Influence of filling technique and curing mode on the bond strengths of composite cores to pulpal floor dentin

Meu ARIYOSHI¹, Toru NIKAI², Richard M. FOXTON² and Junji TAGAMI^{1,3}

¹Cariology and Operative Dentistry, Department of Restorative Sciences, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8549, Japan

²Department of Conservative Dentistry, King's College London Dental Institute at Guy's, King's and St. Thomas' Hospitals, King's College London, London Bridge, London SE1-9RT, UK.

³Global Center of Excellence (GCOE) Program; International Research Center for Molecular Science in Tooth and Bone Diseases. Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8549, Japan

Corresponding author, Meu ARIYOSHI; E-mail: ariyoshi@iro@yahoo.co.jp

This study evaluated the influence of filling technique and curing mode on the microtensile bond strengths (MTBS) of composite cores to pulpal floor dentin. Access cavities of human molars with pulpal floor dentin were restored with a two-step self-etch adhesive system, Clearfil Liner Bond 2V and a composite core, Clearfil DC Core Automix, using different filling techniques and curing strategies. A flowable resin composite, Clearfil Flow FX was placed on the cured adhesive resin prior to restoration with a composite core. Packing the composite in the access cavity was performed in bulk with or without light curing or using an incremental technique with light curing. Microtensile bond strengths to pulpal floor dentin were measured after 24 hours storage in water. Light curing and incremental technique had positive effects on the MTBSs. Lining with a flowable resin composite did not significantly improve the MTBSs, however, influenced the failure mode after debonding. Non-lining and bulk filling with chemical curing strategy provided the lowest MTBS.

Keywords: Composite resin core, Filling technique, Pulpal floor dentin

INTRODUCTION

Recently, tooth-colored composite core materials have been used as core build-up materials to restore non-vital teeth, especially with rapidly escalating patients' demands for esthetic restorations in dentistry. In terms of beneficial effects, composite core systems can prevent root fractures of non-vital teeth, since a good dentin bonding system has been shown to reinforce the remaining tooth structure^{1,2}. Further, in comparison with a metal post, the elastic modulus of a composite core material is similar to that of dentin³, which plays a role in preserving the remaining tooth structure against root fractures⁴.

Selecting a composite core system, comprising a composite core material and an adhesive system, is an important step towards the clinical success of restorations in endodontically treated teeth⁵. Recent self-etching primer adhesive systems have demonstrated good bonding to root canal dentin^{6,7} and pulpal floor dentin⁸⁻¹¹ as well as to coronal dentin. However, several clinical factors affect the bond strength to endodontically treated teeth, such as root dentin region (apical, middle, or coronal)^{12,13} and root dentin condition (normal *versus* sclerotic dentin)^{14,15}.

As for the polymerization of adhesive/composite systems, several curing modes are currently available: light curing, chemical curing, and dual curing. Light polymerization offers the advantage of an extended working time and polymerization on demand. However, light polymerization is not sufficient in deeper regions, such as the bottom of a post cavity, because of limited

light energy transmission through the material. As a result, dual curing emerges as the most popular curing mode in composite core foundation systems, which are able to polymerize chemically in regions without light transmission. Nonetheless, light polymerization of composite resins is essential for achieving good bonding even for dual-cure composite core systems. It was reported that the dentin bond strength of a dual-cure adhesive system without light curing was significantly lower than that with light exposure¹⁶. Although a chemically cured adhesive is beneficial for deep cavities in non-vital teeth, no successful composite core systems with a solely chemically cured adhesive have been reported to-date¹⁶.

Flowable resin composite was initially developed as a flexible intermediate layer in 1991. It was thought that this layer could play the role of an elastic buffer¹⁷. Indeed, this elastic buffer successfully improved the bond strength of adhesive systems and reduced gap formation^{18,19}. From these results, it was suggested that flowable composite liners could also reinforce the bonding performance of bonding agents to the cavity walls since this technique could improve the degree of conversion of a bonding layer²⁰. In particular, the thickness of the flowable liner is sufficient to eliminate the problem of oxygen inhibition, thereby helping to establish a strong and durable bond to dentin²¹. Moreover, it was reported that incremental filling techniques are capable of increasing the degree of conversion on the cavity floor and reducing stress concentration at the tooth interface when a light-activated resin composite is employed^{22,23}. From these

reports, it is a commonly held belief that lining²⁴⁾ or incremental²⁵⁾ techniques are recommended for large cavities. In the case of endodontically treated teeth, the cavities may also become very deep. However, few studies have examined these techniques using dual-cure composite core system in endodontically treated teeth^{5,26)}.

For successful adhesive restorations of non-vital molars, it is important to obtain good dentin bonding to pulpal floor dentin as the latter always remains in any non-vital molar, which requires restoration. To date, several studies have reported on bond strength of composite restorations to pulpal floor dentin⁸⁻¹¹⁾. Akagawa *et al.*⁸⁾ evaluated the shear bond strengths of resin bonding systems to coronal dentin and to the floor of the pulp chamber. They reported that a self-etching primer bonding system was able to provide high bond strengths to pulp chamber floor dentin as well as to superficial and deep coronal dentin. Toba *et al.*⁹⁾ measured the micro-shear bond strengths of a self-etch and an acid-etch dentin bonding system to coronal dentin and to the floor of the pulp chamber. It was found that the self-etching primer system showed more reliable bonding to both regions of the dentin. Moreover, Ariyoshi *et al.*¹¹⁾ evaluated the bond strength of indirect composite cores to pulpal floor dentin. They concluded that resin coating using a combination of a self-etching primer system and flowable resin composite enhanced the microtensile bond strengths of indirect composite cores to pulpal floor dentin.

However, there is very little published research on the bond strength of composite cores to pulpal floor

dentin. Given the paucity of information, there is a need to evaluate the influence of clinical techniques on the bond strengths of direct composite cores to pulpal floor dentin. The purpose of this study, therefore, was to evaluate influence of filling technique, incremental technique, lining, and curing mode on the microtensile bond strengths (MTBS) of direct composite cores to pulpal floor dentin. The null hypothesis proposed was that the filling technique and curing mode did not influence the MTBSs of direct composite cores to pulpal floor dentin.

MATERIALS AND METHODS

Specimen preparation

A total of 30 extracted non-caries human molars, freshly extracted for orthodontic reasons, were used in this study. The research protocol of this study was designed according to the guidelines of the Ethics Committee of the Graduate School and Hospital, Tokyo Medical and Dental University. Prior to extraction, the patients from whom the teeth were extracted gave informed consent to the use of their teeth for this *in vitro* study. The specimen preparation procedure is illustrated in Fig. 1, where the teeth were stored in distilled water at -20°C until use. Initially, the access cavity preparation of the molars was performed using a high-speed diamond bur (ISO #109, Shofu, Kyoto, Japan) under water spray. Following this, the pulpal tissues were carefully removed using endodontic files (K-files, GC, Tokyo, Japan), Patency of the apical foramen was determined using a #35 K-file. Working

Fig. 1 Sample preparation

length was established 0.5 mm short of the length at which this file exited the foramen, ensuring that the apical preparation was complete to within 1mm of the apical foramen. The canals were not irrigated with chemical irrigants. Master gutta-percha cones (gutta-percha points, GC) were fitted to within 1 mm of the working length. The cones were not coated with sealing materials, placed in the canals, and condensed by cold lateral condensation. Gutta percha in the pulp chamber was then completely removed with a steel bur (ISO #012, Shofu) to expose the pulpal floor dentin. The occlusal portion of their crowns were cut perpendicularly to the tooth axis using a high-speed diamond bur under water spray to standardize the cavity walls to a height of 6 mm from the pulpal floor dentin.

Table 1 lists the materials used in this study. The pulpal floor dentin of all the specimens were treated with Clearfil Liner Bond 2V (LB) (Kuraray Medical, Tokyo, Japan) according to the manufacturer's instructions. The specimens were then divided into two subgroups; In one group (LN+), the cavity surfaces treated with LB were lined with a flowable resin composite, Clearfil Flow FX (FX) (Kuraray Medical). In the other group (LN-), the cavities treated with LB were left without any lining. Following this, a dual-cure composite resin core, Clearfil DC Core Automix (DC) (Kuraray Medical) was placed in either bulk (Bulk) or in three increments (Inc). For the incremental groups, 20 s light curing was performed for each increment. For the bulk-filling groups, the specimens were activated by either light-curing for 60 s (Bulk) or chemical curing in darkness for 30 min (CC). All light curing procedures were performed from an occlusal direction using a halogen light curing unit (Optilux

500, Demetron, Danbury, CT, USA) with a standard irradiation mode of 650 mW/cm².

Microtensile bond strength test

All the specimens were stored in water at 37°C for 24 hours. Thereafter, each specimen was cross-sectioned longitudinally using a low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) to obtain beam-shaped specimens measuring 1.0×1.0 mm. The cross-sectional area of each beam was measured using digital calipers (Mitutoyo CD15, Mitutoyo, Kawasaki, Japan) prior to 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, Kyoto, Japan) using cyanoacrylate glue (Zapit, DVA, Anaheim, CA, USA) and subjected to a tensile force at a crosshead speed of 1 mm/min. The number of specimens in each group was five. Since the area of pulpal floor dentin for bonding varies for each tooth, the average bond strength for each tooth calculated was designated as the bond strength of one tooth. The results were statistically analyzed with one-way ANOVA and Tukey HSD test.

Failure modes

The fractured surfaces after debonding were visually inspected and then several representative examples were selected for examination of the ultrastructure of the debonded surface. These specimens were gold sputter-coated 3 µm thick and observed using an SEM (JSM-5310LV, JEOL, Tokyo, Japan). Fracture modes were classified into five categories as follows: A, complete or partial fracture at the interface between DC and adhesive; B, mixed failure including cohesive failure in DC and fracture at the interface between DC

Table 1 Materials used in this study

Material	Batch number	Composition	Procedure
Clearfil Liner Bond 2V	00150B	Primer;	Apply mixture of A+B for 30 s, air-blow
	00149A	Liquid A: MDP, HEMA, photo initiator, accelerator, water Liquid B: HEMA, chemical initiator, water	
	00243A 00058A	Bond; Liquid A: MDP, HEMA, dimethacrylates, microfiller, photo initiator, accelerator Liquid B: HEMA, dimethacrylates, microfiller, chemical initiator	Apply mixture of A+B for 30 s, air-blow, light-cured 20 s
Clearfil Flow FX	0005AA	Bis-GMA, TEGDMA, UDMA, filler, photo initiator	Light-cure 20 s
Clearfil DC Core Automix	0040AA	Catalyst; Bis-GMA, TEGDMA, silanized glass fillers, silica microfillers, photo/chemical initiator	Light-cure 60 s.
		Universal; TEGDMA, methacrylate monomers, silanized glass fillers, silica microfillers, photo/chemical initiator	

Manufacturer; Kuraray Medical, Tokyo, Japan.

HEMA, 2-hydroxyethyl methacrylate; MDP, 10-methacryloyloxy methacrylate; Bis-GMA, bisphenol-A-diglycidyl methacrylate; TEGDMA, triethyleneglycol dimethacrylate; and UDMA, urethane dimethacrylate

and adhesive; C, cohesive failure in DC; D, mixed failure including cohesive failure in DC, flowable resin and adhesive; and E, mixed failure including cohesive failure in DC and fracture at the interface between a flowable resin and DC.

SEM observation at the adhesive interface

Eighteen extracted human molars were divided into six groups; LN-/LC-Inc, LN-/LC-Bulk, LN-/CC-Bulk, LN+/LC-Inc, LN+/LC-Bulk and LN+/CC-Bulk. In order to observe the adhesive interface, each specimen was bonded in the same manner as that for the MTBS test. All the specimens were cut off the roots and trimmed with a diamond bur (F102R, ISO #016, Shofu) under copious water irrigation to a size of 10×10×5 mm. The specimens were then embedded in a self-curing epoxy resin (Epoxicure, Buehler) for 24 hours. After curing of the epoxy resin, each specimen was perpendicularly sectioned to the adhesive interface at the center of the pulpal floor dentin using a low-speed diamond saw (Isomet, Buehler). Each group consisted of 6 specimens from 3 teeth. Each specimen was ground with #600-grit silicon carbide paper under running water, and then finished with abrasive disks and diamond pastes (DP-Paste, Struers, Ballerup, Denmark) down to a 0.25 µm particle size. The specimens were cleaned ultrasonically in distilled water for 2 minutes at each step and dried at room temperature for 24 hours, before being subjected to argon-ion-beam etching (EIS-1E, Elionix, Tokyo, Japan) for 6 min at 0.2 mA and 1 kV to disclose the interfacial structure, then gold sputter-coated 3 µm thick, and observed with a SEM (JSM-5310LV, JEOL). In the lining groups, the thickness of the coating layer for each specimen was determined by averaging the values at the thickest and the thinnest portions of the coating layer in each specimen.

RESULTS

Microtensile bond strengths

The mean MTBSs of the composite resin cores to pulpal floor dentin and fracture modes are presented in Table 2. High bond strengths were obtained in three groups; LN-/LC-Inc, LN+/LC-Inc and LN+/LC-Bulk, which were significantly higher than the other groups. However, there were no significant differences among them. The MTBS of the LN-/CC-Bulk group was the lowest among all the groups ($p<0.05$). There were no significant differences between the lining and non-lining groups ($p>0.05$). For the non-lining groups, the incremental filling techniques significantly improved the bond strengths, while there were no significant differences between incremental filling and bulk filling groups for the lining groups. Moreover, the LC groups provided significantly higher bond strengths than the CC group, regardless of lining.

Failure pattern

The fracture modes after the MTBS test are summarized in Table 2. In the LN-/LC-Inc group and LN-/LC-Bulk group, almost all of these specimens showed mode B (mixed failure including cohesive failure in DC and fracture at the interface between DC and adhesive). On the other hand, in the LN-/CC-Bulk group, all specimens showed mode A (complete or partial fracture at the interface between DC and adhesive). For the lining (LN+) groups, fracture mode E (mixed failure including cohesive failure in DC and fracture at the interface between a flowable resin and DC) was mainly observed.

SEM observations of adhesive interface

SEM observations of adhesive interface between Liner Bond 2V (LB) and dentin with (LN+) or without (LN-) lining are shown in Fig. 2. From the SEM observation

Table 2 MTBSs of composite resin core to pulpal floor dentin (MPa) and fracture modes

Experimental group	Lining	Filling technique	Curing mode	MTBS (MPa)	Fracture mode (%)				
					A	B	C	D	E
LN-/LC-Inc	Non-lining	Increment	Dual	27.7 (3.8) ^a	0	100	0	0	0
LN-/LC-Bulk	Non-lining	Bulk	Dual	18.1 (4.2) ^{b, d}	0	67	33	0	0
LN-/CC-Bulk	Non-lining	Bulk	Chemical	9.9 (3.2) ^c	100	0	0	0	0
LN+/LC-Inc	Lining	Increment	Dual	28.1 (3.3) ^a	0	0	0	40	60
LN+/LC-Bulk	Lining	Bulk	Dual	25.1 (4.3) ^{a, b}	0	0	27	0	73
LN+/CC-Bulk	Lining	Bulk	Chemical	16.0 (3.7) ^{c, d}	0	0	17	0	83

mean (SD); $n=5$.

The same superscript letters represent no statistically significant difference ($p>0.05$).

Fracture modes: A, complete or partial fracture at the interface between DC (a dual-cure resin composite core, Clearfil DC Core Automix); B, mixed failure including cohesive failure in DC and fracture at the interface between DC and adhesive; C, cohesive fracture in DC; D, mixed failure including cohesive failure in DC, flowable resin and adhesive; and E, mixed failure including cohesive failure in DC and fracture at the interface between a flowable resin and DC.

LN, Lining with flowable resin composite; LC, Light cured; Inc, Incremental filling; Bulk, Bulk filling; and CC, Chemical cured

Fig. 2 SEM observations of adhesive interface between Clearfil Liner Bond 2V (LB) and dentin with (LN+) or without (LN-) lining (DC: Clearfil DC Core Automix, LB: Clearfil Liner Bond 2V, FX: Clearfil Flow FX, and D: Dentin). a: Non-lining groups, b: Lining groups with a flowable resin composite, c: The hybrid layer less than 1.0 µm thick was created with LB, and d: In the lining groups, thickness of the lining layer created by a flowable resin composite was less than 850 µm.

at the adhesive interface, no gap and not defect were found in all the groups due to different filling techniques and curing modes. The ultrastructure of pulpal floor dentin seems similar to secondary or reparative dentin and contains irregular, fewer and narrower dentinal tubules. A hybrid layer less than 1.0 µm thick was created with LB (c). In the LN+ groups, the lining created less than 850 µm thick layer on the adhesive surface (d). The thickness of the lining tended to be the same with the three groups (LN+/LC-Inc, LN+/LC-Bulk and LN+/CC-Bulk).

DISCUSSION

In this study, the MTBS test using human teeth was chosen for testing. The dentin bonding performance of composite resin cores to root dentin has been evaluated by several methods. Loading stress is theoretically concentrated around the interface in tensile bond testing. Koibuchi *et al.*²⁷ evaluated the efficacy of a

miniaturized dumbbell test procedure designed to more easily identify defects in bonded dentin test specimens. They suggested that this protocol was capable of clearly elucidating defective resin infiltration of demineralized dentin in bonded interfaces. Separately, Sano *et al.*²⁸ introduced a MTBS test to measure the bond strength of small surface areas (*ca.* 1 mm²), enabling some degree of correlation of bond strength to clinically relevant cavity preparations. Chen *et al.*²⁹ then reported that the non-trimming microtensile test potentially rendered a more realistic expectation of resin-dentin bonding than with conventional bulk specimens. Therefore, in this study, the MTBS test using beam-shaped specimens was selected as the method to measure the bonding performance of composite core materials to pulpal floor dentin.

In clinical situations, direct composite core restorations are the preferred treatment over indirect composite core restorations because they require minimal intervention and cavity preparation. However,

in case of endodontically treated teeth, the cavities may also become very deep. The bulk filling technique for light-cured resin composites is no longer appropriate for large cavities because of the limited depth of cure³⁰. Dual-curing emerges as the most popular curing mode in composite core foundation systems, which are able to polymerize chemically in regions without light transmission. Nonetheless, light polymerization of composite resins is essential in achieving good bonding even for dual-cure composite core systems. It has been reported that the dentin bond strength of a dual-cure adhesive system without light curing was significantly lower than that with light exposure¹⁶. Although a chemically cured adhesive is beneficial for deep cavities in non-vital teeth, no successful composite core systems with a solely chemically cured adhesive have been reported to-date¹⁶. Moreover, it was reported that the microhardness of dual-cure resin composite is affected by the curing mode³¹. A reduction in light energy results in poor mechanical properties and reduced bonding capacity of dual-cure resin composite to dentin³². In this study, as with previous research, the light curing groups provided significantly higher bond strengths than the chemical curing group, regardless of lining.

In this study, the MTBS of the LN-/CC-Bulk group was the lowest among all the groups. Based on the failure mode results, for only this group, all specimens showed complete or partial fracture at the interface between DC and adhesive. Since failure of a bonded specimen theoretically takes place at the weakest point in the bonded interface²⁷, there may have been some difficulty for the LN-/CC-Bulk group to sufficiently reinforce a smear layer to the same level as hybridized intact dentin. However, SEM observations of adhesive interface in this group revealed good adhesion at the interface between each layer and any gap formation was not detected. The two-step self-etching primer adhesive system, Clearfil Liner Bond 2V is composed of a two-bottle primer and adhesive, which can be dual-activated. An acidic monomer, 10-methacryloxydecyl dihydrogenphosphate (MDP) in the primer can dissolve the smear layer and demineralize the underlying dentin, resulting in mild surface etching³³. Good dentin bonding with a self-etching primer system has already been demonstrated in previous laboratory studies^{9,10}. It is essential to create a hybrid layer at the resin-dentin interface in order to obtain proper adhesion. The hybrid layer is created by penetration and polymerization of adhesive monomers after removal and/or modification of the smear layer and superficial demineralization of the dentin³⁴. However, it has been demonstrated that the resin monomers of some adhesive systems penetrate deeper than the hybrid layer distinguished by argon-ion etching³⁵. Inoue *et al.* (2006), suggested that formation of an ABRZ (an acid-base resistant Zone) created by a self-etching primer system would be related to penetration of the adhesive monomers³⁶.

For the LN-/CC-Bulk group, chemical polymerization of the dual-cured composite resin core

occurred at the cavity floor. Tay *et al.*³⁷ demonstrated that there was an inverse relation between the acidity of adhesive and MTBS of resin composite to dentin when a chemical-cured resin composite was used with a photo-cured adhesive. A tertiary amine in the chemical-cured resin composite forms a charge transfer complex with an acidic monomer of the bonding agent, such as MDP in LB, which consequently affects the polymerization of the chemical-cured resin composite²¹. Therefore, the interface might be the weakest link in these complex bonded assemblies. On the other hand, the fracture mode shifted from adhesive failure (mode A) to cohesive failure within the dual-cure resin composite (DC) and between DC and adhesive (mode B and C), when the resin composite was light cured (LN-/LC-Bulk group). However, the MTBS of the LN-/LC-Bulk group was lower than that of the incremental filling group (LN-/LC-Inc group), while the light-curing of composite resin core improved the bond strengths in the this group. Tashiro *et al.*³⁰ reported that the thicker the composite restoration, the greater was the reduction in light intensity through the composite. In light of this report, it was chiefly chemical polymerization of the composite resin core that would have occurred on the cavity floor in this study, because the light emitted by the light curing unit was probably not sufficient.

It is a commonly held belief that incremental filling techniques are capable of increasing the degree of conversion on the cavity floor and reducing stress concentration at the tooth interface when a light-activated resin composite is employed^{22,23}. Incremental filling techniques are expected to ensure satisfactory polymerization of light-cured composite resins in deep preparations³⁸. In addition, an incremental filling technique ought to be effective in reducing the C-factor value (the ratio of bonded to unbonded surfaces)^{39,40} and preventing gap formation³⁹. A dual-cure composite core material was used in this study, while other researchers evaluated this technique using a light-cure condensable composite. However, an incremental filling technique significantly improve the bond strengths. Therefore, it was suggested that this technique may reduce the contraction stress not only in light-cured composites but also in dual-cured composites.

Chikawa *et al.*⁴⁰ demonstrated that the first increment of composite on the polymerized bonding layer might have played the most important role with regards to adherence to the cavity floor. They suggested that the first increment would undergo less volumetric shrinkage than the bulk filled material and the subsequent increment could fill any space resulting from contraction of the preceding increment. Moreover, Yoshida *et al.*⁴¹ reported that a thin first incremental layer could provide a high degree of conversion and improved physical properties on the cavity floor. This would result in a improved bond strength to the cavity floor⁴³. In addition, uncured resin in the oxygen inhibition layer of the dentin bonding system may subsequently polymerize with the free radicals diffusing

from the first increment of resin composite.

Clearfil Flow FX is a flowable resin composite with a multi-purpose use. The indications for a flowable resin composite are direct filling of small cavities without a strong stress-bearing area. Flowable resin composite was initially developed as a flexible intermediate layer in 1991. It was thought that this layer could play the role of an elastic buffer¹⁷⁾. Several reports suggested that this elastic buffer successfully improved the bond strength of adhesive systems and reduced gap formation^{18,19)}. On the other hand, Miguez PA *et al.*⁴³⁾ reported that the use of a flowable composite did not guarantee gap-free restorations or improved bond strength of resin to dentin in bulk-filled restorations, while the incremental technique prevented gap formation.

Although we expected that lining with a flowable composite would improve the MTBSs, there were no significant differences between the lining and no-lining groups in this study. For the incremental filling groups, the bond strengths of the non-lining and lining groups were almost same. Moreover, high bond strengths were observed in three groups; LN-/LC-Inc, LN+/LC-Inc and LN+/LC-Bulk and there were no significant differences among them. There is a similarity between the three groups in that the first increment of composite on the polymerized bonding layer was light cured. From these results, the first increment of a dual-cure composite core may work as a lining, because the physical properties of Clearfil DC Core Automix (DC) are similar to those of Clearfil Flow FX (FX). DC contains 74 wt% filler loading, while FX has 65 wt% fillers.

Several reports have demonstrated that dentin bond strengths to endodontically treated teeth are influenced by many clinical factors⁹⁻¹⁵⁾. Chemical irrigants such as sodium hypochlorite and hydrogen peroxide, which are used in endodontic treatment, affect adhesion to dentin⁴⁴⁾. Moreover, the ultrastructure of the pulp chamber floor dentin appears similar to secondary and reparative dentin, containing irregular, fewer and narrower tubules compared to coronal dentin⁴⁵⁾. Toba *et al.*⁹⁾ reported that the bond strengths of dentin bonding systems to pulp chamber floor dentin were lower than those to coronal dentin, however, the self-etching primer systems provided a more reliable bond to the dentin of both regions. Akagawa *et al.*¹⁰⁾ evaluated the bond strength of a self-etching bonding system to pulpal floor dentin in an access cavity. They demonstrated that the bond strength to pulpal floor dentin was influenced by cavity configuration, dentin depth, and curing behavior of resin composites. In the present study, we sought to evaluate the influence of filling technique and curing mode on MTBSs of composite cores to pulpal floor dentin. However, further research should be carried out to evaluate not only this but also the interaction with these clinical factors on the bond strengths.

The results of this study demonstrated that filling techniques and curing modes influenced the MTBSs. Moreover, light curing and incremental technique had

positive effects on the MTBSs. Therefore, the null hypothesis was partially rejected. In a dual-cure composite resin core, polymerization completion in the areas not reached by the light occurs through a chemical reaction. However, photoactivated polymerization by a light source is an important step toward the clinical success of restorations in endodontically treated teeth. In particular, the first increment of the dual-cure composite on the polymerized bonding layer might have played an important role with regards to adherence to the cavity floor.

CONCLUSIONS

The results of this study suggested that filling techniques and curing modes influenced the MTBSs to pulpal floor dentin. Light curing of the composite is essential to obtain high bond strengths. Moreover, an incremental technique was beneficial in obtaining good dentin bonding. Light curing and incremental technique had positive effects on the MTBSs. Lining with a flowable resin composite did not significantly improve the MTBSs, however, influenced the failure mode after debonding.

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REFERENCES

- 1) Mannocci F, Innocenti M, Ferrari M, Watson TF. Confocal and scanning electron microscopic study of teeth restored with fiber posts, metal posts, and composite resins. *J Endod* 1999; 25: 789-794.
- 2) Ferrari M, Mannocci F, Vichi A, Cagidiaco MC, Mjor IA. Bonding to root canal: structural characteristics of the substrate. *Am J Dent* 2000; 13: 255-260.
- 3) Ukon S, Moroi H, Okimoto K, Fujita M, Ishikawa M, Terada Y, Satoh H. Influence of different elastic module of dowel and core on stress distribution in root. *Dent Mater J* 2000; 19: 50-64.
- 4) Morgano SM. Restoration of purplish teeth: Application of traditional principles. *J Prosthet Dent* 1996; 75: 375-380.
- 5) Foxton RM, Nakajima M, Tagami J, Miura H. Bonding of photo and dual-cure adhesives to root canal dentin. *Oper Dent* 2003; 28: 543-551.
- 6) Mount GJ, Ngo H. Minimal intervention: A new concept for operative dentistry. *Quintessence Int* 2000; 31: 527-533.
- 7) Sanares AM, King NM, Itthagarun A, Tay FR, Pashley DH. Adverse surface interactions between one-bottle light-cured adhesives and chemical-cured composites. *Dent Mater* 2001; 17: 542-556.
- 8) Akagawa H, Nikaido T, Tanaka T, Burrow MF, Tagami J. Shear bond strengths to coronal and pulp chamber floor dentin. *Am J Dent* 2002; 15: 383-388.
- 9) Toba S, Veerapavati W, Shimada Y, Nikaido T, Tagami J.

- Micro-shear bond strengths of adhesive resins to coronal dentin versus the floor of the pulp chamber. *Am J Dent* 2003; 16: 51-56.
- 10) Akagawa H, Nikaido T, Burrow MF, Tagami J. Influence of cavity configuration on the adhesion of two resin-based composites to pulpal floor dentin. *Am J Dent* 2005; 18: 233-236.
 - 11) Ariyoshi M, Nikaido T, Foxton RM, Tagami J. Microtensile bond strengths of composite cores to pulpal floor dentin with resin coating. *Dent Mater J* 2008; 27: 400-407.
 - 12) Aksornmuang J, Foxton RM, Nakajima M, Tagami J. Microtensile bond strength of a dual-cure resin core material to glass and quartz fiber posts. *J Dent* 2004; 32: 443-450.
 - 13) Aksornmuang J, Nakajima M, Foxton RM, Tagami J. Regional bond strength of four self-etching primer/adhesive systems to root canal dentin. *Dent Mater J* 2005; 24: 261-267.
 - 14) Yoshiyama M, Carvalho RM, Sano H, Horner JA, Brower PD, Pashley DH. Regional bond strengths of resins to human root dentin. *J Dent* 1996; 24: 435-442.
 - 15) Burrow MF, Sano H, Nakajima M, Harada N, Tagami J. Bond strength to crown and root dentin. *Am J Dent* 1996; 9: 223-229.
 - 16) Oooka S, Miyazaki M, Rikuta A, Moore BK. Influence of polymerization mode of dual-polymerized resin direct core foundation systems on bond strengths to bovine dentin. *J Prosthet Dent* 2004; 92: 240-244.
 - 17) Kemp-Scholte CM, Davidson CL. Complete marginal seal of Class V resin composite restorations effected by increased flexibility. *J Dent Res* 1990; 69: 1240-1243.
 - 18) Burrow MF, Tagami J, Negishi T, Nikaido T, Hosoda H. Early tensile bond strengths of several enamel and dentin bonding systems. *J Dent Res* 1994; 73: 522-528.
 - 19) Fortin D, Swift EJ Jr, Denehy GE, Reinhardt JW. Bond strength and microleakage of current dentin adhesives. *Dent Mater* 1994; 10: 253-258.
 - 20) Jayasooriya PR, Pareira PN, Nikaido T, Tagami J. Efficacy of a resin coating on bond strengths of resin cement to dentin. *J Esthet Restor Dent* 2003; 15: 105-113.
 - 21) Giannini M, De Goes MF, Nikaido T, Shimada Y, Tagami J. Influence of activation mode of dual-cured resin composite cores and low-viscosity composite liners on bond strength to dentin treated with self-etching adhesives. *J Adhes Dent* 2004; 6: 301-306.
 - 22) Koenigsberg S, Fuks A, Grajower R. The effect of three filling techniques on marginal leakage around Class II composite resin restorations *in vitro*. *Quintessence Int* 1989; 20: 117-121.
 - 23) Neiva IF, de Andrada MA, Baratieri LN, Monteiro Junior S, Ritter AV. An *in vitro* study of the effect of restorative technique on marginal leakage in posterior composites. *Oper Dent* 1998; 23: 282-289.
 - 24) Leevailoj C, Cochran MA, Matis BA, Moore BK, Platt JA. Microleakage of posterior packable resin composites with and without flowable liners. *Oper Dent* 2001; 26: 302-307.
 - 25) Figueiredo Reis A, Giannini M, Ambrosano GM, Chan DC. The effects of filling techniques and a low-viscosity composite liner on bond strength to class II cavities. *J Dent* 2003; 31: 59-66.
 - 26) Foxton RM, Nakajima M, Tagami J, Miura H. Adhesion to root canal dentine using one and two-step adhesives with dual-cure composite core materials. *J Oral Rehabil* 2005; 32: 97-104.
 - 27) Koibuchi H, Yasuda N, Nakabayashi N. Bonding to dentin with a self-etching primer: the effect of smear layers. *Dent Mater* 2001; 17: 122-126.
 - 28) Sano H, Yoshikawa T, Pereira PN, Kanemura N, Morigami M, Tagami J, Pashley DH. Long-term durability of dentin bonds made with a self-etching primer, *in vivo*. *J Dent Res* 1999; 78: 906-911.
 - 29) Chen KK, Shono Y, Ogawa T, Kozono Y, Terashita M. Fracture aspects of resin-dentin bonding in non-trimming microtensile test. *Dent Mater J* 2001; 20: 315-324.
 - 30) Tashiro H, Inai N, Nikaido T, Tagami J. Effects of light intensity through resin inlays on the bond strength of dual-cured resin cement. *J Adhes Dent* 2004; 6: 233-238.
 - 31) Shimura R, Nikaido T, Yamauti M, Ikeda M, Tagami J. Influence of curing method and storage condition on microhardness of dual-cure resin cements. *Dent Mater J* 2005; 24: 70-75.
 - 32) Kanno T, Ogata M, Foxton RM, Nakajima M, Tagami J, Miura H. Microtensile bond strength of dual-cure resin cement to root canal dentin with different curing strategies. *Dent Mater J* 2004; 23: 550-556.
 - 33) Tsuchiya S, Nikaido T, Sonoda H, Foxton RM, Tagami J. Ultrastructure of the dentin-adhesive interface after acidbase challenge. *J Adhes Dent* 2004; 6: 183-190.
 - 34) Nakabayashi N. Bonding of restorative materials to dentine: the present status in Japan. *Int Dent J* 1985; 35: 145-154.
 - 35) Miyazaki M, Onose H, Moore BK. Analysis of the dentin resin interface by use of laser Raman spectroscopy. *Dent Mater* 2002; 18: 576-580.
 - 36) Inoue G, Tsuchiya S, Nikaido T, Foxton RM, Tagami J. Morphological and mechanical characterization of the acidbase resistant zone at the adhesive-dentin interface of intact and caries-affected dentin. *Oper Dent* 2006; 31: 466-472.
 - 37) Tay FR, King NM, Suh BI, Pashley DH. Effect of delayed activation of light-cured resin composites on bonding of all-in-one adhesives. *J Adhes Dent* 2001; 3: 207-225.
 - 38) Leinfelder KF. Using composite resin as a posterior restorative material. *J Am Dent Assoc* 1991; 122: 65-70.
 - 39) Davidson CL, Feilzer AJ. Polymerization shrinkage and polymerization shrinkage stress in polymer-based restoratives. *J Dent* 1997; 25: 435-440.
 - 40) Chikawa H, Inai N, Cho E, Kishikawa R, Otsuki M, Foxton RM, Tagami J. Effect of incremental filling technique on adhesion of light-cured resin composite to cavity floor. *Dent Mater J* 2006; 25: 503-508.
 - 41) Yoshida K, Greener EH. Effects of two amine reducing agents on the degree of conversion and physical properties of an unfilled light-cured resin. *Dent Mater* 1993; 9: 246-251.
 - 42) Yanagawa T, Finger WJ. Relationship between degree of polymerization of resin composite and bond strength to Gluma-treated dentin. *Am J Dent* 1994; 7: 157-160.
 - 43) Miguez PA, Pereira PN, Foxton RM, Walter R, Nunes MF, Swift EJ Jr. Effects of flowable resin on bond strength and gap formation in Class I restorations. *Dent Mater* 2004; 20: 839-845.
 - 44) Sasafuchi Y, Nikaido T, Tagami J. Effect of chemical irrigants and medicaments for endodontic treatment on dentin bonding. *Int Chin J Dent* 2003; 3: 7-12.
 - 45) Yoshida K, Yoshida N, Iwaku M. Histological observations of hard tissue barrier formation in amputated dental pulp capped with alpha-tricalcium phosphate containing calcium hydroxide. *Endod Dent Traumatol* 1994; 10: 113-120.