Transmission of light through fiber-reinforced composite posts

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The aim of this in vitro study was to explore light transmission through an individually formed fiber-reinforced composite (FRC) post compared with two prefabricated FRC posts. Three different glass FRC posts from different manufacturers were used: two groups included prefabricated glass FRC posts (RelyX and GC Fiber Posts) and one group consisted of individually formed E-glass FRC posts with semi-interpenetrating polymer network (semi-IPN) polymer matrix (everStick Post). Various lengths of posts and light-protected cylinders were made. The specimens were light-polymerized on the test tray of a light radiance testing device (MARC Resin Calibrator). Light transmission in the direction of fibers was registered. Light transmission decreased with increasing post length (p<0.001; ANOVA) up to 12 mm in all post groups. The individually formed FRC post showed highest light transmission in all cylinder lengths (p<0.001) compared to prefabricated FRC posts, which could benefit polymerization of post material and luting cement.

Keywords: Root canal posts, Fiber-reinforced composite post, Individually formed fiber-reinforced composite post, Light transmission

INTRODUCTION

Fiber-reinforced composite (FRC) posts are commonly used in combination with composite resin core materials, when building up an endodontically treated tooth with extensive loss of coronal tooth structure¹². Resin-based materials and luting agents are used for FRC post cementation. The existing evidence in the literature demonstrates that the most reliable results in FRC post cementation are still obtained by etch-and-rinse adhesives and dual-cure composite resin cements1³⁴⁶. Although newer and simplified adhesives, such as self-etch adhesives and self-adhesive resin cements, have been proposed⁵⁶, accepted and recommended for clinical use⁷, reliable long-term evidence of their performance in post cementation is still missing¹³⁴⁸. In addition, concern has been focused on the load bearing capacity and clinical long term success of prefabricated FRC posts. This may relate not only to the flexibility of the posts but also to the curing of adhesives and cements in the root canal¹³⁰.

In order to develop adequate mechanical properties for a post system's clinical function, the adhesion of the post must be successful. The unfavorable form of a root canal space, resembling a dark tube, makes it difficult to successfully light-polymerize the materials used for luting FRC posts. In order to achieve proper bonding and polymerization of FRC posts and resin luting cement, good light transmission and scattering through the post is required. It has been stated that even without a post, the light intensity inside the canal, especially in the apical third, decreases to levels insufficient for polymerizing¹¹. Even when looking at translucent FRC posts, it seems that the quantity of light transmitted is significantly reduced when the depth increases¹¹².

Individually formed FRC posts with a semi-interpenetrating polymer network (semi-IPN) polymer matrix have shown an adequate degree of conversion and a tendency towards light conductivity in a simulated root canal¹³. Promising laboratory results for these individually formed FRC posts, which are made from non-polymerized fiber-resin prepregs, consisting of glass fibers and a light-curing resin matrix, have been published¹⁵⁶. Unlike prefabricated FRC posts which consist of a cross-linked polymer matrix, these individually formed FRC posts contain a multiphasic matrix consisting of both cross-linked polymer and linear polymer mixed together (semi-IPN polymer matrix)¹⁰. Better bonding between post and resin cement has been reported with individually formed FRC posts with semi-IPN polymer matrix compared to prefabricated FRC posts with a cross-linked polymer matrix¹³⁵⁷⁹. When looking at fracture load¹⁰ and microleakage¹¹, it seems that the direct method of polymerizing the individually formed FRC post simultaneously with the resin cement in situ in the root canal may be superior to prepolymerizing. These results indicate good light transmission ability of FRC post material with a semi-IPN polymer matrix. However, more information is needed regarding the transmission and scattering of light through this material at different depths of the root canal.

The aim of this in vitro study was to explore light transmission through an individually formed FRC post in comparison to two prefabricated FRC posts. The effect of the length of the FRC post on the light-transmission was evaluated. The null hypothesis tested was that the light transmission of different FRC posts would not differ.
MATERIALS AND METHODS

Three different FRC posts from different manufacturers were tested (Table 1). Two groups included prefabricated FRC posts (RelyX Fiber Post, 3M ESPE, Seefeld, Germany and GC Fiber Posts, GC, Tokyo, Japan) with cross-linked polymer matrix and one group consisted of individually formed E-glass FRC posts with a semi-IPN polymer matrix (everStick Post, GC). The individually formed FRC posts, consisting of unidirectional glass fiber composite, were rolled into the form of a post with a diameter of 1.5 mm by hand between two glass plates. Subsequently, they were light-polymerized with a light-curing device (Elipar S10, 3M ESPE) with a LED lamp radiating blue light (wavelength 470 nm) on three different points; on the coronal third, on the middle third and on the apical third for 40 s each (Fig. 1a).

Various post lengths were tested: 4, 8, 12 and 16 mm ($n=14$ posts/group, Fig. 1b). Light-protected cylinders of the same lengths as the specimens were made out of plastic tube (outer diameter 18.5 mm) and putty polyvinylsiloxane (Lab-Putty, Coltene/Whaledent, Altsätten, Switzerland) which was placed inside the tubes. The FRC posts were then positioned in the middle of the putty before curing it (Figs. 2a and b).

The light-protected cylinders including the FRC posts were placed on the test tray of a MARC Resin Calibrator unit (Blue-light Analytics, Halifax, Canada) and light-polymerized for 10 s with Elipar S10 (3M ESPE, Figs. 3a and b). Light transmission in the direction of the fibers through the FRC posts during

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**Table 1** The tested FRC posts

| Material          | Type of FRC post         | Polymer matrix | Composition                        | Post diameter (mm) | Lot No.    |
|-------------------|--------------------------|----------------|------------------------------------|--------------------|------------|
| EverStick POST (GC) | individually formed     | IPN            | E-glass (electric glass, silanated), bis-GMA, PMMA | 1.5                | 1306181    |
| Relyx Fiber Post (3M ESPE) | prefabricated   | cross-linked  | AR-Glass, resin (Zirconia particles) | 1.6                | 223601307  |
| GC Fiber Post (GC) | prefabricated            | cross-linked   | AR-Glass, methacrylate             | 1.6                | 128991002  |
polymerization was registered as irradiance power at the level of the sensor (bottom surface) in the testing device. The cylinders without the FRC posts were used as a control.

To reduce errors, mean irradiance power of all posts were measured three times and the average of these was calculated. Due to differences in the diameters of the posts, the mean irradiances from the MARC Resin Calibrator (Blue-light Analytics) could not be used directly. The diameter of the test sensor in the calibrator unit is 4 mm and the calibrator divides all the measurements by the area of the sensor and reports the mean irradiance result in mW/cm². The following formula was used to convert the light transmission into mW/mm²:

\[ E_e = \frac{x r^2}{A} \]

In this formula \( x \) is the mean irradiance measured with MARC Resin Calibrator (Blue-light Analytics) in mW/cm², \( r \) is the radius of the test sensor (diameter is 4 mm) and \( A \) is the area of the FRC post.

### Statistical analysis

Statistical analyses were performed with SPSS for Windows (SPSS IBM Statistics, Armonk, NY, USA). The data were analyzed using ANOVA and subsequent comparisons between groups were performed with Tukey post hoc tests to evaluate the height and material of the post. The level of statistical significance was considered to be 0.05.

### RESULTS

The results of the Marc Resin Calibrator test (Blue-light Analytics) are shown in Fig. 4 and Table 2. Light transmission decreased with increased post length \((p<0.001; \text{ANOVA})\) up to 12 mm in all post groups. The

![Fig. 3](image)

**Fig. 3**  a: Schematic diagram of the test set-up.  
 b: The test set-up.

![Fig. 4](image)

**Fig. 4**  Light transmission decreased with increased post length in all post groups.

| Material               | Length of the post (mm) |
|------------------------|-------------------------|
|                        | 0.0   | 4.0   | 8.0   | 12.0  | 16.0  |
| everStick POST         | 32.7±0.2\textsuperscript{Aa} | 16.5±2.4\textsuperscript{Ab} | 10.4±1.4\textsuperscript{Ac} | 7.4±2.7\textsuperscript{Ad} | 4.8±0.6\textsuperscript{Ad} |
| RelyX Fiber Post       | 32.7±0.2\textsuperscript{Aa} | 12.7±3.9\textsuperscript{Abb} | 2.7±0.2\textsuperscript{Cc} | 1.5±0.3\textsuperscript{Bd} | 1.0±0.4\textsuperscript{Bd} |
| GC Fiber Post          | 32.7±0.2\textsuperscript{Aa} | 9.5±0.6\textsuperscript{Bb}   | 4.1±1.0\textsuperscript{Bc}  | 1.8±0.2\textsuperscript{Bd} | 0.9±0.3\textsuperscript{Bc}  |
| Control                | 32.7±0.2\textsuperscript{Aa} | 7.9±0.3\textsuperscript{Cb}   | 2.9±0.1\textsuperscript{Cc}  | 1.8±0.1\textsuperscript{Bd} | 1.4±0.1\textsuperscript{Bc}  |

The same superscript capital letters in the same column and the same superscript small letters in the same row represent non-statistical significance \((p>0.05, \text{Tukey})\) between the groups.
Individually formed FRC post showed highest light transmission in all cylinder lengths ($p<0.001$).

The largest drop in light transmission power occurred between 0 and 4 mm in all post groups. In the RelyX Fiber Post (3M ESPE) group there was also a relatively high decrease of light transmission between 4 and 8 mm. The control group showed the lowest light transmission compared to the other post groups with a cylinder length of 4 mm.

SEM-images (Figs. 5a–c) of the tested posts revealed zirconia particles between the fibers in the RelyX Fiber Posts (3M ESPE, Fig. 5a), whereas no particles were seen in the GC fiber posts (GC, Fig. 5b) or everStick POSTs (GC, Fig. 5c).

**DISCUSSION**

In this study the light transmission through FRC posts with different polymer matrix was investigated. In addition, the effect of the length of the FRC post on the light-transmission was evaluated. According to the results in this laboratory study, the individually formed FRC posts with semi-IPN matrix showed significantly better light transmission in all post lengths compared to the prefabricated FRC posts with a cross-linked polymer matrix. The null hypothesis tested in this study that the light transmission of different FRC posts would not differ was thus rejected. From a clinical perspective this indicates improved polymerization of resins and dual-cure composite resin luting cements in the root canal with individually formed FRC posts with semi-IPN matrix. This has been indicated previously in bonding studies15,17-19).

In order to optimize the flexural properties, especially the strength and the stiffness of fiber posts, the use of continuous unidirectional FRC with the fiber orientation along the long axis of a tooth is justified. FRC of this kind has anisotropic physical properties in relation to mechanical behavior, thermal expansion and optical properties22). Regarding fiber posts, optical anisotropicity is beneficial if the light transmission is considered only through the post, as in this study. However, to a certain extent, light scattering perpendicular from the post would be desirable as well. Surface flaws of single glass fibers of ca. 15 µm in diameter, may enhance the scattering of light from the post if the refraction index of the surrounding resin system allows this to occur. In the case of bis-GMA containing resin systems, the light can indeed scatter from the glass fibers and be transmitted through the sides of the post. The particulate fillers included in the matrices of RelyX Fiber Posts (3M ESPE), could enhance light scattering even more. In this way the amount of light at the ends of the posts, where the light power measurements of this study were performed, could be reduced. In addition, and in particular, the reflection of light back from the tube (here Lab-Putty) as well as the absorption of light into the luting cement requires further investigation.

According to the results light transmission is reduced when the post length is increased for all post groups.
A decrease in light irradiance power by increasing the length of the post, i.e., increasing the material thickness, seems to follow the Beer-Lambert law, as expected29. These results are in agreement with earlier studies10,11, where many different kinds of FRC posts, including so-called light-transmitting posts, have shown a decrease in light intensity with increased depth. The largest drop in light transmission in our study occurred between 0 and 4 mm in all post groups. In the RelyX Fiber Post (3M ESPE) group there was also a relatively high decrease in light transmission between 4 and 8 mm, which was not seen in the other groups (Fig. 4). This may be caused by zirconia particles in the RelyX Fiber Posts (3M ESPE, Fig. 5a), which are blocking and preventing light transmission through the post (Table 2). The composition of the RelyX Fiber Post (3M ESPE) has been shown in an earlier study where structural characteristics of different translucent fiber posts were evaluated30).

The most common mode of failure for FRC posts is still loss of retention e.g. debonding from the post space25,26. Besides the difficulties of light transmission when luting FRC posts, there are many other problems related to the bonding of FRC posts. One problem related to the dentin morphology in the root canal is the significantly lower tubular density in the apical third of the root which will lead to lower bonding values apically27. Significantly lower bond strengths have been stated to exist in the apical segments compared to the middle and cervical segments of roots restored with glass FRC posts11. The length of the FRC post may therefore play an important role in the polymerization of resins and luting cements in root canals. However, more research is needed to determine the effect of post length on the polymerization and clinical outcome.

Our finding that the control group, cylinders without posts, showed the lowest light transmission compared to the other post groups, may be explained by the lack of light conduction and scattering in the empty cylinders. The light does not scatter from the walls of the cylinder, but when light is conducted through an FRC post, the light is scattered from the post surfaces which increases the light transmission values. The optical behavior of a cemented and polymerized FRC post material in a post space is complex15. Therefore, more research is needed to evaluate the interaction of light transmission and scattering for the polymerization of resin matrix of the FRC post and the surrounding luting cement. Clinically, this would help in understanding the luting procedure of FRC posts and in choosing the most long-lasting and optimal FRC post material and luting materials.

CONCLUSION

This study showed that individually formed FRC posts had better light transmission compared to prefabricated FRC posts, which could benefit polymerization of luting cement. More research is needed to determine the interaction between light transmission and light scattering during the polymerization of resin matrix of the post and surrounding luting cement.

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