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Regional Bond Strengths and Failure Analysis of Fiber Posts Bonded to Root Canal Dentin

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Clinical Relevance

The bond strengths of fiber posts to root canal dentin could be affected by the characteristics of the fiber post and its bonding quality. The failure patterns of fiber-post bonded root canal dentin were dependent upon the post system.

SUMMARY

This study evaluated the regional bond strengths of fiber posts to root canal dentin luted with dual-cure resin composite. Twelve extracted human premolars were decoronated and post spaces prepared to a depth of 8 mm. The root canal dentin was treated with Clearfil SE Bond and light-cured for 20 seconds. Three posts from each of the following four types of fiber posts—Snowlight, FibreKor, DT Light-Post and GC Fiber Post—were surface-treated with a mixture of Porcelain Bond Activator and Photobond, then luted into the post spaces with Clearfil DC Core Automix and light-cured for 60 seconds. After 24-hour water storage, each specimen was serially sliced into eight 0.6 x 0.6 mm-thick beams for the microtensile bond strength (μTBS) test. Failure modes were observed using SEM. The μTBS data were divided into coronal and apical regions and statistically analyzed. The highest bond strengths were obtained from FibreKor posts. Regional factors had no effect on bond strength. FibreKor and DT Light-Post specimens primarily failed at the post-resin composite interface, whereas Snowlight and GC Post cohesively failed within the post.

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INTRODUCTION

Esthetic non-metal fiber posts have been increasingly used to restore endodontically-treated teeth, because their moduli of elasticity are comparable to dentin, producing a stress field similar to that of a natural tooth and resulting in a reduction in root fractures.[1-5] Contemporary adhesive systems with dual-cure resin composite core materials are currently used for luting fiber posts into root canals, especially in wide or flared canals, because resin composite has a modulus of elasticity close to dentin and fiber posts and is higher than that of resin cement.[6] In addition, the clinician can simply use the same composite material for post placement and core build-up.

Even though the incidence of root fractures in endodontically-treated teeth has lessened when fiber posts have been used, the failure of fiber post-restored teeth still occurs primarily through decementation between the fiber post-resin and the resin-root dentin interfaces.[7-10] Polymerization shrinkage and contraction stress of the luting resin composite may be one cause of decementation if sufficient interfacial adhesion could not be obtained. In an attempt to solve the problem of debonding, previous studies were conducted by the authors of the current study to evaluate the bond strength of dual-cure resin composite core materials to the fiber-post surface and root canal dentin.[11-14] However, those studies evaluated the adhesion of resin composite to the post surface and resin composite to root canal dentin separately to determine the most favorable method for bonding each interface. In reality, when a fiber post is luted into the root canal, two different types of interfaces—post-resin composite and resin composite-root canal dentin—are created under the polymerization-stressed condition of the luting resin. Moreover, the cavity configuration factor (C-factor), which represents the ratio of bonded to unbonded surface area, increases enormously for fiber-post-bonded teeth. It has been reported that the C-factor in endodontic post-luted cavities may exceed 200; whereas, the C-factor of an intracoronal restoration is in the range of only 1 to 5.[9] The restriction of any free surfaces that might be able to reduce the shrinkage stress would have an additional affect on the adhesion of fiber posts to root canal dentin.[15]

Some studies have suggested that problems in adhesion might occur at the resin composite/root canal dentin interface rather than at the fiber post-resin composite interface.[8,16] On the other hand, previous research has also indicated a problem at the post-resin composite interface.[17-18] Therefore, it is still uncertain which interface is the weaker part of the fiber-post restoration. Vichi and others used scanning electron microscopy (SEM) to evaluate the interfaces created in a fiber post-bonded root canal, and they suggested that an absence of voids at the fiber post-resin cement interface indicates a good bond between the post surface and resin cement.[19] However, SEM evaluation alone cannot be correlated to quantitative bond strength data.

Currently, there are two testing methods that are generally used to evaluate the regional bond strength of fiber-post bonded teeth—the microtensile and push-out tests. The microtensile bond strength test enables the measurement of transverse forces on small bonded areas, such as the inside of the root canal;[20] however, occasionally, premature failure of specimens arises prior to testing when adhesion is weak.[21] The push-out test employs thin slices and has also been useful for evaluating the regional retentive ability of a fiber post to the root canal wall by vertical or shear force loading, although frictional resistance may be relevant in the push-out test.[22] However, the push-out test may not be able to compare the qualities of the two resin interfaces of dentin and fiber post with one specimen at the same time. This study investigated the qualities of two resin interfaces to dentin and fiber post and identified the weaker part by evaluating the regional microtensile bond strengths of four kinds of fiber posts to root canal dentin luted with dual-cure resin composites. Additionally, the failure characteristics were evaluated to determine the poor quality part of restored teeth with fiber posts. The null hypothesis was that the type of fiber post did not have an effect on adhesion to root canal dentin.

METHODS AND MATERIALS

Specimen Preparation

The following four types of fiber posts: Snowlight (Carbotech, Ganges, France), FibreKor (Pentron Clinical Technologies, LLC, Wallingford, CT, USA), DT Light-Post (RTD, Grenoble, France) and GC Fiber Post (GC Corporation, Tokyo, Japan) were used in this study. Three posts of each type were randomly selected from the batch. The posts were cut to a length of 12 mm from the upper end by a diamond bur (201, Shofu, Kyoto, Japan) and mounted in a high-speed handpiece under water spray.[23] The cut posts of Snowlight, FibreKor and GC Post were straight in shape, while the DT Light-Posts were tapered. The surfaces of the posts were then cleaned with alcohol.

Twelve single-rooted human lower premolars, recently extracted from adolescents for orthodontic reasons and stored frozen, were decoronated at the cemento-enamel junction using a low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA). Pulpal tissue was removed using endodontic files, and the post spaces were then prepared using Gates-Glidden drills (Matsutani Seisakusho Co, Ltd, Takanezawa, Japan) and FibreKor drills (Pentron Corporation) in a low-speed handpiece under copious water-cooling to a depth of 8 mm and a diameter of 1.75 mm. All the teeth were prepared with the same type of drill to standardize the canal size and dentin surface characteristics after preparation. The root canals were then rinsed with distilled water and dried with paper points. Prior

Table 1: *Materials Used in this Study*

Material	Manufacturer	Composition
Snowlight	Carbotech Ganges, France	65% volume of zircon- glass fiber, 35% volume of polyester-metacrylate resin matrix
FibreKor	Pentron Clinical Technologies, LLC, Wallingford, CT, USA	30.8% volume of glass fiber, 16.2% volume of filler, 53% volume of resin content
DT Light-Post	RTD, Grenoble, France	60% volume of quartz fibers, 40% volume of epoxy resin
GC Fiber Post	GC Corporation, Tokyo, Japan	58% volume of glass fiber, 42% volume of resin matrix
Clearfil SE Bond	Kuraray Medical Inc, Tokyo, Japan	Primer: MDP, HEMA, water, hydrophilic dimethacrylates, photoinitiator, accelerator Bond: MDP, HEMA, hydrophobic dimethacrylates, microfiller, photoinitiator, accelerator
Clearfil Porcelain Bond Activator	Kuraray Medical Inc, Tokyo, Japan	Hydrophobic dimethacrylate, γ-methacryloxy propyltrimethoxy silane (γ-MPS)
Clearfil Photobond	Kuraray Medical Inc, Tokyo, Japan	Catalyst: MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate, d,l-Camphorquinone, benzoyl peroxide Universal: Ethanol, N,N-Diethanol p-toluidine
DC Core Automix	Kuraray Medical Inc, Tokyo, Japan	Catalyst: Bis-GMA, TEGDMA, silanized glass fillers, silica microfillers, chemical/photoinitiator Universal: TEGDMA, methacrylate monomers, silanized glass fillers, silica microfillers, chemical/photoinitiator

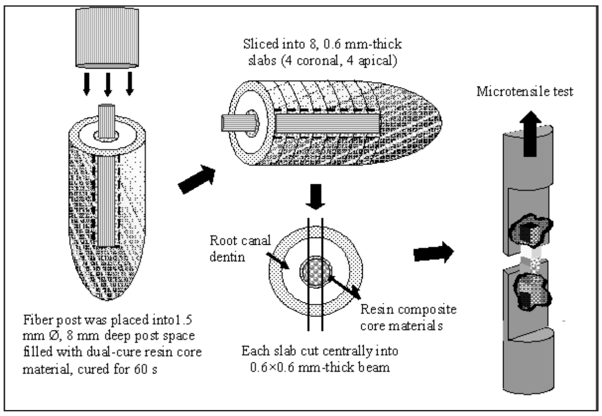

Figure 1. *Schematic illustration of the bonding and µTBS test procedures.*

to the bonding procedures, the external surfaces of the roots were built-up with a resin composite to make grips for testing and prevent external light from affecting the curing tip, which can pass through the thin portion of the dentin wall to the adhesive resin during photo-curing procedures. The materials used in this study and their chemical compositions are presented in Table 1.

Bonding Procedures

Regarding actual bonding procedures, Clearfil SE Bond Primer/Bond (Kuraray Medical Inc, Tokyo, Japan) was applied to the root canal dentin surface in accordance with the manufacturer's instructions. After application of the adhesive, photo-irradiation (Optilux 501, Demetron, Danbury, CT, USA) was performed from a coronal direction with a prolonged photo-exposure time of 20 seconds.[14] The power density of the light source, after checking with a digital radiometer (Jetlite light tester, J Morita, Irvine, CA, USA), was 830 mW/cm^2. The post surface was treated with a silane coupling bonding agent, a mixture of Clearfil Photobond (Kuraray Medical Inc) and Clearfil Porcelain Bond Activator (Kuraray Medical Inc), followed by gentle air blowing.[11] The dual-cure resin composite, Clearfil DC Core Automix (Kuraray Medical Inc), was injected into the post space using an auto-mix cartridge and syringe tip. The treated post was then inserted into the resin-filled root canal and photo-irradiation was performed for 60 seconds from the upper end of the post. The specimens were then stored in water at 37°C for 24 hours.

Microtensile Bond Strength Testing

After 24 hours storage, each bonded specimen was attached to the arm of a low-speed diamond saw (Isomet, Buehler) and eight slabs were serially cut perpendicular to the bonded interface under water-cooling. Each slab was then transversely sectioned at the middle part of the post into approximately 0.6 × 0.6 mm-thick beams. The cross-sectional area of each beam was measured using digital calipers (Mitutoyo CD15, Mitutoyo Co, Kawasaki, Japan). One of two interfaces of each beam was randomly selected for testing. The ends of the beam and the remaining interface were glued to a testing device in a table-top testing machine (EZ Test, Shimadzu Co, Kyoto, Japan) using cyanoacrylate glue (Zapit, DVA, Anaheim, CA, USA) and subjected to a tensile force at a crosshead speed of 1 mm/minute (Figure 1). The microtensile bond strength data of the four coronal beams were considered to represent the coronal portion of the post space corresponding to the coronal third of the root canal, and the apical four beams data were considered to represent the apical region corresponding to the middle third of the root canal.

SEM Observation

For failure analysis, both sides of the fractured beams were mounted on brass tablets and gold sputter-coated. The fracture modes were observed by one operator using a scanning electron microscope (JSM-5310, JEOL, Tokyo, Japan). The fracture mode was classified into five patterns: cohesive failure within the post, cohesive failure within resin composite, failure at the post-resin composite interface, mixed cohesive failure within the resin composite-failure at the post-resin composite interface and mixed cohesive failure within the post-failure at the post-resin composite interface. Since failure only occurred at the fiber-post interface without dentin interface failure, unbonded posts were mounted on brass tablets and gold sputter-coated for observation of the post surface.

Statistical Analysis

The µTBS data were analyzed using two-way ANOVA to test the affect of the post type and region factors on the bond strength. In addition, the interaction between these two factors was tested. Tukey's HSD was used as a post-hoc test for multiple comparison. All statistical analyses were performed at a 95% level of confidence.

RESULTS

Table 2 shows the means and standard deviations of µTBS for each post in each region. Two-way ANOVA revealed that the type of fiber post had a significant effect on bond strength ($p<0.0001$). On the other hand, the regional factor had no effect on bond strength ($p=0.100$). There was no interaction between post type and region factors in the µTBS data ($p=0.416$). At both regions, the highest bond strengths were obtained when FibreKor posts were used ($p<0.05$). The µTBS of Snowlight were significantly higher than those of DT Light-Post and GC Post ($p<0.05$), whose bond strengths were similar in both the coronal and apical regions ($p>0.05$).

Figure 2 presents the percentage of fracture modes for each post. Representative SEM micrographs of the fractured surfaces are shown in Figure 3. There were two main modes of failure: Cohesive failure within the post and failure at the post-resin composite interface. No failure at the resin composite-dentin interface was found in this study. All of the Snowlight specimens failed cohesively within the post. Approximately 75% of the GC Posts specimens also failed cohesively within the post. For FibreKor and DT Light-Post, failures predominantly occurred at the post/resin composite interface.

Table 2: *Microtensile Bond Strength (MPa) of Fiber Posts to Root Canal Dentin*

	Snowlight	FibreKor	DT Light-Post	GC Post
Coronal	22.8(7.1)^{A}	50.1(7.8)^{B}	13.2(2.6)^{C}	9.6(2.6)^{C}
	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$
Apical	19.9(5.5)^{a}	45.3(9.5)^{b}	13.4(3.6)^{c}	8.4(2.3)^{c}

All values are mean (SD) (n=12). The same superscripts within each row demonstrate no significant differences.

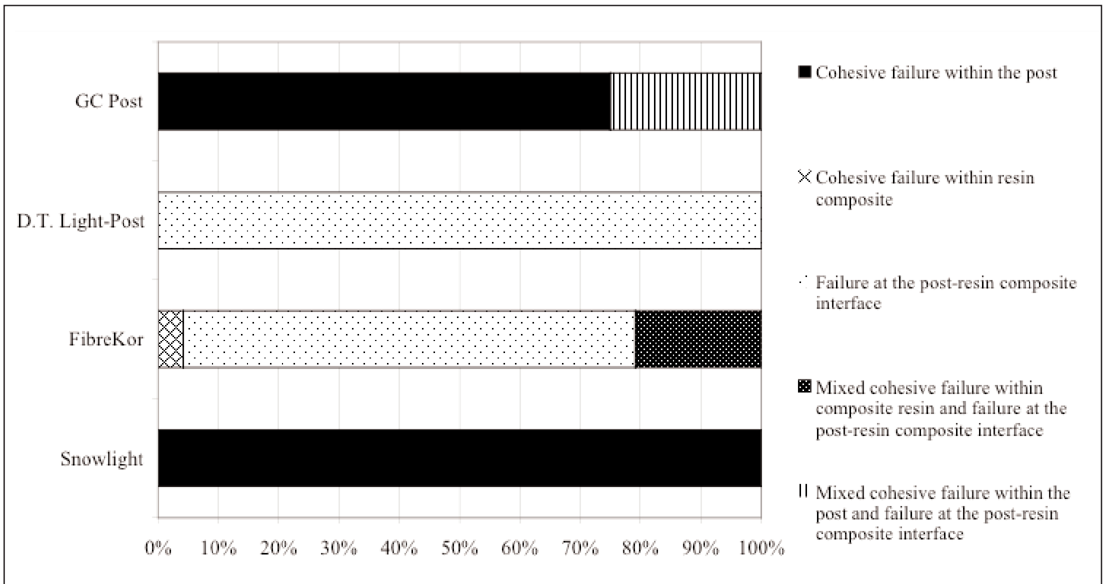

Figure 2. *Percentage of failure mode for each post material.*

DISCUSSION

Polymerization shrinkage creates contraction stresses in resin composite, which were found to be a major cause leading to the failure of composite restorations.[24-25] Shrinkage stress is considered to be a multi-factorial phenomenon, and it can be affected by factors such as volume, c-factor, elastic modulus and the flow of resin composite.[26-28] In the post space, the amount of resin composite lessens when a fiber post is inserted into the cavity when compared with an entirely resin composite-filled post space. A reduction in the amount of luting resin composite may

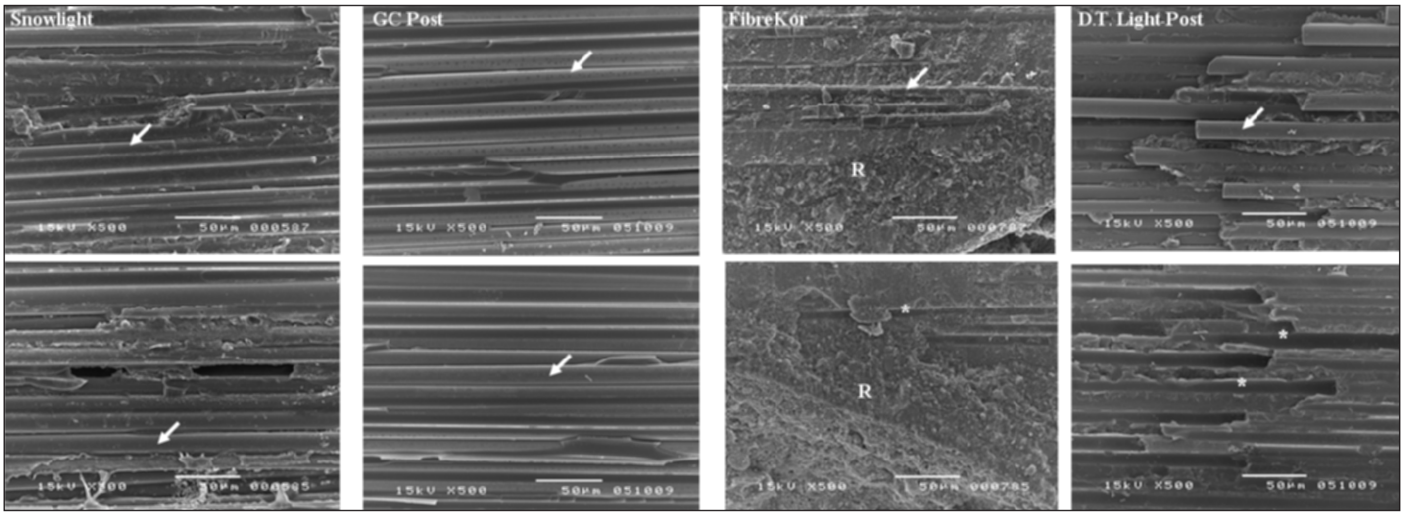

Figure 3. *Representative SEM micrographs of the fractured surface in each post. Snowlight and GC posts mostly failed cohesively within the post, in which parallel fibers (arrows) with some resin matrix in between were observed on both sides of the fractured surfaces. Mixed cohesive failure within resin composite (R) and failure at the post/resin interface was found in FibreKor. Some fibers with fractured resin composite were observed on the post-side surface and impressions of fibers (asterisks) with fractured resin were observed on the opposite resin side surface. On the post-side surface of DT Light-Post, stepped cut fibers were found (arrows), while an impression of the post surface was observed in the resin side surface.*

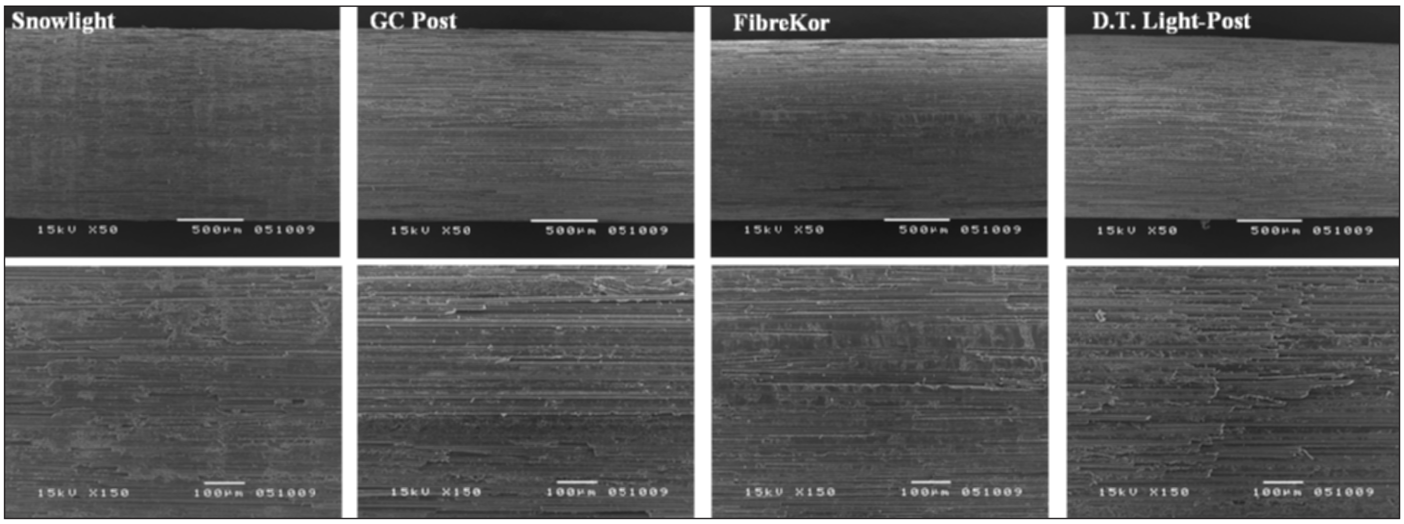

Figure 4. *SEM micrographs of the surfaces of each fiber post. Some loose fibers in the resin matrix were observed on GC Post. The fibers at the surface of DT Light post were found to be cut in steps along the post.*

result in less contraction stress.[29] On the other hand, the bonded surface area increases significantly after a fiber post is inserted. The bonded surfaces, including the root canal dentin and fiber post surfaces, will produce very high c-factor values, which may result in greater contraction stress.[30-32] A reduction in bond strength or gap formation will be perceived if the total contraction stress is higher than the adhesive strength of the interface.

In the current study, no specimen failed during specimen preparation for the μTBS test. This might indicate that no gap formation occurred at the dentin-resin-post interface. Moreover, there was no observed failure on the dentin side for any of the tested posts after specimen fracture. In the current experiment, the photo-cure bonding agent, Clearfil SE Bond, with a prolonged photo-irradiation time of 20 seconds, was used as the bonding procedure for the root canal dentin surface. Previous studies have revealed high bond strength values when photo-cure bonding agents with sufficient photo-exposure time were used for bonding to root canal dentin compared with dual-cure systems.[12,14,33] Considering the efficacy of dual-cure bonding agents and an incompatibility between the acidic monomer and dual-cure mode of the bonding resin,[34] a photo-cure adhesive system is possibly a good choice for bonding to root canal dentin. The dentin-resin interface, therefore, would not be a problem in a fiber post restoration when it is bonded effectively. However, using photo-cure adhesive may affect the seating ability of the fiber post if the adhesive layer is thick. Strong air blowing to spread the adhesive and using paper points to absorb any excess resin probably would eliminate the seating problem.

In the current study, two kinds of failures were predominantly found: cohesive failure within the post and failure at the post-resin composite interface, depending on the type of fiber post. The highest bond strength among the four tested posts was obtained with FibreKor post, in which most failures occurred at the post-resin composite interfaces. In a pilot study on the bonding of dual-cure resin composite to FibreKor posts under free conditions of polymerization shrinkage, the silane-treated FibreKor post produced a bond strength of approximately 50 MPa, which was similar to the current results performed under constrained conditions. It has been demonstrated that a higher C-factor reduced the bond strength at the interface.[35] Therefore, these results indicate that adhesion at the interfaces of dentin and FibreKor post was sufficient to resist contraction stress of the luting resin composite, even though there was a high C-factor with a limited stress-releasing area.

For DT Light-Post, all specimens failed at the post-resin composite interface. The bond strength of DT Light-Post was found to be approximately four times less than that of FibreKor at both regions. In a previous study by the authors of the current study, Light-Post was used to evaluate the bond strength to a dual-cure resin core material, and it was found that the average microtensile bond strength in the group treated in a similar manner as the current study was 53.2 and 46.2 MPa at the coronal and apical regions, respectively.[13] On the other hand, previous studies using the microtensile testing method recorded a low bond strength of approximately 10 MPa when DT Light-Posts were used with silane treatment.[36-37] Light-Post and DT Light-Post are composed of the same components, but they are different in shape. As a result of the anatomical taper shape of the post, fibers on the surface of DT Light-Post were found to be cut in steps, as shown in Figure 4. In contrast, the cylindrical part of Light-Post was employed in the current authors' previous study in which the fibers were parallel to the surface. It is suggested that optimal properties of the fibers are obtained when virgin fibers are used, and their properties might dramatically change when the fibers are scratched.[38] This might be a reason for a reduction in the µTBS of DT Light-Post compared with Light-Post.

In contrast, all the Snowlight specimens failed cohesively within the post through detachment at the fiber and resin matrix interfaces. Additionally, approximately 75% of GC posts failed in a manner similar to Snowlight. SEM micrographs revealed that failure occurred as a result of detachment between the fiber and resin matrix of the fiber posts. A fiber post is a composite material in which surface treated fibers are embedded in a resin matrix. The type of silane coupling agent and silanization process might have an influence on the quality of the bond at the fiber-matrix interface of each post.[39] However, there was a difference in failure morphology between Snowlight and GC Post when the authors of the current study optically observed the fractured beams from the periphery. The fracture positions in the Snowlight group were located inside the post, with some portion of the post remaining on the resin side of the fractured beams. On the other hand, the GC Post specimens seemed to fail predominantly at the interface under optical observation. However, SEM evaluation confirmed that many fibers remained on the resin side of the fractured specimens, which was classified as cohesive failure within the post. This indicates that cohesive failure of GC Post might have occurred at the subsurface of the post. From the SEM micrographs of the post surfaces in Figure 4, it can be seen that more fibers are exposed on the surface of GC Post than on Snowlight. These exposed fibers seem to have less support from the resin matrix and thus might easily pull off during testing. These results indicate that attention should be paid to the adhesion between fibers and resin matrix of the fiber post during post fabrication, and also the surface characteristics of the post might be critical for teeth restored with fiber posts. The null hypothesis therefore must be rejected.

CONCLUSIONS

From the results of this study, it can be concluded that the bond strengths of fiber posts to root canal dentin were various, and they could be affected by the properties of the fiber post and the bonding quality of the resin composite to the post surface or root canal dentin. Among the four fiber posts tested, FibreKor exhibited the highest bond strength at both regions. No regional differences in µTBS were found among all posts. When bonding to root canal dentin using Clearfil SE Bond with prolonged photo-irradiation, failures occurred either at the post-resin composite interface or within the post and not at the resin-dentin interface. Failure patterns were dependent on the post system.

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