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Fracture Resistance of Inlay-retained Fixed Partial Dentures Reinforced with Fiber-reinforced Composite

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In this study, the effect on the fracture load of inlay-retained composite fixed partial dentures (FPDs) caused by reinforcing them with fiber-reinforced composite (FRC) in different positions was examined. Experimental FPDs were fabricated using Estenia/EG Fiber (Kuraray Medical). Pontic reinforcement was then performed in one of the following three ways: reinforced the central area in a single line or in double straight lines, or reinforced the bottom in a curved line. The finding was that, when the area ranging from the connector to the bottom of the pontic was reinforced with FRC in a curved line, the fracture load of the FPDs tended to become higher. In addition, the FPDs fractured mainly at the veneering composite of the connector area. Based on the results of this study, it was concluded that reinforcement using FRC is effective, and that the veneering composite in the connector area needs to have sufficient strength to prevent the fractures.

Key words: Fiber-reinforced composite, Fracture load, Inlay-retained fixed partial dentures

INTRODUCTION

When patients have a few missing teeth in the posterior region, the tooth color of restorations is generally reproduced using porcelain-fused-to-metal (PFM) FPDs[1]. However, PFM FPDs pose some problems, such as poor esthetics due to the exposed metal margin or harmful effects on periodontal tissues due to the release of metal ions. Recently, metal-free FPDs — made using ceramic materials[2−4] or resin materials[5−7] — have come to be used in clinical applications. Resin materials play a particularly important role in advancing the clinical application of metal-free FPDs. This is because a succession of high-strength particulate composite resins have been developed[8,9], as well as advances in adhesion technique[10,11] and the advent of high-strength fiber-reinforced composites (FRC) that can be used to make FPD frameworks[12−14].

On the other hand, there is a growing demand for restorations that conserve as much tooth structure as possible, based on the idea of minimal intervention[15,16]. Even when FPDs are indicated, efforts are made to use inlays that require less tooth reduction for the retainer, if the abutment tooth is intact[17−20]. However, ceramics are such a hard and brittle material that the FPDs themselves failed or presented problems in terms of adhesion to the tooth structure[19,21]. In contrast, FRC — which has a lower modulus of elasticity than ceramics — has characteristics closer to dentin, and thus inlay-retained FPDs[6,17,20] using FRC would seem to have advantages over ceramics in terms of fracture resistance and good adhesion.

It has been reported that in the construction of inlay-retained composite FPDs, the width and thickness of FRC at the connector area are two key important considerations[22]. Another report, a study using finite element analysis, argued that with composite FPDs there is a concentration of stresses at both the connector and the bottom of the pontic[23]. These reports showed that the fracture resistance of inlay-retained composite FPDs can be improved by reinforcing the connector and the bottom of the pontic with FRC.

In this study, inlay-retained composite FPDs simulating the size and shape used in a clinical setting were fabricated. Then, the effect on fracture resistance caused by reinforcing these FPDs with FRC in different positions was examined.

MATERIALS AND METHODS

Our experiment was performed using 3-unit inlay-retained fixed partial dentures fabricated for simulating the treatment of a missing mandibular first molar.

Experimental abutments were fabricated by casting gold-silver-palladium alloy (Purumie, Ishifuku Metal Industry, Tokyo, Japan). Distance between the two abutments was set at 15 mm, inlay cavity was determined as 4 mm wide and 2 mm deep, and the connector was made to measure 4 mm in width and 4 mm in thickness. Mesio-distal length of the inlay cavity of the premolar was 5.6 mm, and that of the inlay cavity of the molar was 7.2 mm (Fig. 1). Tooth roots of each abutment were embedded in denture base resin (Palapress Vario, Heraeus-Kulzer, Hanau, Germany) and pseudo periodontal ligaments were created using rubber tubes (Tokai Rubber Industries, Aichi, Japan), as described in a report by Heinrich[24]. The rubber tubes – which were made of fluorocarbon rubber – measured 10 mm in inner diameter, 13 mm in outer diameter, and 14 mm in length.

Estenia/EG Fiber (Kuraray Medical, Tokyo, Japan) was used to make the FPDs (Table 1)[25]. EG Fiber is a type of FRC used to make the framework of FPDs. Tooth-colored Estenia is then layered onto the framework to produce the final FPDs.

EG Fiber was prepared in pieces (4 mm wide × 1.05 mm thick) according to manufacturer's instructions, consisting of about 15,000 glass fibers each. Reinforcement of FPDs with FRC was then performed in one of the following three ways to produce three test groups (Fig. 2):

1) Central area of pontic was reinforced in a straight line (straight method);

2) Central area of pontic was reinforced in a straight line, and the lower part was also reinforced (double method);

3) Bottom of pontic was reinforced in a curved line along the configuration of the bottom surface (curved method).

FPDs fabricated from Estenia alone, with no reinforcing EG Fiber, were used as controls. Inlay-retained FPDs fabricated from Targis/Vectris (Ivoclar Vivadent, Schaan, Liechtenstein) and Sculpture/FiberKor (Pentron, Wallingford, CT, USA) were also examined. Like EG Fiber, Vectris and FiberKor are alternative FRC options used to make FPD frameworks. Tooth-colored Targis or Sculpture is then layered on the framework to produce the final FPDs.

FRC reinforcement was made using the "straight" method for the Targis/Vectris FPDs and the "double" method for Sculpture/FiberKor FPDs – all according to the manufacturers' instructions. Details of the materials used for the experiment are shown in Table 1. However, since the FPDs using Targis/Vectris and Sculpture/FiberKor were fabricated according to their respective manufacturers' instructions, thicknesses of the resultant FRCs were different from that of the FPDs made of Estenia/EG Fiber. Therefore, strictly speaking, it could not be said that the "straight" method for Targis/Vectris FPDs and the "double" method for Sculpture/FiberKor FPDs were the same as those of Estenia/EG Fiber FPDs.

For the three pontic reinforcement methods ("straight", "double", and "curved"), the three FRC insertion positions were defined using three types of

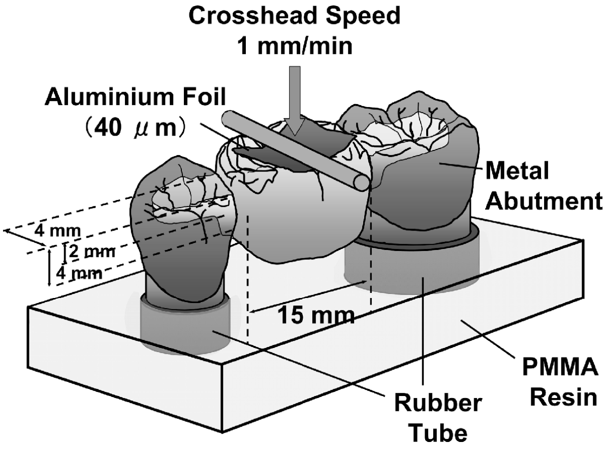

Fig. 1 Schematic diagram of the fracture test.

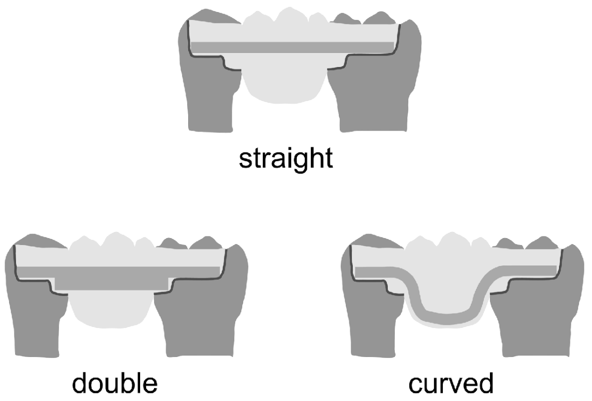

Fig. 2 Positions reinforced by FRC inside the FPD samples subjected to a fracture test.

Table 1 Materials used

Product name	Manufacturer	Monomer composition	Type of composite	Filler/fiber content[25] (wt%)	Fiber diameter (μm)
Estenia	Kuraray	UTMA	Veneering	92 (Filler)	
Targis	Ivoclar Vivadent	Bis-GMA, UDMA	Veneering	80 (Filler)	
Sculpture	Pentron	Bis-GMA, PCDMA	Veneering	78 (Filler)	
EG Fiber	Kuraray	UTMA	Fiber-reinforced	48 (Fiber)	11
Vectris	Ivoclar Vivadent	Bis-GMA, UDMA	Fiber-reinforced	60 (Fiber)	15 (Vectris Pontic)
FiberKor	Pentron	Bis-GMA, PCDMA	Fiber-reinforced	66 (Fiber)	10

UTMA: urethane tetramethacrylate; UDMA: urethane dimethacrylate; PCDMA: polycarboxylate dimethacrylate silicone mold. For the "curved" silicone mold, a silicone mold of the outer shape of each FPD test specimen was first fabricated. Using this silicone mold, a single layer of wax was placed on the bottom surface of the pontic. Then, FRC was applied along the curved line of that base and hardened. With this hardened FRC, a "curved" silicone mold was thus fabricated. Each FPD framework was thereby fabricated and reinforced according to one of the three types studied, and then the veneering composite was layered on it.

FPDs were fabricated using another silicone mold so that the outer shape of each FPD would be the same. Table 2 shows the adherent surface treatment and insertion position of FRC used to prepare the test specimens. Targis/Vectris and Sculpture/FiberKor were surface-treated according to their respective manufacturers' instructions.

The adherend surface of the metal abutments was sandblasted by blasting Al_2O_3 particles with a mean size of 50 μm at a pressure of 0.1 MPa for 10 seconds, washed with water, dried, and then treated with a metal adhesive primer (Alloy Primer, Kuraray Medical). As for the FPDs, each adherent surface was likewise sandblasted, washed with water, dried, and then subjected to silane treatment (Porcelain Bond Activator/Megabond, Kuraray Medical).

The FPDs were bonded to the metal abutments using resin cement (Panavia Fluoro Cement, Kuraray Medical). A total of 60 test specimens were made, 10 for each condition: Estenia/EG Fiber FPDs reinforced by the "curved", "straight", and "double" methods, Targis/Vectris FPDs by the "straight" method, and Sculpture/FiberKor FPDs by the "double" method, and the non-reinforced control samples.

After cementation of the FPDs, the test specimens were immersed in water at 37℃ for 24 hours. Then, they were subjected to a fracture test using a universal testing machine (Auto Graph AG-I, Shimadzu, Kyoto, Japan) at a cross-head speed of 1 mm/min, with the central area of the pontic as the load point (Fig. 1). Statistical analysis of fracture load results was performed using one-way analysis of variance (ANOVA) and Bonferroni's multiple comparison test.

RESULTS

With Estenia/EG Fiber FPDs, fracture loads were 943 N for the "curved" method, 799 N for the "straight" method, and 679 N for the "double" method respectively. All the values were significantly higher than the control ($P<0.05$) (Table 3), but there were no significant differences among the

Table 2 FRC surface conditions and FRC positions

Group	FRC surface condition	FRC position
Estenia	No use	No use
Estenia/EG Fiber	No treatment (unpolymerized surface)	Straight Double Curved
Targis/Vectris	Sandblasting (50 μm, Al_2O_3, 0.1 MPa, 10 sec) Silane treatment Bonding	Straight
Sculpture/FiberKor	No treatment (unpolymerized surface)	Double

Table 3 Fracture loads (N) and fracture positions

Group	Mean	S.D.	Fracture Position		
			Connector	Inlay	Pontic
Estenia	403	184			
Estenia					
Straight	799	152	6	4	0
Double	679	190	8	2	0
Curved	943	233	8	0	2
Targis/Vectris	585	246	4	2	4
Sculpture/FiberKor	570	161	6	2	2

three reinforcement methods: “curved”, “straight”, and “double”.

As for Targis/Vectris and Sculpture/FiberKor FPDs, they had mean fracture loads of 585 N and 570 N respectively (Table 3).

Fracture occurred in the veneering composite area of every specimen. No fractures were observed in the FRC. Seventy-three percent of Estenia/EG Fiber specimens fractured in the connector area (Table 3). In the controls where FRC was not used, the location of the fracture could not be correctly identified because the specimens broke completely after fracture testing.

DISCUSSION

Fracture is one of the greatest concerns when FPDs are fabricated from ceramic or resin material. The maximum bite force of adult males in the posterior region is said to be around 600 N[26,27]. In our experiment, control FPDs that were not reinforced with FRC had such low fracture loads (an average of 403 N) that they probably would not be able to withstand the maximum bite force in the posterior region. The results showed that Estenia, a dental composite resin with a far higher level of flexural strength[25] than other competing products, also could not be used for posterior FPDs if not reinforced with FRC.

By contrast, three types of Estenia/EG Fiber specimens reinforced with FRC exhibited fracture loads of 679 N to 943 N, values that were higher than the maximum bite force of adult males.

From the finite element analysis results, it was shown that in FPDs the largest tensile stress concentrated on the connector area and at the bottom of the pontic[23]. Therefore, it was anticipated that FPDs reinforced with high-strength FRC using the “curved” method would have a high fracture load. In our experiment, the “curved” specimens did show a tendency to fracture under a higher load than the other two types of specimens, but there were no significant differences in fracture load among the three types of specimens. The “double” specimens tended to have a low average value. This was probably because in the “double” method, framework reinforcement with FRC was done at the expense of having a reduced veneering composite thickness in the connector area, thus resulting in lower resistance to fracture. On this note, the effect of the insertion position of FRC on the fracture load of FPDs is yet to be further clarified.

Fracture occurred in the tooth-colored composite resin of the connector area in 73% of the FPD specimens. This prompted us to assume that great tensile stress leading to fracture occurred in the connector area. It has been reported that when all-ceramic FPDs were subjected to a fracture test, fractures were generally observed in the connector area[28,29]. It has also been reported that inlay-retained fixed partial dentures reinforced with FRC must have FRC of adequate width and thickness in the connector area[22], because it was indicated in another finite element analysis report[30] that stress tended to concentrate in the connector area. Based on the results of our experiment and the above-mentioned reports, it can be assumed that the connector area of FPDs — and in particular the strength of the veneering composite — needs to be increased, and/or the stress applied to the veneering composite needs to be reduced. However, with the Targis/Vectris FPDs, 40% of fractures occurred in the connector area. As mentioned in a previous report[31] on the study of FPD fractures, this was probably because the bond strength between Targis and Vectris was so low that fractures occurred sooner at the Targis-Vectris interface where a load was applied, than in the connector area.

Reinforcement using FRC concentrates tensile stress on the FRC frame, which has a high modulus of elasticity, thus resulting in reduced stress on the veneering composite that covers the FRC frame[23]. In this connection, if FPDs were reinforced using FRC that has a higher modulus of elasticity, the stress on the veneering composite would be further reduced, thus leading to improvement in the fracture resistance of the FPDs.

Fracture load of Targis/Vectris and Sculpture/FiberKor FPDs ranged from 570 N to 585 N, values lower than the fracture loads (696-722 N) reported previously for Targis/Vectris combination[32]. This could be mainly due to the difference in the inter-abutment distance used in the previous report (10 mm) and in our experiment (15 mm). In another report[33], it was shown that the fracture load of inlay-retained FPDs reinforced with FRC was reduced by about 25 to 35% when the inter-abutment distance was increased from 7 to 11 mm. In our experiment, we set the inter-abutment distance at 15 mm to simulate a clinically difficult situation, but setting the inter-abutment distance at about 10 mm might help to increase the fracture load level substantially. Further, Estenia/EG Fiber, Targis/Vectris and Sculpture/FiberKor FPDs were fabricated according to their respective manufacturers’ instructions. Therefore, they not only had different types of FRC and veneering composite, but also different FRC thicknesses and bonding conditions between the FRC and the composite. In this experiment, although Targis/Vectris and Sculpture/FiberKor FPDs fractured under a lower load when compared with Estenia/EG Fiber FPDs under the same reinforcement conditions, these results should be regarded as reference data.

It was reported[34] that in the case of all-ceramic inlay-retained FPDs, the alumina-reinforced all-ceramic system had a fracture load of 303±93 N and the zirconia system 1,248±263 N. The fracture load of FPDs reinforced with EG Fiber FRC tended to be greater than that of the alumina-reinforced system, but lower than that of the zirconia-reinforced system. In the above fracture test with all-ceramic FPDs, inter-abutment distance was set at 10 mm. It was therefore difficult to make a strict comparison because the experimental conditions were different. Nonetheless, FPDs reinforced with EG Fiber FRC seemed to have a far higher fracture resistance than alumina-reinforced all-ceramic FPDs.

FRC has come to be used in a variety of dental applications, including denture bases and posts for root canal treatment35,36), but it has only been used for FPDs for a short period of time. It is reported that inlay-retained FPDs reinforced with FRC have a survival rate of 72 to 75% at 36 to 63 months after treatment37,38). It is also said37) that the functional survival rate can be improved to 93% by repair or reinstallation, because the cause of failure in most cases is attributable to dislodgment or partial fracture. There is room for improvement in the area of strength reliability, in particular for those who wish to take advantage of this type of composite material and encourage its wide clinical use. From the above discussion, it may be inferred that reinforcement with FRC is effective, but that sufficient thickness of the veneering composite in the connector area should be ensured to prevent fractures in that area. All the more so in a clinical setting, it is necessary to ensure sufficient thickness in the connector area — which is prone to breaking.

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