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Mechanical properties of roots combined with prefabricated fiber post

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This study examined the mechanical properties of roots combined with prefabricated fiber post. Three types of specimens were evaluated: (1) prefabricated fiber post alone (FP); (2) core composite resin with FP (CFP); and (3) root with CFP (RCFP). The volume fractions of the prefabricated fiber post in the core composite resin (FP/CFP ratio) were set to 0, 0.16, 0.22, 0.28, and 0.48. Bending test for FP and CFP, and diametral compression test for FP, CFP, and RCFP were carried out. The FP/CFP ratio showed no effect on the diametral tensile strength (DTS) of RCFP; and there were no significant differences in DTS with/without FP. The flexural strength of CFP increased with increase in FP/CFP ratio. The DTS of CFP declined in comparison with that of core composite resin only.

Keywords: Fiber post, Flexural strength, Diametral tensile strength

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INTRODUCTION

Fiber post is widely seen as a more functional alternative to prevent severe root fractures in endodontically treated roots[1]. Prefabricated fiber posts generally consist of fibers and a resin matrix[2]. In endodontic treatment, they require the additional use of post-and-core materials in restoration work[3,4]. Offering strong flexural strength and a modulus of elasticity close to that of dentin, they are well established as a functional post material[5-9]. Furthermore, endodontically treated teeth show a lower incidence of root fractures when the adhesive technique used to unify the root and the core composite resin includes a prefabricated fiber post rather than a metal post. It has been suggested that this is due to a more even stress distribution throughout the root, resulting in fewer root fractures[10]. This suggests that a prefabricated fiber post is preferred to a metal post in enhancing fracture resistance in endodontically treated teeth. The use of a post is to retain the core in endodontically treated teeth, and prefabricated fiber posts offer this capability when used in conjunction with post-and-core materials and an adhesive resin cement.

Several studies have investigated the mechanical properties of post-and-core components, including the flexural strength of the prefabricated fiber post[11-14], the influence of the ratio of glass fibers to the resin matrix on the mechanical properties of fiber-reinforced composite resin[15,16], and adhesion between an endodontically treated tooth and prefabricated fiber post[17]. However, it is difficult to evaluate the mechanical properties of a root combined with a prefabricated fiber post, due to the diversity of the components and complexity of structure. Several studies have reported on the distribution of compressive and tensile stresses transmitted to the root through the post[18-20]. Occlusal forces, which may be transmitted through the post, can cause vertical root fracture[21]. Although the mechanical properties of a root combined with several different post-and-core materials have been investigated by finite element analysis[22], little information is available on how a root and post-and-core materials may be safely combined. Furthermore, the effect of reinforcement with a prefabricated fiber post on a root restored with a post-and-core system remains to be determined.

To evaluate the mechanical properties of such complicated combinations, the traditional compression and/or bending tests are no longer adequate, because of limitations posed by the dimensions and form of the specimens. In place of these traditional testing methods, the diametral compression test has been used to evaluate the tensile strength of post-and-core materials and the bond strength between a prefabricated fiber post and an adhesive resin cement[23-26]. This test can direct tensile stress in, or between, component materials by means of a compressive load applied longitudinally to the root. Therefore, this test offers a rational method to evaluate the mechanical properties of a root combined with a prefabricated fiber post.

The purpose of this study was to investigate the effect of different volume fractions of prefabricated fiber post on flexural strength and diametral tensile strength. It was hypothesized that an increase in volume fraction would enhance the diametral tensile strength (DTS) of the root, against tensile stress applied perpendicularly to the longitudinal direction of the glass fibers; that is to say, use of a prefabricated fiber post would yield a significant increase in DTS.

MATERIALS AND METHODS

The following three types of specimens were prefabricated or fabricated for mechanical testing, as shown in Fig. 1a: (1) prefabricated fiber post alone (FP); (2) core composite resin with FP (CFP); and (3) root with CFP (RCFP). The chemical compositions and batch numbers of the materials used in this study are shown in Table 1, and all materials were handled according to the manufacturers' instructions. All specimens, except the FP specimens, were fabricated to the same length/diameter ratio[27]. As the length/diameter ratio of a specimen affects diametral tensile strength[28], this ratio was set to 0.5 in accordance with ADA specification No. 27.

Preparation of specimens

1. Prefabricated fiber posts (FP)

For the bending test, commercially available FPs (Fiber Post, GC Inc., Tokyo, Japan) of three different diameters (1.2, 1.4, and 1.6 mm) were cut to 15 mm in length, and with a uniform diameter throughout, by means of a water-cooled cutting machine (IsoMet™ 1000, Buehler Inc., Illinois, USA).

For the diametral compression test, specimens of 1.6 mm diameter and 2 mm length were prepared using the water-cooled cutting machine (n=3).

2. Core composite resin with FP (CFP)

Three sizes of FP and a dual cure-type core composite resin (Unifil® Core, GC Inc., Tokyo, Japan) were used for specimen fabrication. Cylindrical specimens of 3 mm diameter and 16 mm length were fabricated, each with a different volume fraction of prefabricated fiber post in the core composite resin. These volume fractions (FP/CFP ratios) are shown in Table 2, namely — core composite resin only (FP/CFP=0); ϕ1.2 mm × 1 piece (FP/CFP=0.16); ϕ1.4 mm × 1 piece (FP/CFP=0.22); ϕ1.6 mm × 1 piece (FP/CFP=0.28); and

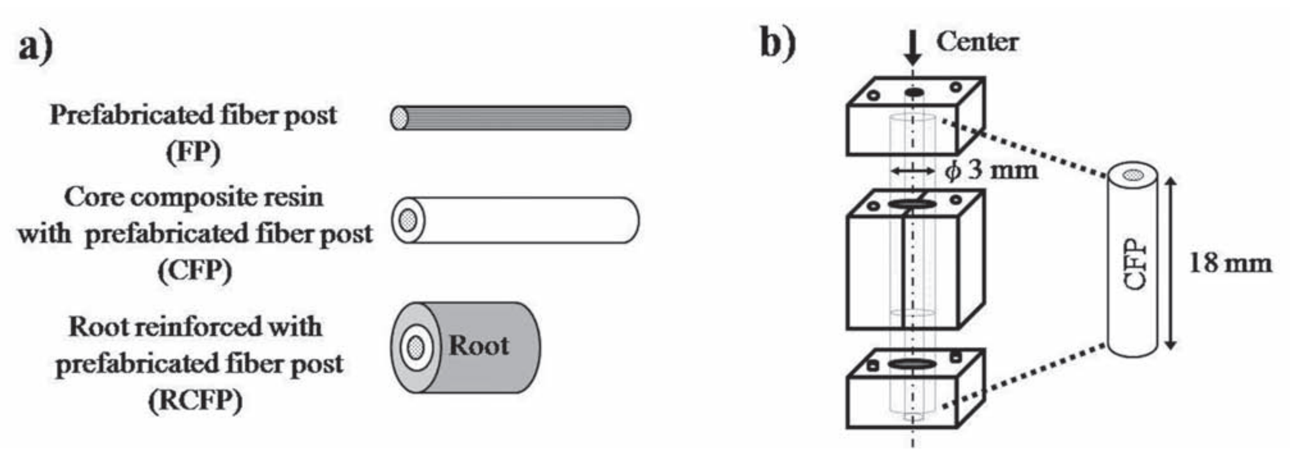

Fig. 1 (a) Three types of specimens, either prefabricated (FP) or fabricated (CFP and RCFP). (b) Metal mold to prepare the specimens (CFP).

Table 1 Compositions and batch numbers of all the materials used in this study

Material	Batch No.	Manufacturer	Composition
Fiber Post	0606061 0610191 0610271	GC	Glass fibers, methacrylate resin matrix, Bis-GMA
Ceramic Primer	0606132	GC	Methyl methacrylate, ethanol, UDMA, 2-HEMA
Unifil® Core Self-etching Bond	0612211 0612221	GC	Ethanol, water, 4-META, dimethacrylate, silica, catalyst
Unifil® Core	0607061	GC	Urethane dimethacrylate, dimethacrylate, silicon dioxide, photo/chemical initiator, fluoro-alumino-silicate glass
Super Bond C&B	ML1	Sun Medical	Tri-n-butylborane derivative, 4-META, MMA, PMMA
Green Activator	ME2	Sun Medical	Citric acid, ferric chloride, water
Porcelain Liner M	ML3	Sun Medical	MMA, 4-META, γ-MPTS

Table 2 Volume fractions of prefabricated fiber post in core composite resin (FP/CFP ratios)

Diameter of FP	Piece	FP/CFP ratio
—	0	0
ϕ 1.2	1	0.16
ϕ 1.4	1	0.22
ϕ 1.6	1	0.28
ϕ 1.2	3	0.48

ϕ 1.2 mm × 3 pieces (FP/CFP=0.48).

A custom-made mold was used to prepare the specimens. The mold consisted of three sections divided into four compartments: an upper and lower compartment, and a main body which could be subdivided into two equal compartments (Fig. 1b). Three sizes of upper and lower compartments were prepared, each with a different bore diameter (1.2 mm, 1.4 mm, or 1.6 mm) at the center.

A silane coupling agent (Ceramic Primer, GC Inc.) and bonding agent (Unifil® Core Self-etching Bond, GC Inc.) were applied to all the FPs. Next, for all the specimens except the FP/CFP=0.48 specimens, core composite resin was poured into the bores of the mold, and the FPs were inserted. To make the FP/CFP=0.48 specimens, three pieces of FP were covered with core composite resin in advance and inserted directly into the bore of the main body of the mold. They were then equally placed along the inside wall of the main body by hand.

The core composite resins were light-cured for 30 seconds with a halogen curing light (Griplight II, Shofu Inc., Tokyo, Japan), which was applied to the boreholes at the top and bottom of the mold.

After 10 minutes' storage, the FP-core composite resin combination was removed from the mold. The specimens were light-cured again for 30 seconds with the halogen curing light directly from either side, and then stored in distilled water at 37°C for 24 hours.

By means of a water-cooled cutting machine (FINE CUT, Heiwa Technica Inc., Tokyo, Japan), all the CFPs were cut to 16 mm in length for the bending test (n=6), and 1.5 mm in thickness for the diametral compression test (n=6).

3. Root with CFP (RCFP): Root combined with prefabricated fiber post

Intact anterior bovine teeth with a root canal smaller than 3 mm in diameter were sectioned at the cervical area using a water-cooled cutting machine and stored in distilled water at 4°C. The roots were ground into a pipe shape 6 mm in diameter and 10 mm in length using a manual copy-milling unit (CELAY system, Microna Technology Inc., Switzerland). Root canals were widened to 3 mm in diameter with drills under water.

The bovine root canal walls were then etched with Green Activator (Sun Medical Inc., Shiga, Japan) for 5 seconds, rinsed with water, and dried with paper points. The surfaces of the prepared CFPs were sandblasted with 50-μm Al_2O_3, rinsed in streaming water, and ultrasonically cleaned in distilled water for 5 minutes. These dried surfaces were treated with a silane coupling agent (Porcelain Liner M, Sun Medical Inc., Shiga, Japan).

CPF was luted into each treated bovine root with an adhesive resin cement (Super-Bond C&B, Sun Medical Inc., Shiga, Japan) and stored in distilled water at 37°C for 24 hours.

Disk-shaped specimens were cut from RCFP to 6 mm in diameter and 3 mm in thickness using a water-cooled cutting machine for the diametral compression test (n=8).

Mechanical properties

1. Bending test

Using a universal testing machine (Autograph AG-I, Shimadzu Inc., Kyoto, Japan) with a 10 mm span, the cylindrical specimens were subjected to a three-point bending test at a crosshead speed of 1.0 mm/min. Each specimen was loaded until initial failure occurred. Flexural strength (in MPa) was calculated for each specimen according to the following formula:

$\sigma=8FL/\pi D^3$ (F=load, L=length, D=diameter)

2. Diametral compression test

Using the universal testing machine, the disk-shaped specimens were subjected to a diametral compression test at a crosshead speed of 0.1 mm/min. Each specimen was loaded until initial failure occurred. Diametral tensile strength (DTS) in MPa was calculated for each specimen according to the following formula:

$\sigma=2P/\pi DT$ (P=load, D=diameter, T=thickness)

Fractured specimens were viewed under an optical microscope (VH-5000, Keyence Inc., Osaka, Japan) and by scanning electron microscopy (JSM-6340F, Joel Datum Ltd., Japan) after mechanical testing to ascertain fracture mode.

3. Statistical analysis

Mean values and standard deviations for flexural strength and diametral tensile strength were calculated and the data were statistically analyzed with one-way ANOVA and *post hoc* Tukey–Kramer test (α=0.05).

RESULTS

Prefabricated fiber posts (FP)

Flexural strengths of FP 1.2, 1.4, and 1.6 were 1199±38, 1284±7, and 1212±54 MPa respectively, yielding no significant differences (p>0.05). No

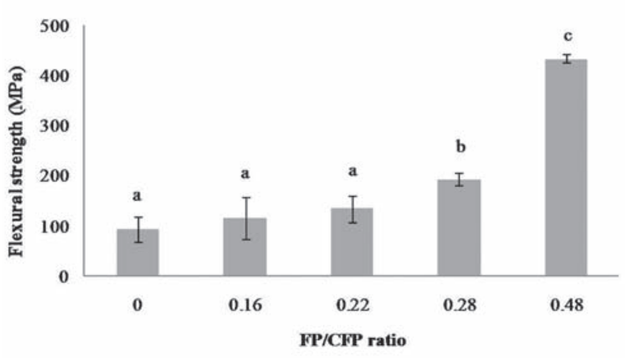

Fig. 2 Flexural strengths of CFPs with different FP/CFP ratios. Different letters indicate statistically significant differences (p<0.05).

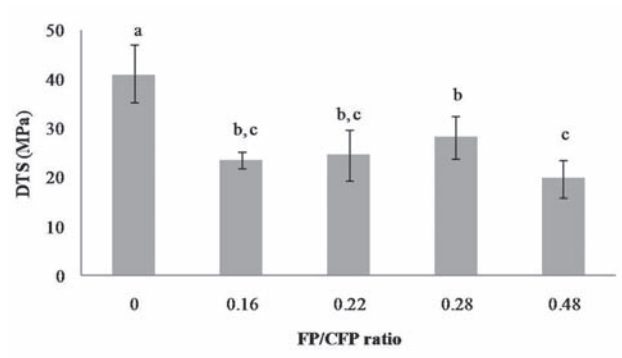

Fig. 3 DTS results of CFPs with different FP/CFP ratios. Different letters indicate statistically significant differences (p<0.05).

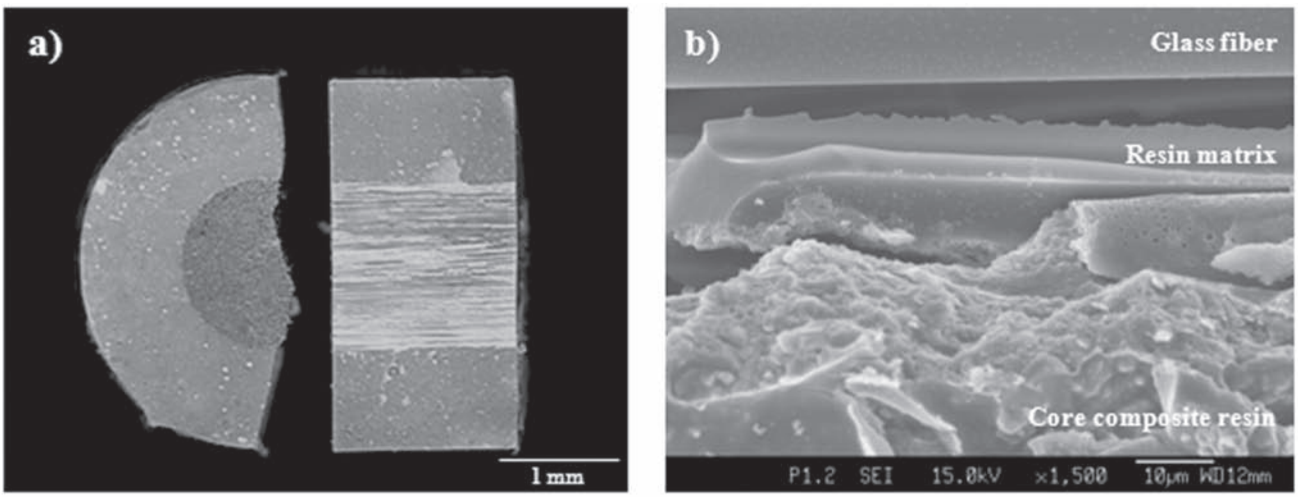

Fig. 4 Typical fracture image of FP after diametral compression test: (a) Optical microscopy revealed fracture through FP which broke the specimen into two. Failure through FP was predominant in all groups; and (b) Fracture between glass fibers and resin matrix in FP.

specimens were completely broken into two during the three-point bending test. The resin matrix showed delamination of glass fibers, as in a greenstick fracture.

The DTS of FP with 1.6 mm diameter was 25±4.6 MPa. Every specimen showed failure in the form of a crack propagated along the loaded diameter and the fiber-resin matrix interface. SEM observation revealed fracture between the glass fibers and resin matrix after the diametral compression test.

Core composite resin with FP (CFP)

Figure 2 shows the flexural strengths of CFPs with different FP/CFP ratios. Flexural strengths for FP/CFP ratios 0, 0.16, 0.22, 0.28, and 0.48 were 92.6±24.0, 115.8±41.4, 133.7±27.5, 192.4±13.7, and 434.0±8.3 MPa respectively. The highest mean value was shown by FP/CFP=0.48, and the lowest mean value by FP/CFP=0. Flexural strength increased with increase in FP/CFP ratio. The FP/CFP=0 specimens completely broke into two in the middle, whereas the FP-containing specimens did not. The resin matrix of the FP showed delamination of glass fibers.

Figure 3 shows the DTS results of CFPs with different FP/CFP ratios. The DTS values for FP/CFP ratios 0, 0.16, 0.22, 0.28, and 0.48 were 41.1±5.9, 23.5±1.8, 24.5±5.2, 28.2±4.4, and 19.8±3.8 MPa respectively. The highest mean value was shown by FP/CFP=0, and lower mean values were shown by FP/CFP=0.16, 0.22, 0.28, and 0.48. Significant differences in DTS were detected between FP/CFP=0 and the others (p<0.05).

Optical microscope observation revealed failure through the FP (Fig. 4a). SEM observation revealed fracture between the glass fibers and the resin matrix of the FP after the diametral compression test (Fig. 4b). Failure through the FP was predominant in all groups

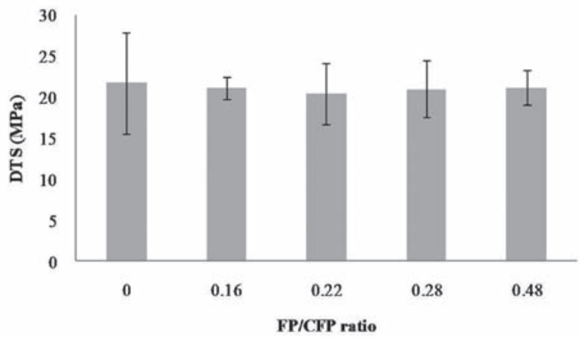

Fig. 5 DTS results of RCFPs with different FP/CFP ratios. No significant differences were observed between any groups (p>0.05).

Table 3 Classification of fracture modes after diametral compression test of RCFP

FP/CFP	Type1	Type 2	Type 3	Total
0	100	0	0	100
0.16	0	50	50	100
0.22	12.5	12.5	75	100
0.28	0	12.5	87.5	100
0.48	0	0	100	100

(%)

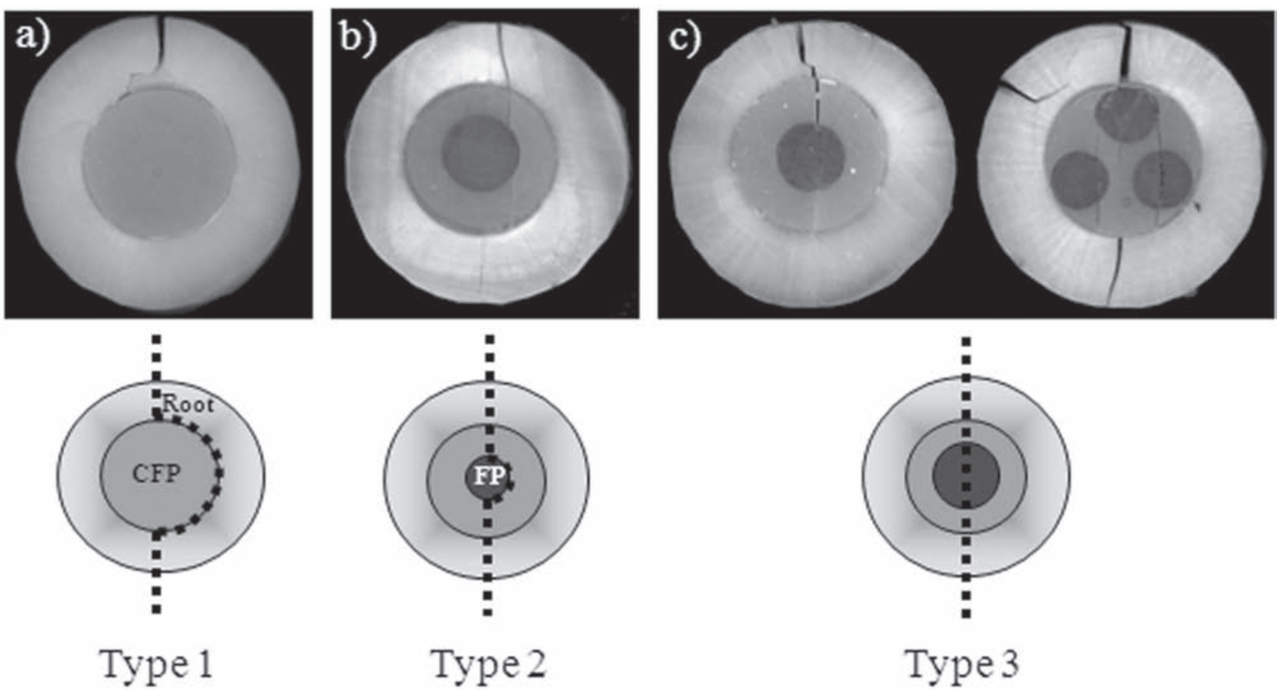

Fig. 6 Typical failure images of RCFP after diametral compression test: a) Failure occurred at interface between root-CFP (Type 1); b) Failure occurred at interface between core composite resin-FP (Type 2); and c) Failure occurred through FP (Type 3). Dotted line indicates propagation line of crack along which fracture occurred.

after the diametral compression test.

Root with CFP (RCFP): Root combined with prefabricated fiber post

Figure 5 shows the DTS results of RCFPs with different FP/CFP ratios. The DTS values for FP/CFP ratios 0, 0.16, 0.22, 0.28, and 0.48 were 21.8±6.2, 21.2±1.4, 20.4±3.8, 21.0±3.5, and 21.3±2.1 MPa respectively. No significant differences in DTS were observed between any group (p>0.05).

Classification of fracture modes and the corresponding percentages are shown in Table 3. The fracture modes were namely — Type 1: fracture between root and CFP (without cohesive failure of CFP); Type 2: fracture between core composite resin and FP (without cohesive failure of FP); and Type 3: fracture through FP (cohesive failure of FP), in which fracture occurred between the glass fibers and the resin matrix of the FP (Fig. 6). Type 1 indicated weak adhesion between root and CFP, but sound cohesion of CFP; Type 2 indicated weak adhesion between core composite resin and FP, but sound adhesion at root-composite resin interface; and Type 3 indicated sound adhesion at root-core composite resin-FP interfaces, and a sound combination of these components. All FP/CFP=0 specimens exhibited Type 1 failure. With gradual increase in FP/CFP ratio, Type 2 and Type 3 failure modes became predominant.

DISCUSSION

Results showed that the flexural strength of FP was approximately 1200 MPa, and that the DTS of FP was approximately 25 MPa. Angle of stress yielded a marked difference in the mechanical properties displayed, with FP showing strong flexural, but weak tensile, properties against stress applied perpendicularly to the longitudinal direction of the glass fibers.

Flexural strength of CFP

Flexural strength of CFP showed an increase with increase in FP/CFP ratio. It has been suggested that an FP can reinforce the flexural property of the core composite resin in a post-and-core complex. In this study, the flexural strength of CFP was lower than that of FP alone, which was approximately 1200 MPa. At this juncture, it should be mentioned that the span length/diameter ratio of the bending test and the orientation of fibers in the specimen affect flexural strength[29,30]. In terms of fracture, CFP alone (core composite resin only, FP/PFC=0) broke into two after the bending test. On the other hand, CFP with FP did not break into two. Fracture in the resin matrix and delamination of glass fibers from the resin matrix were observed in the FP. It is thus possible that a large FP can enhance the flexural properties of a root combined with a CFP, as long as the diameter of the FP can be accommodated by the root canal.

DTS of CFP

The DTS values of CFPs with FP in any FP/CFP ratio were weaker than those of CFP without FP, and these DTS values were almost the same as that of FP alone. These results supported those of Santos *et al.*[31], which showed that the DTS of CFP with FP ranged between 11 to 20 MPa. In another study[32], the DTS of CFP without FP was approximately 46 MPa.

SEM observation revealed fracture between the glass fibers and the resin matrix of the FP in all the CFP groups, despite good adhesion between the resin matrix of the FP and the core composite resin (Fig. 4b). Therefore, FP did not reinforce the CFP against tensile stress applied perpendicularly to the longitudinal direction of the glass fibers.

These results suggested that to improve the tensile properties of CFP, it is necessary to reinforce the adhesion between the glass fibers and the resin matrix of the FP. It should also be mentioned that the composition, diameter, density, and surface treatment of the glass fibers influence the tensile properties of FP.

DTS of RCFP

Results showed that the tensile properties of an RCFP are mainly determined by those of the root dentin. This was quite evident from the fracture mode. Adhesive/cohesive/mixed failure at each interface could not be classified rigidly because specimens did not break into two until initial failure occurred.

All specimens of RCFP without FP (FP/CFP=0) exhibited Type 1 failure. The initial crack appeared to have occurred at the root dentin, propagating to the root-core composite resin interface, which had a lower adhesive strength than the cohesive strength of composite resin. On the other hand, specimens of RCFP with FP at different FP/CFP ratios exhibited Type 2 and Type 3 failures. The initial crack appeared to have occurred at the root dentin, propagating to the FP through the brittle core composite resin in the CFP, and eventually penetrating the glass fibers and resin matrix of the FP. Although it was hypothesized that there would be a significant increase in the DTS of the RCFP, this was rejected by the results obtained in this study. There was no evidence that an FP can reinforce the mechanical property against tensile stress applied perpendicularly to the longitudinal direction of the glass fibers. In general, core composite materials can reinforce the mechanical properties of brittle components, if the adhesion among the component materials is adequately sound.

In this study, commercial adhesive resin cement with no filler was used to lute a CFP to a root. Although SEM observation revealed the appearance of sound adhesion between the root dentin and CFP, the root-CFP combination with or without an FP could not be reinforced. Core composite resin and adhesive resin cement shrink upon polymerization. In this study, the polymerization shrinkages of core composite resin in CFP and adhesive resin cement increased with decrease in FP/CFP ratio. Such polymerization shrinkages then weakened the adhesion at FP-core composite resin-root interface. Specimens with a smaller FP/CFP ratio showed fracture at the root-core composite resin-FP interface. This suggested that the largest possible volume fraction of prefabricated fiber post that can be accommodated by the root canal should be used in obtaining root unification, in combination with components predicted to yield the lowest amount of polymerization shrinkage in the resinous post-and-core materials. However, further studies are needed to verify this suggestion.

CONCLUSIONS

The flexural and diametral tensile strengths of the prefabricated fiber post were approximately 1200 MPa and 25 MPa respectively.

The flexural strength of core composite resin with prefabricated fiber post showed an increase with increase in the volume fraction of prefabricated fiber post. A volume fraction of 0 yielded the lowest mean value (93 MPa), whilst a volume fraction of 0.48 yielded the highest mean value (434 MPa). The diametral tensile strength of core composite resin with prefabricated fiber post ranged from 20 MPa to 28 MPa — which was lower than that of core composite resin without prefabricated fiber post and almost the same as that of the prefabricated fiber post alone.

The diametral tensile strength of the root combined with prefabricated fiber post ranged from 20 MPa to 22 MPa. The prefabricated fiber post yielded no significant increase in the mechanical properties of the root against tensile stress applied perpendicularly to the longitudinal direction of the glass fibers, at any volume fraction.

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