Effect of fiber-premixed indirect resin composite substructure on fracture resistance of MOD composite inlays adhered with two different adhesive resin cements

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This study evaluated the effect of a fiber-premixed indirect resin composite (FMC) substructure on the fracture resistance of mesial-occlusal-distal (MOD) indirect composite restorations adhered to extracted human upper premolars. The teeth received a standardized MOD cavity preparation, and indirect composite inlays were fabricated with or without using the FMC. Inlays were cemented into the cavity preparations using either Super-Bond C&B or Panavia F2.0. A total of 28 specimens, namely seven specimens for four groups, were thus fabricated. Failure load and failure energy were determined after thermocycling (4–60°C for 5,000 cycles). In terms of failure load, no significant differences were found among the four groups. In terms of failure energy, FMC substructure exerted a significantly favorable effect on Super-Bond C&B-bonded group but a negative one on Panavia F2.0-bonded group. In conclusion, the failure energy of the group using FMC substructure and which was adhered using Super-Bond C&B was significantly higher than the other groups.

Keywords: Fiber-premixed indirect resin composite, Indirect resin composite inlay, Fracture resistance

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INTRODUCTION

Indirect composite restorations have been widely used for inlays, onlays, crowns, and fixed partial dentures because of improvements in physical and mechanical properties¹⁾, wear resistance²⁾, and color stability³⁾. In a closely related manner, advances in adhesion technique to abutment teeth⁴⁾ also helped spur the popularity of indirect composite restorations.

With composite restorations, clinicians often encounter crack formation or bulk fracture due to the brittleness of composite materials. To prevent bulk fracture, reinforcement techniques with glass and/or polymer fibers were developed. In terms of clinical application, some indirect composite restorative systems using pre-impregnated fibers have been introduced. Some *in vitro* studies have reported that fiber incorporation increased the fracture resistance of indirect resin composite crowns^{5,6)} and bridges^{7,8)}, whereas others^{9,10)} concluded that composite materials did not benefit from fiber reinforcement for crowns.

Recently, a novel fiber-premixed indirect resin composite (FMC) was developed¹¹⁾ as a core material for indirect composite restorations, which does not necessitate further fiber incorporation. Satisfactory interfacial bonding between the FMC and indirect composite, and improved toughness and impact resistance of the indirect resin composite have been reported¹²⁾. Although most reinforced composite systems are applicable for fabrication of crowns^{5,6,9,10)} and bridges^{7,8)}, the FMC can be used only for single

tooth restorations as a core material in crowns, onlays, and inlays.

The hypothesis to be tested in this study was that the use of FMC would improve the fracture resistance of indirect composite restorations. In line with this hypothesis, the purpose of this *in vitro* study was to evaluate the effect of this FMC as a substructure on the fracture resistance of class II mesial-occlusal-distal (MOD) indirect composite restorations adhered to extracted human upper premolars using two different adhesive resin cements.

MATERIALS AND METHODS

Materials used

Materials used in this study are presented in Table 1. Fiber-premixed indirect resin composite (Jacket Opaque JMO, A3 opaque shade: FMC, Sun Medical Co. Ltd., Moriyama, Japan) and a microfilled indirect resin composite (Meta Color Prime Art Body Paste A3-B, A3 body shade: IC, Sun Medical Co. Ltd.) were used as inlay materials. Panavia F2.0 (PV, Kuraray Medical Inc., Tokyo, Japan) and Super-Bond C&B (SB, Sun Medical Co. Ltd.) were used as luting materials.

The composition of FMC has been reported by a dental manufacturer and detailed in a previous study¹²⁾. It contained UDPAC as comonomer at 41.93 wt% and TEGDMA as matrix resin at 27.82 wt%, as well as silanized milled glass fiber at 24.84 wt% and colloidal silica as filler at 4.97 wt%. The organic components of FMC were dissolved in acetone for 60 minutes, and the

residual glass fibers were air-dried and gold-coated using an ion-sputtering device (Fine Coat Sputter, JCF-1100, JEOL, Tokyo, Japan). When observed under a scanning electron microscope (SEM) (JSM-1100, JEOL), it was shown that FMC contained silanized milled glass fibers with a diameter of 11 μm and an average length of 150 μm (Fig. 1).

MOD cavity preparation

Twenty-eight maxillary premolars were collected immediately after extraction and stored in isotonic sodium chloride solution at 4°C before being used in this study. They were nearly identical in size (buccal-palatal width: 9.52 ± 0.29 mm, mesial-distal width: 7.59 ± 0.26 mm, coronal height: 8.89 ± 0.32 mm), and all of them were intact and caries-free. The apex of each root was sealed with adhesive resin cement (Super-Bond C&B) without removal of pulp tissue, and then the teeth were mounted into stainless molds perpendicular to their long axis using an autopolymerizing resin. A standardized class II mesial-occlusal-distal (MOD) cavity with convergent walls was prepared in all teeth (Fig. 2) with rotating diamond burs (SF206CR and SF103CR, Shofu Inc., Kyoto, Japan) under copious water spray. A high-speed

handpiece combined with a dental surveyor (Ney Surveyor, JM Ney Co., CT, USA) was used to achieve standardized cavity preparations.

Impressions of the preparations were made using a polyvinylsiloxane impression material (Exafine, GC Corp., Tokyo, Japan) with a two-step impression

Fig. 1 SEM micrograph of the milled glass fibers contained in FMC.

Table 1 Materials used in this study

Material	Product name	Abbreviation	Component	Manufacturer	Lot No.
Fiber-premixed indirect resin composite	Jacket Opaque JMO (A3 body shade)	FMC	UDPAC, TEGDMA	Sun Medical Co. Ltd.	RS3
			Silanized milled-glass fiber (10- μm diameter, 150- μm length) Colloidal silica (0.007 μm) Photoinitiator, Stabilizer		
Indirect resin composite	Meta Color Prime Art Body Paste A3-B (A3 body paste)	IC	UDMA, TEGDMA Reactive prepolymerized filler Photoinitiator	Sun Medical Co. Ltd.	RS1
Luting materials	Panavia F2.0	PV	Paste A: MDP, Methacrylate monomer, Filler, Photoinitiator, Chemical initiator	Kuraray Medical Inc.	00117A
			Paste B: Methacrylate monomer Photoinitiator, Chemical initiator		00087A
			Oxyguard II: Polyethylene glycol, Accelerator		00525A
	Super-Bond C&B	SB	Catalyst: TBB Monomer Liquid: 4-META, MMA Powder (Clear): PMMA	Sun Medical Co. Ltd.	LV11 LS2 LV21

UDPAC: urethane dimethacrylate with polyaliphatic carbonate segment

TEGDMA: triethylene glycol dimethacrylate

UDMA: urethane dimethacrylate

MDP: 10-methacryloyloxydecyl dihydrogen phosphate

TBB: tri-*n*-butylborane derivative

4-META: 4-methacryloxyethyl trimellitate anhydrate

MMA: methyl methacrylate

PMMA: poly(methyl methacrylate)

technique. Impressions were poured with a type IV improved dental stone (Suprastone, Kerr Corp., Orange, CA, USA). After setting, the stone dies were removed from the impressions and coated with a proprietary separating medium (Prime Sep, Sun Medical Co. Ltd.) of 10 μ m thickness.

Specimen fabrication

Table 2 summarizes the characteristics of the fabricated specimens. Half of the specimens ($n=14$) were fabricated without using the FMC, and the remaining specimens ($n=14$) were fabricated with FMC.

The FMC substructures were layered in three increments into a final thickness of approximately 0.5 mm. The thickness of each increment was measured using a customized periodontal probe which allowed 0.2-mm depth measurements, and each increment was polymerized in a laboratory photopolymerizing unit (α -Light II, Morita, Tokyo, Japan) for 90 seconds. Indirect resin composite was built up in two increments to acquire an inlay with simplified occlusal surface configuration. Each increment was polymerized in the laboratory photopolymerizing unit (α -Light II, Morita) for 90 seconds. All the inlays were finished with

silicone polishing burs (CompoMaster, Shofu, Kyoto, Japan) and removed from the stone dies.

The inner surfaces of the inlays were air-abraded with 50- μ m aluminum oxide particles (Hi Aluminas, Shofu) under 0.2 MPa for 5 seconds, and then thoroughly air-blasted. For both with-FMC and without-FMC groups, half of the inlay preparations ($n=7$) were cemented into the prepared cavities using either SB or PV.

Prior to cementation, the enamel surfaces of prepared cavities were etched with 65% phosphoric acid (Red Activator, Sun Medical) for 30 seconds for SB-bonded groups, and 40% phosphoric acid (K-etchant Gel, Kuraray Medical) for 10 seconds for PV-bonded groups. Following which, the dentin surfaces were treated with a dentin conditioner (Green Activator, Sun Medical) for 5 seconds for SB-bonded groups, and a dentin primer (ED Primer II, Kuraray Medical) for 30 seconds for PV-bonded groups. The inlays were cemented into the prepared cavities according to manufacturers' instructions under a 1.0 kgf static load, and excess cement was removed. A total of 28 specimens, namely seven specimens for four groups, were thus fabricated (Fig. 3).

Fig. 2 Dimensions of inlay preparation:
a: 3.2 mm (same as the diameter of SF206CR bur)
b: 1.4 mm (same as the diameter of SF103CR bur)
c: 3.6 mm (same depth and taper of SF206CR bur)
d: 1.0 mm above the cement-enamel junction

Table 2 Characteristics of fabricated specimens in four different groups

Group name	Inlay materials	Adhesive cements
IC/SB	Indirect resin composite	Super-Bond C&B
FMC/IC/SB	Fiber-premixed indirect resin composite/Indirect resin composite	Super-Bond C&B
IC/PV	Indirect resin composite	Panavia F 2.0
FMC/IC/PV	Fiber-premixed indirect resin composite/Indirect resin composite	Panavia F 2.0

Fig. 3 MOD composite inlay cemented into the prepared cavity.

Fracture test

Specimens were removed from the molds and stored in 37°C distilled water for 24 hours. After water storage, the specimens were subjected to thermocycling between 4°C and 60°C with 1-minute dwell time at each temperature for 5,000 cycles. Each specimen was remounted into the mold, and a fracture test was carried out using a universal testing machine (Autograph AGS-5kNG, Shimadzu Corp., Kyoto, Japan). A vertical load was applied through a 4-mm-diameter sphere onto the mesial occlusal pit of the composite inlay at a crosshead speed of 1.0 mm/min until initial crack occurred.

Load-displacement curve was recorded throughout the fracture test using an analog recorder (AR-6422, Shimadzu Corp.) at a chart speed of 100 mm/min. The load at initial crack was determined as failure load (N). The initial crack was detected as the first sharp drop in the load (Fig. 4) with a snapping sound. The energy required to cause initial crack (J) was calculated from the area under the load-displacement curve. All the load-displacement curves were captured using a scanner (GT-9800F, Seiko Epson Corp., Nagano, Japan). To calculate failure energy (J), the area bounded by the load-displacement curve and the x-axis until the initial crack occurred was computed using an image analysis software (Microanalyzer, Nihon Poladigital Corp., Tokyo, Japan).

Statistical analysis

Both failure load and failure energy data of each group were analyzed and depicted with box and whisker plots using a statistical analysis software (SPSS 13.0, SPSS Inc., Chicago, IL, USA). Each box represented the 25th

Fig. 4 Typical trace of a load-displacement curve during fracture test.

and 75th percentiles, and the bar represented the median. Whiskers were drawn to show the range 1.5 times the interquartile range beyond the 25th and 75th percentiles. For values outside 1.5 times the interquartile range, they were marked as outliers ("o").

Owing to large variations in both the failure load and failure energy data, non-parametric Kruskal-Wallis test was performed to determine significant differences among the four groups. The Mann-Whitney U test was used for subsequent comparisons between groups. The level of significance was set at 0.05 for all statistical analyses.

RESULTS

Figures 5 and 6 present the failure load (N) and failure energy (J) results for each group.

On failure load, Kruskal-Wallis test showed that there were no significant differences among the four groups ($p=0.1081$) (Fig. 5).

On failure energy, Kruskal-Wallis test showed that there were significant differences among the four groups ($p=0.0034$) (Fig. 6). The Mann-Whitney U test showed that the mean failure energy of FMC/IC/SB group was significantly higher than the other three groups ($p=0.004-0.018$). Between the SB-bonded groups, the failure energy of FMC/IC/SB group was significantly higher than that of IC/SB group

Fig. 5 Failure load of each group.

Fig. 6 Failure energy of each group. The asterisks denote significant difference ($p < 0.05$).

($p=0.0181$). In other words, the fiber substructure exerted a significant positive effect on the SB-bonded specimens. Between the PV-bonded groups, failure energy of FMC/IC/PV group was significantly lower than that of IC/PV group ($p=0.035$). In other words, the fiber substructure exerted a negative effect on the PV-bonded specimens.

Initial cracks were observed in the composite resin inlays, and fracture of tooth structure did not occur for all groups. No delamination of FMC from IC was found for the with-FMC groups.

DISCUSSION

This *in vitro* study evaluated the effect of fiber-premixed indirect resin composite, as a substructure, on the fracture resistance of class II indirect composite restorations adhered with two different adhesive cements under static loading. The hypothesis was partially accepted because the fiber substructure showed a significant positive effect on the failure energy of SB-bonded specimens, but there was no significant effect on failure strength.

A previous study¹²⁾ reported that the impact resistance of indirect composite was affected by the thickness of FMC. Therefore, in this study, influence of this variable was stringently excluded by measuring each element of the cavity preparation to ensure uniform FMC thickness.

The maximum bite force and single tooth bite force in the premolar region have been reported to be 246–398 N¹³⁾ and 179–291 N¹⁴⁾ respectively. The failure loads obtained for all the groups in this study were greater than these values. In particular, the failure loads obtained in this study agreed with the mean

value of 422 N as reported by Sorrentino *et al.*¹⁵⁾. Notably, loading in the study of Sorrentino *et al.*¹⁵⁾ was performed in a similar manner as the current study. Therefore, the specimen preparation conditions employed in this study might be acceptable for clinical simulation.

The UDPAC monomer used for FMC possesses a soft segment of polyaliphatic carbonate segment¹²⁾. While the high impact resistance of FMC could be attributed chiefly to the silanized milled glass fiber (Table 1), the ductile property of the FMC should be ascribed to the soft segment of the UDPAC monomer. Indeed, the ductile property of FMC seemed to be more pronounced when compared against the stiff properties of indirect resin composite, as the fracture energy of the FMC was approximately 3.5 times that of indirect resin composite¹²⁾. Nonetheless, combining these two different types of materials might have improved the impact resistance of the indirect resin composite, as gleaned from the results of the present study.

For the FMC/IC/SB group, the intermediate layer consisting of FMC and SB might have functioned as a shock-absorbing structure between the composite resin and dentin. Consequently, a significantly higher failure energy was obtained for FMC/IC/SB group as compared to group IC/SB. The clinical implication of this finding could be a prolonged life of composite resin inlays in intra-oral conditions. In sharp contrast, the failure energy of PV-bonded specimens declined when combined with FMC. It should be pointed out that for efficacious reinforcement of indirect resin composites, the FMC substructure must be approximately 30% in thickness¹²⁾. However, the stiff PV layer between FMC and dentin in the FMC/IC/PV group reduced the relative thickness of FMC within the total thickness of

the inlay-PV complex. Consequently, this phenomenon blunted the effectiveness of FMC as a shock absorber, thereby resulting in significantly lower failure energy of group FMC/IC/PV as compared to groups IC/PV and FMC/IC/SB.

To date, many studies have reported on the dentin bond strengths of the adhesive resin cements tested in this study¹⁶⁻¹⁹. In the study by Al-Assaf *et al.*¹⁶, it was reported that PV showed comparable bond strength with SB. On the other hand, other studies¹⁷⁻¹⁹ reported that SB exhibited higher bond strength than PV. As for the bonding between the adhesive resin cements and restorative materials employed in this study, Taira *et al.* reported that the FMC showed superior bond strength compared to indirect resin composite²⁰. As for the comparison between SB and PV, SB showed significantly higher bond strength when bonded to indirect resin composite but no significant differences were observed for the bonding to FMC²⁰. In the present study, there were no significant differences in failure load among the four groups. Against this backdrop of contradictory and confusing results, the clinical significance of FMC toward the fracture resistance of restored premolars needs to be further evaluated to ensure the longevity of restorations and restored teeth.

CONCLUSION

Within the limitations of this *in vitro* study and based on the results obtained, it was shown that the use of fiber-premixed indirect resin composite (Jacket Opaque) for indirect composite (Meta Color Prime Art) MOD inlays enhanced the fracture energy when cemented to dentin using Super-Bond C&B.

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