Original Article

Development of fibre-reinforced composite disk for computer-aided design-computer-aided manufacturing milled posts; Experimental composite disk using e-glass fibre in different fibre direction

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Abstract

Aims: To evaluate the flexural properties of computer-aided design-computer-aided manufacturing (CAD-CAM) milled posts fabricated from the experimental fibre-reinforced composite disks in different fibre direction, and to compare the flexural properties of the CAD-CAM milled posts to those of commercial prefabricated posts, RelyX and FRC PostecPlus.

Settings and Design: *In vitro* comparative study.

Materials and Methods: E-glass fibre was used to fabricate the CAD-CAM composite disks. The fibres were prepared in unidirectional and multidirectional arrangements into the epoxy resin, at 70% by weight. The disk was milled by the Cerec InLab CAD-CAM system to fabricate a post. Ten posts for each type of disk were prepared. Two types of commercial fibre posts, RelyX fibre post, and FRC PostecPlus were used as control. The three-point bending test was performed.

Statistical Analysis Used: The data were analysed using one-way ANOVA and Game-Howell *post-hoc* test.

Results: The results indicated that both commercial fibre posts had the highest flexural strength and flexural modulus. The unidirectional experimental post yielded significantly lower values in both flexural strengths (739.1 ± 24.1 MPa) and flexural modulus (21.0 ± 3.5 GPa) compared to the control posts, while the multidirectional experimental posts had extremely low flexural strength and flexural modulus.

Conclusions: The direction of the fibres significantly influenced the mechanical properties of the posts. The experimental unidirectional fibre-reinforced composite disk showed the potential to be used as a CAD-CAM disk for post and core fabrication.

Keywords: Computer-aided design-computer-aided manufacturing disk, computer-aided design-computer-aided manufacturing milled post, fibre post, multidirectional fibre, unidirectional fibre

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INTRODUCTION

An endodontically treated tooth with extensive loss of coronal structure often requires a post to retain the core material, as part of the restoration. The posts are categorized depending on the type of material used, such as metal, ceramic, carbon fibre, and glass fibre. A high success rate in using glass fibre posts for cases with severe loss of dental structure was recorded. This may be attributed to the fact that its modulus of elasticity is similar to the root dentin elastic modulus.[1] Thus, there is a uniform load distribution and absorption of stresses to the dentin interface, decreasing stress concentration and the risk of root fractures.[2]

Glass fibre and quartz fibre posts are composed of the fibre of silica surrounded by a resin matrix, usually an epoxy resin. Because of its translucency and white colour, glass fibre posts can be used in aesthetic zones.[3,4] Commercial fibre posts are composed of glass fibres which are in a unidirectional arrangement in the resin matrix.[5] The fibre component of posts provides resistance against flexure, while the resin matrix gives resistance to compressive stress, and may have an effect on bonding with an adhesive cement.[2]

Computer-aided design-computer-aided manufacturing (CAD-CAM) milling technique in Dentistry provides outcomes with high precision, efficiency, and accuracy. It results in reduced processing time and decreased error rate of manufacturing dental appliances. In CAD-CAM systems, the posts can be freely designed and milled in different angulation, shape, and size, with or without a core.[6] Thus, using CAD-CAM technology to manufacture prefabricated intra-radicular retainers is a feasible option.

There are different factors that may affect the mechanical properties of posts. These include using different processing techniques, and various fibre post characteristics such as composition, type of fibre, fibre/matrix relation, positioning of the fibre with the matrix, shape, direction, and diameter.[5]

This study developed the experimental CAD-CAM disk by using E-glass fibres, which are glass fibres with low electrical conductivity, arranged in different fibre directions into the epoxy resin matrix. The purpose of this study was to evaluate the flexural properties of CAD-CAM milled posts fabricated from the experimental fibre-reinforced composite disks, and to compare the flexural properties of the CAD-CAM milled posts to those of commercial prefabricated posts, RelyX and FRC PostecPlus.

MATERIALS AND METHODS

This study was approved by institutional review board. Two types of experimental fibre-reinforced resin composite disk for CAD-CAM were prepared: The unidirectional glass fibre-reinforced composite disk, and the multidirectional glass fibre-reinforced composite disk. The electrical-grade Alumino-Borosilicate glass fibre (E-glass fibre, concrete composite Co. Ltd., Bangkok, Thailand), with a diameter size of 12–14 μm, was selected for this study. The continuous glass fibre strand was selected and cut into 120 mm length, arranged parallel together to the same direction in the mold to produce the unidirectional experimental disk. The continuous nonwoven glass fibre fabric was used and cut to the same size as a mold to produce the multidirectional experimental disk. The chemical-cured epoxy resin was incorporated into the fibre, at a fibre concentration of 70% by weight in the plastic mould (size 120 mm × 120 mm × 30 mm). After complete curing, the composite disk was milled into a circular disk (size 98.4 mm × 12.0 mm). This size included the actual middle ring size (94.4 mm × 12.0 mm) plus the 4.0 mm increase in the diameter of the outer ring to fit the jig in the CAM machine (inLab MC X5, Dentsply Sirona Inc, PA, USA). Three disks were fabricated for each type of experimental disk.

Two commercials prefabricated fibre posts, RelyX fibre post no. 1 (3M ESPE, MN, USA) and FRC PostecPlus no. 0 (Ivoclar Vivadent AG, Schaan, Liechtenstein) were selected as a control group. Both posts have the same length of 20.0 mm. The top half (10.0 mm) of both posts is straight, and the remaining half of the post length is tapering. The coronal and apical diameters of FRC PostecPlus were 1.3 mm and 0.6 mm, respectively, while the diameters of RelyX were 1.3 mm and 0.7 mm, respectively.

Digital data of the experimental CAD-CAM milled post were created by SOLIDWORKS software (SOLIDWORKS® Education edition 2018–2019 SP4.0, Dassault Systèmes SolidWorks Corporation, MA, USA). The shape and size of the posts were made identical to that of RelyX posts, in which the coronal diameter is 1.3 mm, the apical diameter is 0.7 mm, and the length is 20.0 mm. The data were exported to (standard triangle language [STL]) file. Schematic figures of all the posts used in this study are shown in Figure 1. The STL data were sent to the inLab MC X5 machine to mill the experimental composite disk into posts. The direction of the milling of the post was made parallel to the fibre direction of the unidirectional fibre-reinforced composite disk. The photographs of the milled posts still in the disks are shown in Figure 2. Ten milled posts fabricated from the three disks of each experimental group were randomly selected for testing.

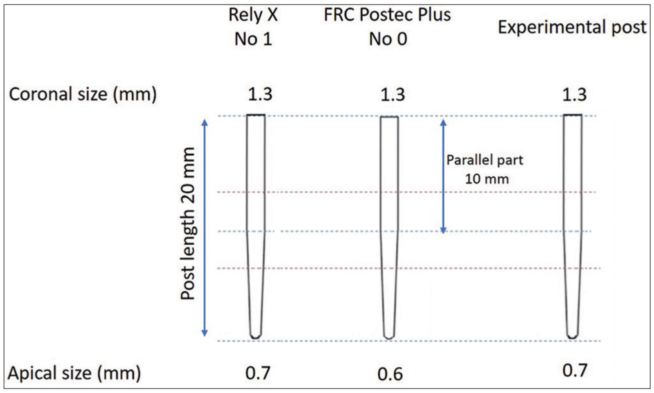

Figure 1: Schematic figure and dimensions of the commercial and experimental posts

The three-point bending test with an 8.0 mm span length was conducted with a Universal Testing Machine (Intron 5566; Instron Ltd., Buckinghamshire, England), using a 1000 N load cell and 0.5 mm/min crosshead speed, following ISO 14125:1998.[7] Each post was subjected to the three-point bending test at its parallel part until fracture. Before the test, the diameter of each post was measured using a digital micrometre (Mitutoyo, Japan). The flexural strength (σ) and flexural modulus (E) were calculated using the following equations:

Flexural strength $\sigma = 8FMax\ L/\pi d^3$ (in MPa)

Flexural modulus $E = 4FMaxL^3/(3D\ \pi d^4)$ (in GPa)

Where;

FMax is the applied load (in Newton) at the highest point of the load-deflection curve, L is the span length (8.0 mm), d is the diameter of the posts (in mm), and D is the deflection (in mm) corresponding to load F.

Flexural strength and flexural modulus data were analysed using one-way ANOVA and Games-Howell *post hoc* test.

All fibre posts were examined using Scanning Electron Microscope (SEM) (JSM-6610 LV, JEOL Ltd., Tokyo, Japan) to obtain cross-section images of the posts.

RESULTS

The mean and standard deviation of the flexural strength and flexural modulus of the experimental and control posts are tabulated in Table 1. The results of ANOVA showed no significant difference in the flexural strength (987.3 ± 44.8 MPa for FRC PostecPlus; 971.8 ± 42.2 MPa for Rely X) and flexural modulus (26.5 ± 1.3 GPa for FRC PostecPlus; 27.1 ± 1.0 GPa for Rely X) of the two control posts. The

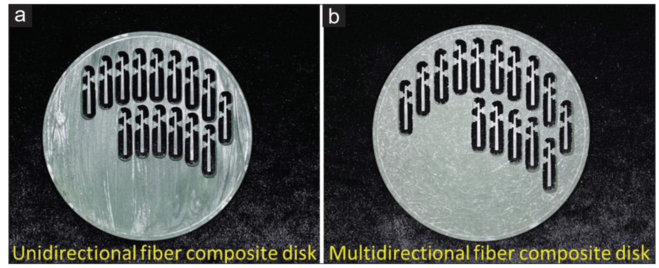

Figure 2: Photographs of the CAD-CAM milled posts in the experimental fibre-reinforced composite CAD-CAM disks. (a) Unidirectional fibre-reinforced composite CAD-CAM disk. (b) Multidirectional fibre-reinforced composite CAD-CAM disk. CAD-CAM: Computer-aided design-computer-aided manufacturing

Table 1: Flexural strength and flexural modulus of the experimental post and control

	Mean±SD	
	Flexural strength (MPa)	Flexural modulus (GPa)
FRC Postec Plus	987.3±44.8[a]	26.5±1.3[a]
Rely X	971.8±42.2[a]	27.1±1.0[a]
Unidirectional disk	739.1±24.1[b]	21.0±3.5[b]
Multidirectional disk	385.4±41.1[c]	10.1±0.9[c]

Same superscript letters in each column indicate no significant difference. SD: Standard deviation

unidirectional fibre-reinforced posts showed a significantly lower flexural strength (739.1 ± 24.1MPa) and flexural modulus (21.0 ± 3.5 GPa) compared to the control posts. The multidirectional fibre-reinforced posts showed the lowest flexural strength (385.4 ± 41.1 MPa) and flexural modulus (10.1 ± 0.9GPa) among all of the posts.

The SEM cross-sectional photomicrographs of the posts are shown in Figure 3. Based on the low magnification photomicrographs, the fibres of FRC PostecPlus showed the most homogeneous distribution compared to the other posts. However, in the high magnification photomicrographs, all posts appeared to have the same fibre distribution.

DISCUSSION

The results of the study showed that the direction of the fibres significantly influenced the mechanical properties. The unidirectional arrangement of the fibres parallel to the length of the postprovided a higher flexural strength in both commercial and experimental posts. Although the experimental posts had a significantly lower flexural strength compared to the commercial posts, their flexural properties are still in the range of acceptable values of posts available in the market.[8,9] The difference in flexural properties could be due to the difference in the fibre load between the commercial posts (70%–80% by weight) and the experimental posts (70% by weight). Several

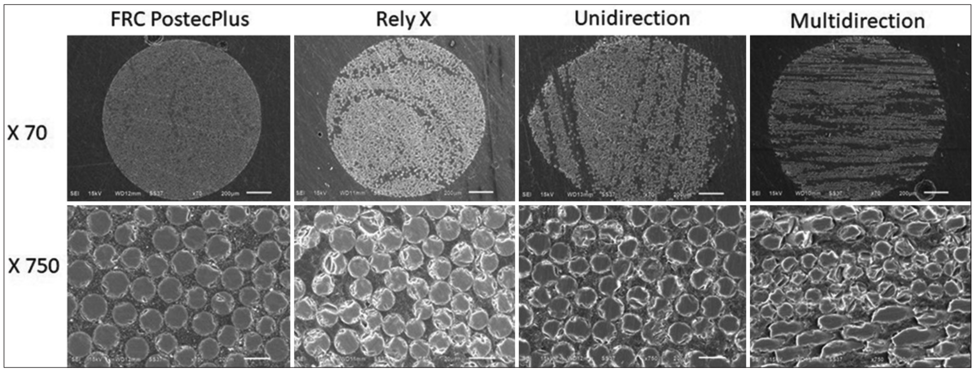

Figure 3: Scanning electron microscope photomicrographs of the cross-sectional surface of the post (×70 and ×750)

studies[10,11] have found that the higher the filler content of the composite, the better the flexural properties. The experimental posts had a limitation when it comes to fibre loading due to the short working time of the epoxy resin. The fibres had to be incorporated and aligned manually before the epoxy resin hardened or cured. It should be mentioned that upon checking the percentage of fibre packing from the photomicrographs with an image analysis software (ImagePro Plus software v. 7.0, Media Cybernetics, MD, USA), it was found that the percentage of fibre packing of the four types of posts utilized in the study was about 55%–70% and were not significantly different. Moreover, not only fibre loading, or fibre packing affected the flexural properties but also the type of fibre, type of matrix and other filler added would also affect the flexural properties[12,13] FRC PostecPlus uses E-glass fibre as the same as the experimental groups. However, it uses a Dimethacrylates resin which is stronger resin than epoxy as a matrix. While RelyX uses epoxy as a matrix as the same as the experimental groups, but it uses S-glass fibre which is the strengthening type of Borosilicate glass as a filler with zirconia powder filler for more strengthening.[14] This might be the reason why the flexural strength of the unidirectional experiment post was not as high as the control. Therefore, increasing fibre load with a more efficient fibre packing technique, the addition of a coupling agent including using more strengthening fibre and matrix to increase flexural properties could be investigated in the future.

It should be noted that most of the commercial posts in dentistry are made from E-glass fibres (Alumino-Borosilicate glass)[14] including FRC Postec Plus, one of the controls in this study. Although some commercial posts such as Rely X post was used S-glass fibre which is the strengthening type of Borosilicate glass with zirconia filler.[15] However, E-glass fibre is more widely used as a medical device, although the properties are not the best, its advantages are suitable for dental application.[15]

One of the critical factors of the CAD-CAM composite disk is the alignment of the fibres in the disk. This study showed that the direction of the fibres parallel to the post length highly influenced the mechanical properties of the posts. The multidirectional fibre-reinforced posts yielded extremely low mechanical properties, both in flexural strength and flexural modulus. There are some commercially available glass-fibre composite disks for CAD-CAM in the market, and they are multidirectional glass fibre composite disks with a fibre load of 75% by weight. The highest flexural strength of these commercially available CAD-CAM milled posts was nearly the same as the experimental multidirectional fibre-reinforced post in this study.[5,6] This could be the reason behind the failure during the use of commercially available CAD-CAM milled posts.[5,6] To correctly the fibres proved to be challenging not only during the preparation and processing of the disks but also during the CAD-CAM milling of the posts. This study confirmed the results of previous studies wherein the difference in mechanical properties could be attributed to the variations in the direction of fibres of the single disk produced.[5]

The higher flexural modulus of the unidirectional fibre-reinforced posts compared to that of the multidirectional fibre-reinforced posts obtained in this study is consistent with the results of other studies.[8,9] It is worth mentioning that the flexural modulus of the unidirectional fibre-reinforced milled posts obtained in this study (21.0 ± 3.5 GPa) is closer to the flexural modulus of the endodontic treated human dentin (17.5 ± 3.8 GPa)[1,16,17] than that of the commercially available prefabricated posts. Hence, the use of these experimental unidirectional fibre-reinforced milled posts may be beneficial for restoring endodontically treated teeth requiring a post and core. Recent reports suggest that the rigidity of the post should be equal or close to that of the tooth to distribute the occlusal force evenly along the root.[18-20]

Although the flexural strength of the unidirectional fibre milled post (739.1 ± 24.1 MPa) was notably lower than the commercially available prefabricated posts, it is within the range of the flexural strength (450–980 MP) of other commercially available prefabricated posts.[5,9,16] This strength could still be improved by increasing the fibre load and incorporating silane to strengthen the bond between the fibres and the epoxy resin matrix.[10,21] Moreover, since CAD-CAM posts can be freely designed and milled together with the core, this is also one way of strengthening the post and core assembly to better support and retain the crown in the clinical situation over the usage of prefabricated post combined with composite as a core to retain the crown.[22]

CONCLUSIONS

Within the limitations of this study, it may be concluded that the direction of the fibres significantly influenced the mechanical properties of the posts. The experimental unidirectional fibre-reinforced composite disk showed the potential to be used as a CAD-CAM disk for post and core fabrication.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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