stress was observed at the coronal part of the post, lower stress was observed along the post.  
(b)  PP+Co: moderate stress was observed at the coronal part of the post, lower stress level distributed along the post to the apical end.  
(c)  Fiber+Am: moderate stress was observed at the coronal part and middle part of the fiber-reinforced post but not to the apical.  
(d)  Fiber+Co: less stress was observed than other groups.
connected with the probe chuck assembly (model 2830-006; Instron). For the vertical load procedure, the puncture probe was pressed vertically onto the crown at a cross-head speed of 0.5 mm/min (Fig. 1). Photographs were recorded when the load reached 60 N. For the angled load testing, each photoelastic block was inclined 30 degrees. The puncture probe was pressed against the crown with a cross-head speed of 0.5 mm/min, with the load set at 35 N (Fig. 2). Photographs were made for each post-and-core system (Figs. 3, 4). The observation of stress distribution is demonstrated by the formation of fringe orders along the post. The fringe orders on each specimen were counted for statistical analysis. The data were tested with Kolmogorov-Smirnov statistics for normal distribution. Then Levene’s test was used to evaluate the homogeneity among groups and to ensure the variances was not different. One-way ANOVA was then used to analyze the data at \( p = 0.05 \), and Scheffe test were used to compare the differences in stress generated by each post-and-core system. All statistical analysis was performed by SPSS 11.5 for windows (SPSS Inc, Chicago, IL, USA).

**RESULTS**

Results were analyzed by counting the fringe orders developed on each specimen with loading vertically and at a 30-degree angle (Table 1). Figures 3 and 4 display examples of the fringe patterns for each group under vertical load and 30-degree angle load, respectively. At 60-N vertical loads, the Fiber+Co was the least stress generated followed by Fiber+Am and PP+Am. The PP+Co were the highest. However, there was no significant difference in stress developed between the 4 groups (ANOVA, \( p = 0.159 \)) (Table 2). At a 30-degree angle and 35-N load, there were significant differences among the 4 groups (ANOVA, \( p = 0.000 \)) (Table 3). The Fiber+Co was the least stress generated followed by Fiber+Am and PP+Co. The PP+Am were the highest. The comparison groups that showed a significant
difference in stress generated were: (1) the Fiber+Co group compared with group PP+Am (Scheffe Test, \( p = 0.000 \)), (2) the Fiber+Co group compared with the PP+Co group (Scheffe Test, \( p < 0.001 \)), and (3) the Fiber+Am group compared with group PP+Am (Scheffe Test, \( p = 0.011 \)).

**DISCUSSION**

Previous studies\(^5,8,18,19\) have reported that stress was generated when loads were placed directly on the posts or on the cores. Clinically, the loads are applied to the crown. In this study, the prefabricated posts-and-cores were covered with complete metal crowns. Then they were subjected to vertical and angled loads. In this study, the attached load values are differences. At 60 N vertical loads, the stress was demonstrated clearly from the post specimen and distributed in the photoelastic block. At 30 degree angle, 60 N loads produced fringe patterns throughout the photoelastic block, and were difficult to interpret. Therefore, the angle load was justified to 35 N which demonstrated fringe patterns from the specimen clearly and can be photographed.

In some situations it is better for the photoelastic model to resemble the shape of an actual tooth\(^{37}\). However, in this experiment, the modulus of elasticity of the photoelastic sheet is similar to that of human dentin, and fringe values developed from the stresses were well demonstrated around the post, which was the primary objective of the study. With the preformed photoelastic sheet it was easier to control residual stress when compared with a cast photoelastic model, which would have been required to develop tooth-shaped specimens.

The photoelastic method has been used to measure stresses around posts\(^5,6,19\). This method has the advantage of applying a given stress state to an actual model and using the fringe value of the material to evaluate the stress distribution within the model. Virtual models have also been developed with finite element analysis (FEA) to measure stresses induced by posts\(^{37}\). FEA has proven valuable in health sciences research. Nevertheless, the use of FEA requires an estimation of the modulus of elasticity and Poisson’s ratio of living tissues, and the results can only be a good as the accuracy of these estimated properties of the tissues involved.

When the specimens were under vertical compressive load at 60 N, there were no significant differences among the 4 groups. The vertical load applied in this study was meant to simulate posterior teeth that are subjected to loads parallel to the long axis of the root. The photoelastic results indicated that stresses were concentrated at the coronal part of the PP higher than the Fiber (Figs. 3a and 3b). The observed stress distributed along the middle part to the apical part of the Fiber (Figs. 3c and 3d). The Fiber + Co demonstrated the least stress generated under 60 N, vertical load. However, there were no significant differences among the 4 groups. This can be explained that post-and-core with complete coverage crown when subjected to vertical load, forces
were transmitted to the core and along the post then to the photoelastic medium through the cement layer. Zinc phosphate cement was chosen to cement the crowns because it is dental cement with a long history of success that is commonly used by many dentists, including the authors. It is inexpensive and easy to manipulate. Clean up of excess cement is uncomplicated. The cement has good working time; nevertheless it reaches approximately 75% of its maximal compressive strength within 1 hour after setting\textsuperscript{[20]}. The cement serves to buffer the force to allow better stress distribution. The designs of both systems are passive fit with grooves to allow venting of hydraulic pressure from the cement. These grooves appeared to have contributed to the distribution of stresses along the post. The core materials seemed to have little effect on stress generated under vertical load. The results are in agreement with those reported by Christian et al.\textsuperscript{[13]}. When specimens were loaded at a 30-degree angle, there were significant differences among the groups. The Fiber+Co group displayed the least stress generation. When considering only the post materials at a 30-degree angled load, the fiber-reinforced post appeared to absorb stress better than the stainless steel post. The fiber-reinforced post has a lower modulus of elasticity when compared with the metal post, and it appears that this post can flex and absorb stress better than the metal post evaluated under an angle load. When considering the core materials, forces were transmitted from the crowns to the cores, then along the posts. The LuxaCore composite resin which has a lower modulus of elasticity (8.8 GPa) compared with silver amalgam (26 GPa), may absorb stress and reduce dentinal stress along the post\textsuperscript{[30]}. When the specimens were loaded, the entire specimen (post and photoelastic material) appeared to flex in unison.

These findings may be clinically relevant. When teeth are restored with a prefabricated post system, the stress-producing characteristics of the post must be considered. Core materials can reduce or exacerbate stress concentration around post. When the crown of an endodontically treated tooth has lost a large portion of its tooth structure, a function of the post is to provide retention for the core material, substituting the lost coronal dentin. Fredriksson et al.\textsuperscript{[21]} reported favorable outcomes of the Composipost system after 2 to 3 years. However, different results were reported in a long-term clinical study by Segerstrom et al.\textsuperscript{[25]} The authors reported that the success rate of teeth restored with the Composipost system was 65% after a mean follow-up time of 6.7 years (35 teeth failed). In the study by Segerstrom et al.\textsuperscript{[25]} 32 teeth were extracted (14 because of fracture) and 3 posts were dislodged. In addition to the reported 35 failures, 9 teeth experienced recurrent dental caries; however, the authors did not include these carious teeth in the failure calculations.

There are a number of factors that can influence the clinical success of restored pulpal teeth, and stress distribution is only 1 of them. Other factors include the presence of an adequate ferrule, the role that the tooth will play after restoration (single crown, abutment to fixed partial denture, abutment to removable partial denture), the location of the tooth in the dental arch and the number of proximal contacts\textsuperscript{[20]}. It appears that teeth restored with fiber-reinforced posts are more commonly associated clinically with recurrent dental caries\textsuperscript{[22,29]}.

These clinical findings suggest that a relatively flexible post could be damaging, especially when there is limited remaining tooth structure and the ferrule is minimal or is absent. Under occlusal loads, the post can flex as it exits the post preparation, allowing micromovement of the core. The cement seal at the margin of the overlying crown could eventually fail, resulting in marginal leakage and recurrent dental caries\textsuperscript{[29]}. Also, composite resin cores have been associated with microleakage because of problems with dimensional instability\textsuperscript{[15]}. Perhaps the presence of a relatively flexible post exacerbates this problem of dimensional instability.

The study by Segerstrom et al.\textsuperscript{[25]} also reported a tooth fracture rate of 32%, an inordinately high percentage of fractures when compared with clinical studies of metal posts\textsuperscript{[16,17]}. If stress distribution were improved with these relatively flexible posts, it could be assumed that the rate of fracture would be less than that reported for rigid posts. Perhaps these fiber-reinforced posts flexed within the post channel as a result of an inadequate ferrule effect, placing tensile stresses on the radicular dentin that eventually produced fracture. Although the present study suggested improved stress distribution with fiber-reinforced posts, and the study by Mannocci et al.\textsuperscript{[22]} reported less root fractures with these posts, caution is suggested when prescribing these posts. Perhaps when the ferrule exceeds minimal recommendations these posts can reduce the potential for fracture, but the reverse effect would likely to be seen when the ferrule is limited or absent.

A limitation of this study is the relatively light applied loads. However, this was used as a way to demonstrate the influence of fiber-reinforced post over a photoelastic model. Further research is suggested, such as studies of load until failure and dynamic loading of fiber-reinforced posts \textit{in vitro}, combined with thermocycling, as well as further long-term follow-up survival studies of teeth restored with fiber-reinforced posts \textit{in vivo}.

CONCLUSION

The purpose of this study was to investigate stress developed by a combination of a stainless steel post or a fiber-reinforced resin post with a silver amalgam core or a composite resin core. Two-dimensional photoelastic models were used to simulate root dentin. Within the limitations of this study, the following conclusions were drawn:

1. Under vertical loading, there were no significant differences among post-and-core materials.
2. Under 30-degree angled loading, there were significant differences among post- and-core materials.
3. The fiber-reinforced post combined with composite resin core produced the least stress when subjected to 30-degree angled loading.

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