The effect of post type and length on the fracture resistance of endodontically treated teeth

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Statement of problem. Few studies have been conducted to determine a correlation between the flexural modulus of metal and fiber-reinforced posts and the fracture resistance and failure mode of teeth restored with posts. Questions remain as to whether a longer post length or a post with a higher flexural modulus will significantly improve the fracture resistance of a tooth restored with a prefabricated post and core.

Purpose. The purpose of this study was to compare the fracture resistance and mode of failure of endodontically treated teeth restored with 3 different post systems, including 2 fiber-reinforced posts (Light-Post and Snowlight) and a stainless steel post (ParaPost XP).

Material and methods. Seventy single-rooted premolars were sectioned at the cemento-enamel junction and then endodontically treated. Teeth were distributed into 7 groups. Three different prefabricated posts were cemented into a post space either 5 or 10 mm in depth, and composite resin (ParaPost ParaCore automix) cores were fabricated. A composite resin core group without a post served as a negative control. Specimens were loaded at 90 degrees to the longitudinal axis until ultimate failure occurred. An initial failure load and mode of failure were also recorded. Statistical analysis was performed for initial and ultimate failure loads of groups by using 2-way ANOVA (P=.05).

Results. The groups with ParaPost XP posts demonstrated significantly higher initial and ultimate mean failure loads when compared with the fiber-reinforced post groups. The highest mean (SD) initial failure load was with the ParaPost XP group with a 10-mm post length (170.05 (60.08) N), and the lowest was with the Snowlight group with the 5-mm post length (62.85 (18.47) N).

Conclusions. The stiffness and the load to initial fracture of the teeth restored with ParaPost XP posts were higher compared with the fiber-reinforced post groups. (J Prosthet Dent 2009;101:174-182)

Clinical Implications

The results of this study suggest that a stainless steel post may provide better support for a composite resin core than a fiber-reinforced post when a 90-degree load is applied.

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Selection of a prefabricated post has largely been a decision between stainless steel and titanium, threaded and nonthreaded, and tapered and nontapered posts. The advent of more advanced composite resin and ceramic materials has led to the development of a wide variety of nonmetal posts, including fiber-reinforced posts. Some retrospective studies of fiber-reinforced posts have reported good clinical success for up to 6 years.[1-3] Another retrospective study, however, showed poor success rates after a mean of 6.7 years, with 35% of teeth failing and 32% resulting in extraction.[4] Regardless of the type of post, loosening of a post has been shown to be the most common type of failure for post-and-core restored teeth.[5] Use of resin cement with a bonding agent when placing a post may help to limit microleakage[6] and increase retention of prefabricated posts.[7-12] Nonetheless, the quality of bonding may diminish at greater apical post space depths,[13,14] and, therefore, an increased post length may not provide any increase in predictable bonding area. It has been shown that resin bonding can reinforce the remaining root structure to help counteract the effects of a flared canal or poorly adapted post.[15-17]

Some studies have suggested that a shorter post length may be used without loss of retention,[12,18,19] and that serrations on a post may increase retention.[20] However, when a fiber-reinforced post is used and a ferrule is absent or minimal, core debonding may be the primary mechanism of failure because of a lack of bending resistance of these posts.[21] In such a scenario, a shorter length of the fiber-reinforced post may not have as great a role in failure as the lower flexural modulus of the post.

Fiber-reinforced posts can be separated into 3 primary groups: carbon fiber, glass fiber, and quartz fiber. One study reported that a carbon fiber-reinforced post had flexural modulus values comparable to a stainless steel post.[22] Other studies have shown glass fiber-reinforced posts to possess lower strength values when compared with other types of fiber-reinforced posts,[23] and certain carbon fiber-reinforced posts to be less stiff than stainless steel posts.[24,25] It has been demonstrated in vitro that the reduced stiffness of certain fiber-reinforced posts can be beneficial for preventing catastrophic root fracture.[26-30] However, it is not clear whether fiber-reinforced posts can actually provide adequate support for a core. Flexure of a fiber-reinforced post may result in greater stress on the composite resin core, causing premature failure of the core restoration.[26,28,30-32] This problem is of particular importance clinically in instances where little or no coronal tooth structure remains.[21] Finite element analysis has indicated that blunt traumatic or transverse loading may concentrate stresses at the cervical aspects of a tooth[32-34] and place more load on the post.

The purpose of this study was to compare the fracture resistance and mode of failure of endodontically treated teeth restored with composite resin cores only (negative control) and 3 different post systems of 2 lengths, including 2 light-transmitting fiber-reinforced posts and a stainless steel post (positive control). The null hypothesis was that there would be no statistically significant difference in the failure load of the restorations between the different post systems and different post lengths.

MATERIAL AND METHODS

Five posts each of either stainless steel (positive control) (ParaPost XP, #42024; Coltène/Whaledent, Inc, Cuyahoga Falls, Ohio), quartz fiber reinforced (Light-Post, #0200005207; Bisco, Inc, Schaumburg, Ill), or glass fiber reinforced (Snowlight, #LB051; Abrasive Technology, Inc, Lewis Center, Ohio) were tested for flexural modulus in a universal testing machine (Instron Model 5565; Instron Corp, Norwood, Mass). The specimens were loaded in a 3-point bending test with a 12-mm fixed width at a crosshead speed of 0.5 mm/min. The diameter of each post was recorded and the flexural modulus was calculated. A group with core reconstructions and no posts served as a negative control. Significant differences between the posts were determined by using 2-way ANOVA.

A total of 70 recently extracted single-rooted human premolars with similar dimensions were selected. The selected teeth had a minimal root length of 13 mm from the root apex to the buccal cemento-enamel junction (CEJ). The teeth were examined under a microscope (Nikon SMZ1500; Nikon Instruments, Inc, Melville, NY) to exclude any teeth with carious lesions, cracks, previous endodontic treatment, or a restoration closer than 2 mm coronal to the CEJ. Teeth were then arbitrarily assigned to 7 groups with 10 teeth per group.

The teeth were sectioned at the buccal CEJ and stored in a 0.2% sodium azide solution (Laboratory Grade Sodium Azide; Fisher Scientific, Fair Lawn, NJ). Each tooth was endodontically treated by using a conventional step-back technique.[35,36] Canals were cleaned and shaped by using rotary instrumentation to an ISO file size of 35 (K-Reamer; Dentsply Intl, York, Pa). Condensation with gutta-percha (Maillefer Gutta Percha Points; Dentsply Maillefer, Ballaigues, Switzerland) and noneugenol sealer (AH Plus, #9905000956; Dentsply Intl) was completed to 1 mm from the tooth apices by using a lateral condensation technique. Post spaces were prepared to either 5 or 10 mm in length and 1.4 mm in diameter from the coronal extent of each tooth. All post spaces were initiated using #2, 3, and 4 slow-speed rotary instruments (Gates Glidden Drills; Dentsply Intl), followed by 1.0-mm, 1.14-mm, and 1.25-mm ParaPost XP drills. The 1.4-mm-diameter post drills provided by the manufacturer for each post system were used to create the final post spaces. During the post space preparation, specimens were surveyed to align the space at a 90-degree angle to the coronal tooth floor. Next, a 0.1- to 0.2-mm-thick silicone film (Plasti Dip; Plasti Dip Intl, Blaine, Minn) was coated on the root to within 1 mm of the coronal floor to simulate a periodontal ligament space. These periodontal ligament spaces were not standardized, but the thicknesses of the coatings were measured with a mechanical depth gauge (Absolute Digimatic Depth Gage; Mitutoyo America Corp, Aurora, Ill).

The root extensions of the posts were 5 or 10 mm with a coronal extension fixed at 3 mm. The variables and group name designations are shown in Table I. The posts were sectioned to the corresponding length required (8 mm or 13 mm, total), and tapered or noncylindrical ends were removed so that only parallel-sided cylindrical posts remained. The ParaPost XP posts had the flat coronal head removed, while the Light-Post and Snowlight posts had the tapered apical portions removed. To standardize specimens, core formers were custom made for each individual tooth as follows. A ParaPost XP post (1.4 mm in diameter) was placed into each post space for alignment purposes. A prefabricated, machined, resin (Delrin; DuPont Engineering Polymers, Wilmington, Del) cylindrical sleeve with a 3.4-mm outer and 1.4-mm inner diameter and an 8-mm height was placed around the post, flush with the tooth. A translucent vinyl polysiloxane material (Star VPS ClearBite; Danville Materials, San Ramon, Calif) was injected around the Delrin sleeve and undercut root structure to create a custom core former (Fig. 1). The Delrin sleeve and post were removed, leaving the clear vinyl polysiloxane core former. The core former was removed from the tooth and the orientation was marked as related to the tooth.

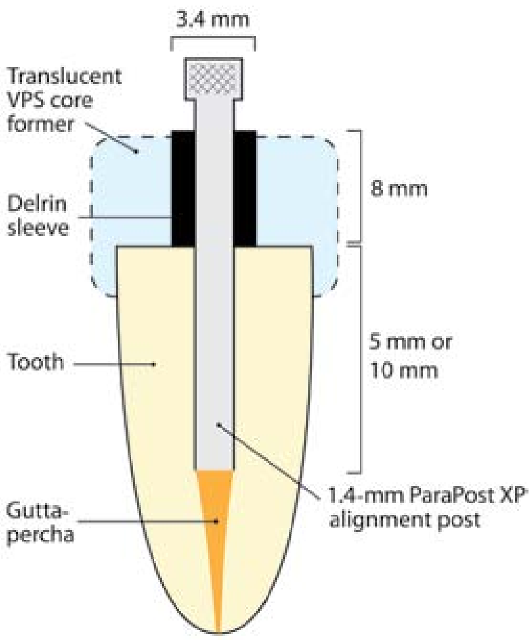
The tooth surface and post space were etched for 15 seconds with 37% phosphoric acid (UNI-ETCH; Bisco, Inc), rinsed, and left moist. A dual-polymerizing bonding agent (ParaPost Adhesive Conditioner A and ParaPost Adhesive Conditioner B; Coltène/Whaledent, Inc) was then applied to the surface of the post and light polymerized for 20 seconds by using a quartz-tungsten-halogen light (Optilux 501; Kerr Corp, Orange, Calif). The polymerization tip was held 1 cm away from the post surface. Bonding agent was also applied to the tooth's surface and post space and allowed to polymerize without light polymerization for 30 seconds. Excess bonding agent was absorbed with paper points. Next, a dual-polymerizing composite resin core material (ParaPost ParaCore automix, #LE726; Coltène/Whaledent, Inc) was injected into the post space and a Lentulo spiral (Lentulo spiral filler; Dentsply Intl) was used to spread the material. The post was slowly seated and held for 5 seconds. The translucent custom core former was then reseated around the tooth and the dual-polymerizing composite resin core material was injected into the core space surrounding the post to a height of approximately 6 mm. The core was then light polymerized directly at the core former surface for 40 seconds from the occlusal surface and for 20 seconds from the buccal and lingual surfaces. The cores were finished to a height of 4 mm from the coronal tooth floor by using a fine diamond rotary cutting instrument (#8837 Fine Diamond Instrument; Brasseler USA, Savannah, Ga) and a high-speed handpiece with water coolant (Ti-Max NL-95S; Brasseler USA) (Fig. 2).

The negative control group (no post) had post spaces prepared to a 5-mm depth using the ParaPost XP post drill. Custom core formers were fabricated as previously described. As an alternative to a post cemented within the root, a vinyl polysiloxane impression material (Extrude, Light body regular set; Kerr Corp) was used to fill the post spaces. This core-only group of specimens received composite resin cores by using the translucent core formers as previously described, but did not have posts cemented, allowing the effect of bonding a composite resin core directly to tooth, without a post for support.

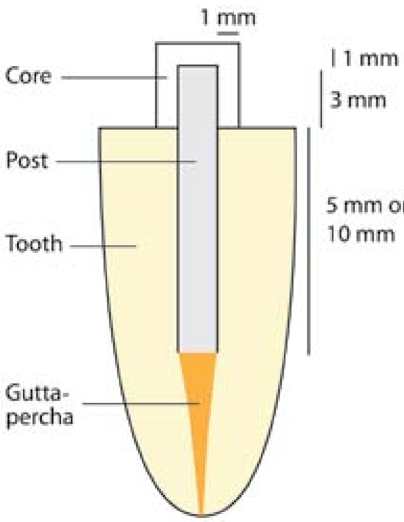
All specimens were then secured

Table I. Experimental design for testing

Group (n=10)	Post Type	Post Diameter	Post Length (in Root)	Root/Crown Post Ratio
PP10	ParaPost XP (stainless steel)	1.4 mm	10 mm	3.33
LP10	Light-Post (quartz fiber reinforced)	1.4 mm	10 mm	3.33
SL10	Snowlight (glass fiber reinforced)	1.4 mm	10 mm	3.33
PP5	ParaPost XP (stainless steel)	1.4 mm	5 mm	1.67
LP5	Light-Post (quartz fiber reinforced)	1.4 mm	5 mm	1.67
SL5	Snowlight (glass fiber reinforced)	1.4 mm	5 mm	1.67
Core	Control (composite resin core only)	NA	NA	NA



1 Schematic diagram of translucent VPS core former surrounding Delrin sleeve and alignment post.



2 Schematic diagram of post-and-core specimens.

within a 1.25-inch PVC pipe ring (PVC White Pressure Fitting; Lasco Fittings, Inc, Brownsville, Tenn) by using ISO Type 4 die stone (Silky-Rock Die Stone; Whip Mix Corp, Louisville, Ky) at a distance of 1 mm from the buccal CEJ. Specimens were aligned with a dental surveyor (Ney Surveyor; Dentsply Ceramco, York, Pa) to ensure that the long axis of the specimen was parallel to the axial surface of the mounting ring. The specimens were then stored in 100% humidity at 37°C for 24 hours prior to mechanical testing.

Following storage, the specimens were positioned in a mounting device so that the longitudinal axis was perpendicular to the load direction. The teeth were then loaded from the buccal surface of the core at 90 degrees to the long axis and 3 mm from the tooth-core interface. A universal testing machine (Instron Model 5565; Instron Corp) with a 1-mm-diameter rounded loading plunger was used to load the specimens at a crosshead speed of 0.5 mm/min. The specimens were loaded until catastrophic failure occurred, and the ultimate failure load was recorded. In addition, the mode of failure was recorded as root fracture, core fracture, post fracture, or any interface debonding. Catastrophic failure was designated as the point at which specimens were no longer intact. Subcatastrophic failure occurring prior to the ultimate failure load was also recorded as the initial failure load during the load sequence. Teeth were then radiographed by using radiographic film (Kodak Insight F-speed film; Eastman Kodak Co, Rochester, NY) to determine if post pullout or post-core debonding had occurred. Post pullout was evident as separation of the post from the endodontic filling at the apical extent of the post space. Post-core debonding was radiographically evident as separation of the post from the core material at the occlusal extent. Finally, a light microscope (Nikon SMZ1500; Nikon Instruments, Inc) at ×20 magnification was used to make photographs of specimens and verify the mode of failure.

Average initial failure load and ultimate failure load were calculated for each group. To calculate the maximal bending stress for the post-and-core configuration, the following equation was used: $\sigma_{max} = M \times y/I$, where M = the applied bending moment acting on a cross-section, y = the distance from the point of loading to the tooth interface of the post and core, and I = the moment of inertia about the longitudinal axis. In the case of the cylindrical post and core, $I = \pi r^4/4$. For the purposes of the experimental design, r = 0.0017 m, where M = (Load applied) (0.0017 m), and y = 0.003 m, simplifying the above equation to: σ_{max} = 777,471.7 x load (in newtons).

Once compiled, the data were analyzed with a statistical software program (SAS V8.2; SAS Institute, Inc, Cary, NC) by using a 2-way ANOVA to evaluate the effects of post type and post length and the interaction of the variables. A post hoc comparison of individual post types was conducted using 2-way ANOVA with a Tukey HSD adjustment. Individual pairwise comparisons using 2-way ANOVA with Bonferroni adjustment were also conducted between different post type and length groups to elucidate specific significant differences. A 1-way ANOVA using a post hoc *t* test with a Bonferroni adjustment was also used to compare the composite resin core control group to all the post groups. The Bonferroni adjusted *P* values were determined by using the original *P* value and dividing by the number of comparisons.

RESULTS

Table II lists the average diameter and flexural modulus of the prefabricated posts. A 1-way ANOVA with Tukey HSD adjustment detected significant differences in diameter and flexural modulus ($P<.001$), demonstrating the ParaPost XP diameter was significantly lower than the fiber-reinforced posts and had a significantly higher flexural modulus. The 2 fiber-reinforced posts had diameters and flexural moduli that were not significantly different from one another.

During mechanical loading of the specimens, it was determined that an initial failure of the post and core was occurring, by visual observation of separation of the core at the tooth interface. Upon review of the loading data, the initial failure load was designated as the first drop in the load values. At initial and ultimate (catastrophic) failure loads, group means and standard deviations were determined. In addition, the mean maximal failure bending stress was calculated for each group. Table III displays the data. Analysis of the data demonstrated normal distributions.

The effect of post type, post length, and the interaction of the 2 variables on the initial and ultimate failure loads were evaluated by using 2-way ANOVA. For initial failure loads, it was found that both the post type ($P<.001$) and post length ($P<.001$) were significant, while the interaction of the variables was not ($P=.096$). The 10-mm post length specimens had significantly higher mean initial failure loads compared with the 5-mm post length specimens. For ultimate failure loads, it was found that the type of post placed ($P<.001$) was significant, but post length within the root ($P=.514$) was not. There also was not a significant interaction between post type and length ($P=.574$).

Further 2-way ANOVA using a Tukey HSD adjustment revealed that, when grouping the 5-mm and 10-mm specimens together, the ParaPost XP groups had significantly higher initial failure loads and ultimate failure loads when compared with both the Light-Post groups ($P=.004$, $P<.001$) and the Snowlight groups ($P<.001$, $P<.001$). No significant differences in initial or ultimate failure load were found between the Light-Post and Snowlight groups ($P=.129$, $P=.682$).

Post hoc pairwise comparisons of the initial and ultimate failure loads for individual groups using 2-way ANOVA with a Bonferroni adjustment are shown in Table IV. A comparison of groups with different post types with the same post length (5 mm or 10 mm) was first conducted. Next, a comparison of the initial and

TABLE II. Mean diameter and flexural modulus for different post types

Post Type (n=5)	Mean Diameter (SD) (mm)	Post Diameter Significance ($P<.001$)*	Mean Flexural Modulus (SD) (GPa)	Flexural Modulus Significance ($P<.001$)*
ParaPost XP	1.30 (0.02)	A	132.1 (13.3)	A
Light-Post	1.38 (0.02)	B	39.1 (1.1)	B
Snowlight	1.39 (0.02)	B	38.2 (1.7)	B

*Same letters indicate no significant difference at $P<.001$ using Tukey HSD.

TABLE III. Initial and ultimate failure load and maximum bending stress

Group (n=10)	Mean Initial Failure Load (SD) (N)	Mean Maximum Initial Failure Bending Stress (SD) (MPa)	Mean Ultimate Failure Load (SD) (N)	Mean Maximum Ultimate Failure Bending Stress (SD) (MPa)
PP10	170.05 (60.08)	132.21 (46.71)	200.04 (47.34)	155.52 (36.81)
LP10	123.29 (46.64)	95.85 (36.26)	170.34 (30.67)	132.43 (23.85)
SL10	70.43 (32.26)	54.76 (25.08)	153.59 (16.60)	119.41 (12.90)
PP5	111.08 (49.84)	86.36 (38.75)	206.94 (25.00)	160.89 (19.44)
LP5	64.25 (33.83)	49.95 (26.30	164.79 (16.48)	128.12 (12.81)
SL5	62.85 (18.47)	48.86 (14.36)	166.67 (21.65)	129.58 (16.83)
Core	40.24 (9.52)	31.28 (7.40)	40.24 (9.52)	31.28 (7.40)

Table IV. Pairwise comparisons of initial failure load and ultimate failure load using 2-way ANOVA with Bonferroni adjustment

Group Comparison	Initial Failure Load *P*	Ultimate Failure Load *P*
PP5 vs. LP5	.050	.005
PP5 vs. SL5	.042	.007
LP5 vs. SL5	1.00	1.00
PP10 vs. LP10	.051	.069
PP10 vs. SL10	<.001	.002
LP10 vs. SL10	.022	.576
PP10 vs. PP5	.003	.588
LP10 vs. LP5	.003	.663
SL10 vs. SL5	.691	.307

Table V. Mode of ultimate failure for test groups

Group (n=10)	Microscopic	Visual Observation	Radiographic	Root Fractures
PP10	1/10 total core debonding	9/10 core fracture	6/10 post bending	2/10
LP10	7/10 total core debonding	8/10 core fracture	4/10 post bending 4/10 core/post debond	0/10
SL10	8/10 total core debonding	9/10 core fracture	2/10 post bending 1/10 core/post debond	0/10
PP5	8/10 total core debonding	6/10 core fracture	9/10 post bending	3/10
LP5	10/10 total core debonding	10/10 core fracture	no post bending	0/10
SL5	10/10 total core debonding	1/10 core fracture	9/10 post bending and post pullout	0/10
Core	10/10 total core debonding	N/A	N/A	0/10

ultimate failure loads at different post lengths was conducted for each post type group. At 5-mm post lengths, the ParaPost XP group showed significantly higher initial and ultimate failure loads compared to the Snowlight group (P=.042, P=.007) and was significantly higher at ultimate failure load compared to the Light-Post group (P=.005). There were no significant differences between the Light-Post and Snowlight groups. At 10-mm post lengths, the ParaPost XP group was again significantly higher than the Snowlight group for both initial and ultimate failure loads (P<.001, P=.002). Additionally, the Light-Post group showed significantly higher initial failure loads compared to the Snowlight group (P=.022). Comparing the ParaPost XP groups with 5-mm and 10-mm post lengths, the 10-mm group showed significantly greater loads at initial failure (P=.003), but not ultimate failure. Likewise, the Light-Post specimens showed significantly greater initial failure loads at 10-mm post lengths compared to 5-mm post lengths, but no significant difference at ultimate failure load. The Snowlight groups at different lengths showed no significant difference for either initial or ultimate failure load.

A post hoc *t* test with Bonferroni adjustment comparing the control group (Core) to all the other groups revealed that the PP5, PP10, and LP10 groups had significantly higher initial failure loads. All other groups were not significantly different. For ultimate failure load, all experimental groups demonstrated a significantly greater load compared to the control.

The mode of ultimate failure for each test group is displayed in Table V. Identified in the table is a microscopic analysis of the tooth-core interface, the visual observation of ultimate failure, and a radiographic analysis of the specimens. The microscopic analysis indicated the number of tooth-core debonds for each group in which the core was completely debonded from the tooth during loading. The radiographic analysis also indicated whether post bending occurred during loading and if any core-post debonding or post pullout occurred.

DISCUSSION

The data support rejection of the null hypothesis that there is no statistically significant difference in the fracture strength between the different post systems and different post lengths. For initial failure loads, post type and length down the root proved to be significant variables. At ultimate failure load, only post type was significant, but length was not. For both initial and ultimate failure loads, there was no statistically significant interaction between post type and length, indicating that they did not influence one another. Loads at initial failure and at ultimate failure were significantly higher for the ParaPost XP specimens compared with the Light-Post and Snowlight specimens when combining 5-mm and 10-mm specimen data. When combining all post types together and comparing all 10-mm specimens to 5-mm specimens, there were significantly higher loads at initial failure for 10-mm specimens compared with the 5-mm specimens. However, at ultimate failure, there was no significant difference between the different lengths.

The selection of the 2 light-transmitting posts for this study was intended to compare glass and quartz fiber-reinforced posts from 2 manufacturers to each other and to a standard stainless steel post (positive control). Results demonstrated only a significant difference at initial failure load between the 2 fiber-reinforced posts at a 10-mm post length down the root. There was no difference noted between the 5-mm groups. As Table II demonstrates no significant difference between the flexural moduli of the Light-Post and Snowlight posts, it may only be speculated that perhaps there was a dissimilarity of the adhesive properties of the posts at deeper lengths down the canal, or other mechanical property disparities that accounted for this difference. This warrants further investigation.

Placement of a crown ferrule has been shown to be an important factor in increasing the fracture resistance and clinical prognosis of teeth with posts and cores. However, this study aimed to eliminate ferrules and crowns from the methodology, because these features could introduce many more variables that could complicate interpretation of the results of load testing. Instead, this study was designed to simulate a nonclinical situation in which neither a crown nor a ferrule was present and the load had to be borne primarily from the post-and-core system. In addition, a perpendicular angle of loading was used in this study because it has been shown to be the most traumatic to a post-and-core system, and a likely manner in which many systems fail.[33,34] Initial failure may occur with the debonding of the core and further failure with post loosening. Post debonding has been reported as the most common complication found clinically in post-and-core systems[5] and may have a significant role in the incidence of root fractures that occur clinically. Because of the successive failure of individual components within the post-and-core specimens, it was decided to load the specimens to catastrophic failure. Each loading curve was analyzed and the first decrease in load values was reported as the initial failure load.

This study loaded the specimens with a continuously increasing load. Cyclic loading may be more clinically relevant; however, it has been found to produce large standard deviations with more technique sensitivity.[21,37,38] Clinically, however, cyclic loading and multiple other variables that can cause deterioration of a post and core, with or without a crown, may magnify disparities between different post systems over many years. Such is the case with a retrospective study by Segerstrom et al,[4] who reported an alarming rate of failure of carbon-fiber-reinforced posts. With a mean follow-up time of 6.7 years (ranging from 1 month to 10 years), 32% of the teeth restored with a carbon-fiber post were extracted. Reasons for extraction included fractures (14%), periapical lesions (10%), and periodontitis (5%). The incidence of fractures appears high, especially for a post purported to have a flexural modulus similar to dentin to minimize the potential for fracture.

The loading parameters in this study were designed to be similar to a cantilever arrangement; thus, the post-and-core restoration was subjected to a bending stress with the maximum stress at the interface with the tooth. Once the bending stress surpasses the tensile bond strength between the core and the tooth, the core debonds from the tooth. However, the compressive bond strength of the core and tooth may not be reached until a greater load is applied. Therefore, the post-and-core system may remain intact, with only slight separation of the core at the tensile load interface (buccal portion of the core). This is the phenomenon that was observed with most specimens in which the buccal portion of the core debonded at initial failure. This was usually followed by lingual core debonding. Once fully debonded, core flexure, while the core was retained by the post, resulted in several other modes of failure, including core fracture, root fracture, post bending and pullout, and core-post debonding. The composite resin core control specimens had a lower mean initial and ultimate failure load than any test group. There was no evidence of post-cement debonding in any group, and only a loss of post retention was evident in the Snowlight 5-mm group.

As shown in the statistical analysis, the initial failure of specimens recorded significant differences with respect to the post type and post length. The 10-mm posts appear to have provided more support for the core. With a greater percentage of the post length secured within the root, it is likely that stress could be better distributed to the root upon loading, and bending of the coronal portion of the post could be reduced. When viewed in terms of stress distribution, a post with a higher flexural modulus and greater length appears to give more support to a core.[29,39] A post with a lower flexural modulus or a shorter length shifts more of the load to the core and tooth.[29,39] Once the core debonded, as was the situation with most groups, post bending or core fracture was the predominant outcome.

The ultimate failure values of specimens showed significant differences with respect only to post type. However, the clinical significance of these ultimate failure values could be questioned. In a clinical situation, once initial failure of a post-and-core restoration has occurred, the restoration can be expected to eventually fail as a result of cyclic loading. Thus, the ultimate failure load of the groups was given only for the purpose of comparison to other studies. Clinically, catastrophic failure with a metal post may present as root fracture or loss of post retention. Failure with a fiber-reinforced post may present as core or post debonding, resulting in microleakage, and subsequent core or crown failure.

When comparing the mode of failure (Table V), it should be noted that the microscopic and radiographic examination occurred following ultimate failure. Thus, the results may not be indicative of a clinical situation. Further studies to examine specimens following initial failure could help determine more specifically what part of each specimen fails first and, therefore, provide more clinical relevance. It is evident that only the ParaPost XP 10-mm group did not typically exhibit complete core debonding. While microscopically, the ParaPost XP 10-mm group displayed some evidence of buccal core debonding, there was only one specimen that displayed complete core debonding following ultimate failure. All other groups displayed buccal core debonding for every specimen. Root fracture of stainless steel specimens may be due to the bending stress placed on the root following initial failure. The fiber-reinforced posts did not appear to transfer the same degree of bending stress to the root. Instead, the stress appeared to be transferred to the core and the post cement. This observation would account for the post pullout and post bending within the fiber-reinforced groups. It is interesting to note that the Light-Post 5-mm group did not experience visible post bending or pullout. This result may be due in part to a stronger bond to the post cement that did not allow for post pullout and subsequent post bending until core fracture had occurred. The Snowlight 5-mm group clearly had a loss of post retention at ultimate failure. From the results, it appears that the Snowlight 5-mm post length may not be adequate to provide sufficient retention to a composite resin core.

Preventing microleakage within post-and-core restorations is of primary importance. Once the coronal seal is broken, the root canal is susceptible to bacterial penetration, and endodontic failure may occur. Therefore, separation of the core material from the coronal tooth structure is of clinical relevance because it will almost certainly cause microleakage. It was found that the post length had a statistically significant effect on the fracture resistance of post-and-core systems when resin cement was used. Thus, a shorter post may provide adequate retention for a core, but may not provide as much resistance to bending and may place more stress on the root dentin when loaded. Clinically, it could be argued that a longer post is preferable to a shorter post, but is of even greater importance when horizontal stresses on the coronal tooth are great.

Although the methodology chosen in this study cannot reproduce what would occur clinically, it does result in fewer variables and allows for a more specific evaluation of the performance of the post systems at different lengths. Thus, the findings of this study do warrant additional investigation. Further research into the effect of cyclic loading on similar specimens would provide more clinical relevance. Also, tests to identify microleakage at the core-tooth interface after such loading would help reveal whether debonding is occurring, where, and to what extent. Additionally, microscopic and radiographic examination of the core-tooth and post-tooth interfaces at initial failure could better determine what part of the post-and-core restoration is failing first. Finally, an investigation into the effect of varying post diameter would provide a different variable that may have a significant role in the success of different posts of different lengths.

CONCLUSIONS

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

1. The mean flexural modulus (stiffness) of the stainless steel ParaPost XP was significantly higher ($P<.001$) when compared with the mean of either the fiber-reinforced Light-Post or Snowlight post.

2. The stainless steel ParaPost XP groups had a significantly higher mean initial fracture load when compared with the Light-Post ($P=.004$)

and Snowlight (P<.001) groups.

3. The 10-mm post length groups had significantly higher (P<.001) mean initial fracture loads when compared with the 5-mm post length groups.

4. The mode of initial failure for all groups was core debonding from the tooth.

5. The mode of ultimate failure for groups varied. The stainless steel posts had an incidence of 25% root fractures, while no root fractures were observed with fiber-reinforced posts.

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