Chapter 6 Fluid Flow after Resin Composite Restoration in Extracted Carious Teeth

A manuscript submitted for publication in

the European Journal of Oral Science
ABSTRACT

The purpose was to investigate fluid flow in dentin after restoration of carious teeth with resin composite bonded with a total-etching adhesive, with or without glass-ionomer cement lining. The roots of extracted third molars were sectioned and the crowns were connected to a fluid flow measuring device. Each carious lesion was stained with caries detector dye and removed using slow-speed burs and spoon excavators. Caries-excavated teeth were divided into two groups for restoration with resin composite bonded with a total-etch adhesive: a) without lining; and b) lined with glass-ionomer cement before bonding. In non-carious teeth, cavities of similar dimensions were prepared, divided into two groups and restored in the same manner. Fluid flow was recorded after restoration for up to 1 month. Caries-affected dentin was examined by scanning electron microscopy, and the bonded interfaces were observed using a confocal laser scanning microscope. No significant difference in fluid flow was observed between the two restorative procedures as well as between the carious and non-carious groups. SEM images showed that the dentinal tubules of acid-etched, caries-affected dentin were usually still occluded while some were patent. Limited fluorescent dye penetration into dentin and bonded interfaces of restored carious teeth was observed.
INTRODUCTION

Polymerization shrinkage of resin composite restorative material creates stresses affecting bonds between the restoration and cavity walls. Micro-gaps are formed if the bond is ruptured by the forces from polymerization shrinkage stress (1). Adhesive and hybrid layers at the resin-dentin interface are permeable (2-5) and can be penetrated by silver nitrate or fluorescent dyes; this phenomenon is the so-called “nanoleakge” (6) or “micro-permeability” (7). Therefore, these layers do not provide a perfect seal after restoration even when micro-gap formation is not clearly detected.

Many studies have investigated the sealing ability of resin composite restorations by measuring fluid flow through restored cavities (2, 8-10). It is believed that fluid moves into and fills gaps formed at the bonded interface and also through the permeable adhesive layer. However, these results have all been obtained from extracted non-carious (intact) teeth. The restorations were bonded to ‘normal’ dentin with patent dentinal tubules rather than to naturally caries-affected dentin deep to a carious lesion.

Caries-affected dentin remaining after caries removal is different from normal dentin. In a slowly progressing lesion, dentinal tubules of caries-affected dentin are commonly occluded by precipitation of crystals and mineralization of intratubular dentin. Moreover, intertubular dentin becomes hypermineralized and sclerotic. Hence, permeability of caries-affected dentin is very low even after acid etching (11, 12). It seems that the defense mechanisms provide some degree of “natural barrier” for the remaining dentin. Response of dentin beneath to a rapidly progressing lesion is slightly different, as the natural defense mechanisms are sometimes deficient and
imperfect. Complete occlusion of dentinal tubules and hypermineralized intertubular dentin are only partially observed (13). Occasionally, patent dentinal tubules and demineralized affected dentin are detected after caries removal (13). Therefore, caries-affected dentin below a rapidly progressing lesion might be more permeable than the affected dentin of a slowly progressing lesion.

Since caries-affected dentin of slowly or rapidly progressing lesions provides a barrier, sealing ability of a restoration on such dentin might be enhanced relative to normal dentin. However, lower bond strengths of resin-based adhesives to caries-affected dentin than to normal dentin have been reported, and an atypical hybrid layer has been observed at the bonded interface (14, 15). These factors might affect the sealing of a resin-based adhesive over the low-permeable, caries-affected dentin.

Investigating non-carious teeth, RATIH et al. (16) proposed that placing a glass-ionomer cement (GIC) liner can inhibit fluid flow after MOD resin composite restorations bonded with a two-step, total-etching adhesive. GIC lining was applied on an unconditioned or conditioned dentin surface in which smear plugs remained and the permeability was low (17). However, a lack of difference in fluid flows after occlusal resin composite restorations with or without GIC lining has been reported (18). Furthermore, frequent micro-gap formation in restorations lined with a resin-modified GIC has been noted (18, 19). Hence, the benefits of a GIC lining to improve sealing ability of a resin composite restoration, whether on normal or caries-affected dentin, are still unclear.

Therefore, the purpose of this study was to investigate fluid flow for up to 1 month after resin composite restoration of carious teeth or of non-carious teeth with a similar sized cavity, restored with or without GIC lining. In addition, caries-affected
dentin was investigated using a field-emission scanning electron microscope. Bonded interfaces between restorations and dentin were also examined using confocal laser scanning microscopy. The null hypotheses were that: 1) there is no significant difference in fluid flow rates after restoration between the two restorative procedures; and 2) there is no significant difference in fluid flow between carious and non-carious teeth.
MATERIAL AND METHODS

Twenty four third molars with occlusal caries deep into dentin and twenty intact human third molars extracted from patients 18 to 40 years-old were used. The teeth were cleaned with an ultrasonic scaler, disinfected in 2% thymol solution and then stored at 4°C in phosphate buffered saline solution (PBS). The study was approved by the Ethics in Human Research Committee of the University of Melbourne, Australia, and patient consent was obtained to use the extracted teeth.

The teeth were prepared as follows: each tooth was sectioned 3 mm below the cemento-enamel junction (CEJ), using a slow-speed diamond blade with water coolant (Struers, Ballerup, Denmark), and pulpal tissue was carefully removed using tweezers and a barbed broach. The sectioned teeth were cleaned in an ultrasonic cleaner (Model 2009, L&R, Kearny, New Jersey, USA) for 5 min.

The testing apparatus for measuring fluid flow was set up according to the previous study (18). Each tooth was mounted on a polymethylmethacrylate plate, containing an 18-gauge needle in the centre, using cyanoacrylate glue (Bostik, Thomastown, Victoria, Australia) and subsequently covered with epoxy resin (Araldite, Selleys, Padstow, NSW, Australia) above the level of the CEJ. The mounted tooth was connected via PBS-filled silicone tubing to a glass capillary tube, 30 cm long and internal diameter 0.84 mm, mounted horizontally in an automated fluid flow measurement device (Flodec, De Marco Engineering, Geneva, Switzerland). The other end of the glass tube was connected to a reservoir containing PBS to simulate intrapulpal pressure. Fluid flow measurement was conducted at room temperature (24±1°C) and an intrapulpal pressure of 1.3 kPa. Throughout the
experiment, the prepared teeth were covered with a humidified container to minimize outward fluid flow from evaporation.

**Fluid flow measurement**

Sixteen carious and intact teeth were used. Before caries removal, fluid flow through each carious tooth was measured for 10 min under a simulated pulpal pressure of 1.3 kPa. Next, in cases where the lesion entrance was small and caused difficulty in removing the underlying carious lesion, initial access was gained using a high-speed fissure diamond bur diameter 010, standard grit (Heico, Steinach, Switzerland) with air-water coolant. The caries lesion was then stained with caries detector dye (Caries Detector, Kuraray Medical, Tokyo, Japan) for 10 s, and the dye-stained area was carefully removed using slow-speed round steel burs (Emil Lange, Engelskirchen, Germany) and spoon excavators. The procedure was repeated two to three times until the affected dentin was stained pale pink and relatively hard to the touch with a blunt dental explorer. Cavity depth was measured using a periodontal probe (PCP-UNC 15, Hu-Friedy, Chicago, IL, USA) at 4-6 points around the cavity walls, and cavity width and length were recorded at the narrowest and widest areas, which were then averaged. Overall caries activity was defined as rapidly or slowly progressing; a rapidly progressing lesion is relatively softer and yellowish, while the slowly progressing lesion is relatively harder and discolored (i.e. brown or black) (13). Following caries removal, fluid flow was recorded for 10 min.

To serve as a control, a similar cavity was prepared on a matched intact tooth, using a high-speed fissure diamond bur with water coolant and subsequently with a slow-speed round steel bur for cutting dentin. The cavity dimensions were measured
in the same manner as the cavity in the carious tooth. Fluid flows were recorded before (intact) and then after cavity preparation for 10 min each.

Sixteen caries-excavated teeth were divided equally into two groups in rank order of cavity depth. In the first group, the cavity was bonded with a two-step, total-etching (TE) adhesive [Single Bond 2 (SB2)], without lining. In the second group, the TE adhesive was applied after lining the cavity with a resin-modified GIC liner. Cavity-prepared teeth from the intact (non-carious) group were divided into two groups in the same way. Overall, four groups using the TE adhesive were evaluated: (1) TE-C: carious teeth, without lining; (2) TE-I: intact teeth, without lining; (3) GIC-C: carious teeth, with GIC lining; and (4) GIC-I: intact teeth, with GIC lining. Table 6-1 shows the compositions, batch numbers and manufacturers of the adhesive, GIC liner and resin composite. All lining, adhesive and restorative procedures were performed under a simulated pressure of 0 kPa to simulate the reduced pulpal blood flow when a local anesthetic is administered.

When GIC liner was indicated, it was applied over the entire dentin surface (pulpal floor and surrounding walls up to the dentino-enamel junction) to an approximate thickness of 0.5-1.0 mm and then light-cured for 20s. Fluid flow during the initial GIC setting (application and light curing) was recorded under a pressure of 0 kPa. After that, the entire cavity (and lining) was etched with 37% phosphoric acid (Scotchbond Etchant, 3M ESPE, St. Paul, MN, USA) for 15 s and then rinsed thoroughly with 5 mL of PBS. In the groups without lining, fluid flow through acid-etched dentin was recorded at the simulated pulpal pressures of 0 and 1.3 kPa for 10 min each. The etched cavity was gently air blown to remove excess PBS and achieve a moist dentin surface. Adhesive was applied according to the manufacturer’s
instructions and then light cured for 10 s (C8 Blue Phase, Ivoclar Vivadent, Schaan, Lichtenstein).

A nano-filled resin composite (Filtek Supreme XT) was placed into the bonded cavity in two horizontal increments to ensure effective light curing. The first layer was approximately 0.5-1 mm thick, and then the second increment filled the cavity entirely and was contoured to produce anatomical form. Each increment was light cured for 20 s.

After restoration, the simulated pulpal pressure was raised from 0 to 1.3 kPa. Fluid flow was recorded during the first hour and then at 24 h, 1 week and 1 month after restoration, over 10 min intervals. The restored teeth were immersed in PBS and stored at 37°C between measurements.

Fluid flow volume in nL was calculated using the formula below:

\[
\text{Fluid flow volume (nL)} = \pi r^2 \times D \times 10^{-3}
\]

Where \( r \) = radius of the glass tubule (0.42 mm); \( D \) = linear displacement (mm) of the bubble in the glass tube. Fluid flow rate in nL.s\(^{-1}\) was obtained from the volume in nL divided by measuring time in second.

**SEM analysis of caries-affected dentin**

Four carious third molars, including either rapidly or slowly progressing lesions, were used. Each tooth was horizontally sectioned below the CEJ and then at the coronal middle one-third to remove coronal tooth structure above the carious lesion, using a slow-speed diamond blade with water coolant (Struers). Dentinal caries on the pulpal floor was stained with the caries detector dye (Caries Detector) and
excavated in the same manner previously described for the fluid flow experiment. Normal dentin on the sectioned occlusal surface was ground with a slow-speed round bur to create a new smear layer, replacing the smear layer derived from tooth sectioning. Before acid etching, an adhesive tape was placed over one half of the cavity and sectioned surfaces to preserve the smear-layer covered caries-affected and normal dentin as controls. The other half was etched with 37% phosphoric acid for 15 s and then thoroughly rinsed, and the adhesive tape was removed. The specimens were dried, gold-sputter coated and examined using a Field–Emission Scanning Electron Microscope (FE-SEM), (Philips XL30 FE-SEM, Eindhoven, the Netherlands) at 1,000-4000X magnification. After that, the specimens were vertically fractured through the excavated caries lesion (etched and un-etched areas) using a chisel after guiding slots were created. The fractured specimens were re-dried, coated and examined in the plane of longitudinal sections of dentinal tubules at 4,000X magnification.

Micro-permeability test

Caries and intact third molars were prepared and restored in exactly the same manner as in the fluid flow measurements, two for each restorative procedure. After restoration, each restored tooth was connected to a tubing system filled with 1% Rhodamine B fluorescent dye (Chem-supply, Gillman, South Australia, Australia- 1% solution in PBS) under a simulated pressure of 1.3 kPa. After 24 h, the tooth was removed, rinsed thoroughly to remove excess dye in the pulp chamber, and then serially sectioned bucco-lingually at the center of the restoration, using a diamond blade with water coolant (Struers), to obtain 0.5 mm-thick specimens. The specimens were sequentially polished with Si-C paper grit up to 2500-grit, then with 3 and 1 μm
diamond pastes. The specimens were photographed under a light microscope (Leica S8AP0, Leica Microsystems, Heerbrugg, Switzerland) at low magnification. The specimens were kept in a dark container, under humidification and then investigated as soon as possible. Specimens were mounted on a glass slide with glycerin and examined using a confocal laser scanning microscope (CLSM), (Olympus FV 1000, Olympus Optical Co. Ltd., Tokyo, Japan) at 40X magnification to observe fluorescent dye penetration at the bonded interface.

**Statistical analysis**

Cavity length, width and depth of the carious and non-carious groups were statistically compared using the general linear model analysis of variance (ANOVA) (Minitab14, Minitab Inc., State College, PA, USA). Fluid flow rate changes after caries removal/cavity preparation, after acid etching and during initial GIC setting as well as fluid flow rates after restoration were analyzed using the general linear model ANOVA (Minitab14) and multiple comparisons were carried out using Tukey’ test at level of significance of $p < 0.05$. 

RESULTS

Cavity sizes and depth of carious and non-carious teeth are shown in Table 6-2. There were no significant differences in cavity width, length and depth between the carious and non-carious teeth ($p = 0.640$, $0.756$ and $0.972$, respectively). In the carious group, 10 lesions were in the rapidly progressing category and 6 lesions were in the slowly progressing category, which were distributed equally in the TE-C and GIC-C groups. Baseline flow rates and changes in fluid flow rates are shown separately in Table 6-3, according to the categories of caries activity. Minimal differences (in numerical value) were noticed between the results from the two categories, so the data for carious teeth could be combined for statistical analysis.

Fluid flow measurement

A change in fluid flow rate from 0.35±0.09 to 0.40±0.09 nL.s$^{-1}$ after caries removal of carious teeth was minimal. After cavity preparation of intact teeth, fluid flow rate markedly increased from near zero (0.06±0.05 nL.s$^{-1}$) to 0.42±0.12 nL.s$^{-1}$. The increase in fluid flow rate of the intact group was significantly higher than that of the carious group ($p<0.001$), but the actual flow rates after caries removal and cavity preparation were similar (Table 6-4). After acid etching, there was a modest increase in fluid flow rate from baseline in the carious group (Table 6-5). In contrast, the fluid flow rate in the non-carious group was double that of the baseline, and the increase was significantly higher than in the carious group ($P=0.014$).

When a GIC lining was placed, there were significant increases in fluid flow rates during setting of the GIC from baseline ($p<0.001$) (Table 6-6). Increase in the
flow rate of the caries group, GIC-C, was numerically lower than the non-carious group, GIC-I; however, the increases in fluid flow rates of the two groups were not statistically significantly different ($P > 0.05$).

Figure 6-1 summarizes fluid flow rates after restoration, presented as percentage change from baseline (a cavity covered with smear layer) of carious and non-carious teeth using the two restorative procedures. Comparison between the two restorative procedures demonstrated no significant difference in fluid flow rates at the same time in either the restored carious or non-carious teeth ($p > 0.05$). In addition, fluid flow rates at the same time were not significantly different between the restored carious or non-carious teeth, whether restored with or without GIC liner ($p > 0.05$). Within each experimental group, significant differences in fluid flow rates among the time-points were found only in the groups without lining (TE). In the TE-C group, the fluid flow rate at 15 min was significantly higher than at 1 week ($p = 0.0083$) and 1 month ($p = < 0.001$). In the TE-I group, the fluid flow rate at 15 min were significantly greater than those of 24 h ($p = 0.0247$) and 1 month ($p = 0.0014$).

**SEM analysis of caries-affected dentin**

The dentin surface was covered with a smear layer after caries removal in carious tooth (6-2A) or cavity preparation in non-carious tooth (Figure 6-2B). Dentinal tubules were patent in acid-etched dentin of non-carious tooth (Figure 6-3A). In carious tooth, dentinal tubules of caries-affected dentin were still partially occluded after acid etching (Figure 6-3B); however, dentinal tubules were patent in some areas (Figure 6-3C). Figures 6-4 compare SEM images of acid-etched, caries-affected dentin beneath to a rapidly progressing lesion (Figure 6-4A) and a slowly progressing lesion (Figure 6-4B). Some dentinal tubules of caries-affected dentin subjacent to
slowly progressing caries were completely occluded even after acid etching (Figure 6-4A). Caries-affected dentin in response to rapidly progressing caries was observed that the occluding substances at entrances of dentinal tubules were partially removed by acid etching (Figure 6-4B). In a longitudinal section of acid-etched, caries-affected dentin in carious tooth, the dentinal tubule was completely blocked along the tubule (Figure 6-5A). In contrast, dentinal tubules in non-carious tooth were patent and funnel-shaped as smear plugs and some peritubular/intratubular dentin were removed by acid etching (Figure 6-5B).

**Micro-permeability test**

The light microscopy images of restored non-carious teeth show that fluorescent dye diffused throughout dentin and stained at the bonded interfaces, whether with or without GIC lining (FLC) (Figure 6-6A). Sections of restored carious teeth showed changes in dentin affected from dental caries (Figures 6-6B, 6-6C for TE-C and Figures 6-6D, 6-6E for GIC-C). Dye penetration was limited in some areas of caries-affected dentin, but dye label was still detected at bonded interfaces.

Fluorescent dye labeling at the interfacial areas was clearly observed from the CLSM micrographs of the two non-carious groups (Figure 6-7A and 6-7B). Diffusing through dentinal tubules, fluorescent dye accumulated and deposited at the bonded interfaces. Fluorescent dye was also present in the bulk of the resin-modified GIC lining (Figure 6-7B). In contrast, dye penetration through dentinal tubules was inhibited and partially stained bonded interfaces of the two carious groups (Figures 6-7C and 6-7D); however fluorescent dye detected in some areas was comparable to that of restored non-carious tooth (Figure 6-7E).
DISCUSSION

Many studies have used intact teeth to investigate the sealing ability of resin composite restorations (8-10, 20). However, affected dentin subjacent to carious lesions is quite different from normal dentin of intact teeth (11, 12). Therefore, carious teeth were used in this study in an attempt to simulate the clinical situation more closely.

Measuring fluid flow before and after restoration placement has been widely used to examine the seal of the restoration (8, 9, 18, 20). It is believed that fluid can move into micro-gaps formed at bonded interfaces. Nevertheless, the adhesive layer does not provide an absolute seal even when no micro-gap is detected (5, 18, 21). In a restoration bonded with a self-etching adhesive that etches and primes simultaneously, incomplete removal of the water component might result in incomplete polymerization and/or hydrogel formation of the adhesive/hybrid layer (22). These imperfections can be penetrated by fluorescent dyes in the micro-permeability test (2, 18, 21, 23) or by silver nitrate in a nano-leakage test (5, 22, 24, 25).

Some studies have used two different fluorescent dyes to achieve better image contrast; a dye is mixed with the dentine adhesive while another dye is used for the penetration test (21, 26). However, changes in the physical properties of the dentine adhesive are a concern (27). Hence, only one fluorescent dye (Rhodamine B) was used in this study. The results from the micro-permeability test confirmed that micro-gap free areas did not create a seal, and caries-affected areas were less permeable.
Some clinicians have suggested that application of a GIC lining may improve the seal or reduce postoperative sensitivity after resin composite restoration (28-30). It is believed that dentinal fluid movement might be limited and subsequent postoperative sensitivity is unlikely to occur if a restorative technique which provides superior adaptation is used. However, the adaptation and seal of GIC lining subjacent to a restorative material is still controversial, due to the high incidence of micro-gap formation (18, 19). Therefore, restorations with or without a GIC lining were compared in this study.

In the groups bonded with the total-etching adhesive without lining (either carious or intact teeth), the initial fluid flow rate following restoration was significantly higher than after storage. Immediately after restoration, the testing fluid might not only flow into micro-gap areas, but also diffuse into any nano-gap areas.

In contrast, no significant difference in fluid flow rates was observed over time in the groups lined with the resin-modified GIC (FLC). This may be due to water sorption reaching equilibrium rapidly. Due to the initial polymerization reaction of resin components, the maturation of this resin-modified GIC is not as delayed as for conventional GIC (31). Hydrolytic degradation of GICs (32) and bond deterioration of some resin-based adhesives (33) may occur after long-term storage, which might affect the restoration seal. However, expansion of these materials due to water sorption also takes place, which might compensate and reduce gap size (34). Net fluid movement may depend on which factor provides the greater effect. In this study, the fluid flow rates did not change significantly up to 1 month of storage.

Permeability after acid etching caries-affected dentin is much lower than of normal dentin due to occluded dentinal tubules and hyper-mineralized intertubular
dentin (11, 12). However, fluid flow after restoration in this study was not significantly influenced, regardless of the restorative procedures. The total-etching adhesive was able to seal permeable, normal dentin as well as caries-affected dentin. In restorations lined with the GIC liner, the smear layer was not removed before lining, and permeability of the smear-layer covered, normal dentin was as low as the smear-layer covered, caries-affected dentin. It has been reported that the smear layer can provide an initial seal to a cavity (35). However, the permeability of restored carious teeth was qualitatively less than that of restored intact teeth as a lesser amount of fluorescent dye was observed in the micro-permeability test.

Carious dentin is often over-prepared when a caries detector dye is used and therefore careful removal is necessary (36). The shape of a carious lesion is usually conical and the depth uneven (37). Hence, using conventional methods to remove dental caries might unintentionally expose normal dentin in some areas (36). However, the caries-affected area that showed patent dentinal tubules in FE-SEM or fluorescent dye penetration in the micro-permeability test may possibly be due to either lack of the natural defense mechanisms or over-removal of carious dentin.

No significant difference between the two restorative procedures was previously reported in the earlier study examining restored intact teeth (18). Hence, a total-etching adhesive could effectively coat acid-etched, permeable dentin as well as the resin-modified GIC liner did on smear-layer covered, low-permeable dentin. In carious teeth, the permeability was still low even after acid etching, so a restoration may be just an additional seal of the cavity. Regardless of whether the tooth is carious or intact, a restoration with GIC lining provides a comparable seal to that without the lining.
In conclusion, fluid flow rates obtained from carious and intact teeth were not significantly different, regardless of the restorative technique. Nevertheless, the null hypotheses have been rejected because significant differences were found in fluid flow rates among the post-restoration periods of the TE groups. No advantage of GIC lining in providing a superior seal was found. The total-etching adhesive effectively covered caries-affected dentin as well as normal dentin. In the clinical situation, it is likely that both caries-affected dentin and normal dentin were exposed after caries removal. However, caries-affected dentin should be preserved as much as possible since this layer provides a natural seal. Less tooth sensitivity during caries removal and postoperative sensitivity after restoration might be anticipated. A randomized controlled clinical trial should be conducted to provide clinical evidence for or against the recommendation that a GIC liner should be used to reduce postoperative sensitivity in resin composite-restored teeth.
ACKNOWLEDGEMENTS

This study was supported by Melbourne Dental School, the University of Melbourne. The authors are grateful to Dr. Simon Crawford (the School of Botany, the University of Melbourne) for his support in scanning electron microscopy; Dr. Sandy Clark (the Statistical Consulting Centre, the University of Melbourne) for her assistance in statistical analysis; and Yuvadee Siriyasub (the Center of Nanoimaging, the Faculty of Science, Mahidol University) for her support in laser confocal microscopy. The materials were generously supplied by GC Corp. and 3M ESPE.
REFERENCES


37) WONG FSL, WILLMOTT NS, DAVIS GR. Dentinal carious lesion in three dimensions. *Int J Paediatr Dent* 2006; **16**: 419-423.
Figure 6-1 This graph shows the trend of fluid flow after restoration in carious and intact (non-carious) teeth, restored with or without GIC lining. The flow rates are expressed as % change of baseline flow rates. In all groups, fluid flow rates were initially high at 15 min, dramatically declined at 60 min, and were below the baseline flow rates, thereafter. There was no significant difference in fluid flow rates between the two restorative procedures, regardless of carious or intact teeth ($p > 0.05$). In addition, fluid flow rates after restoration were not significantly different between the carious and intact groups, whether with or without GIC lining ($p > 0.05$).

Bonded with TE adhesive, (1) TE-C: carious teeth, without lining; (2) TE-I: intact teeth, without lining; (3) GIC-C carious teeth, with GIC lining; and (4) GIC-I: intact teeth, with GIC lining.
Figure 6-2 SEM image at 1,000X magnification of dentin surface after caries removal using low-speed round steel burs is shown in Figure 6-2A. The surface was irregular and covered with the smear layer, but entrances of dentinal tubules were observed in some areas (arrow). Figure 6-2B shows SEM image of dentin surface on the cavity floor of a cavity-prepared, non-caries tooth.
Figure 6-3 SEM images of acid-etched dentin at 4,000X magnification. Dentin surface after acid etching of cavity prepared, non-carious tooth is shown in Figure 6-3A, which the smear layer and plugs were removed and dentinal tubules were patent. In contrast, dentinal tubules of caries-affected dentin were still occluded after acid etching, but the smear layer was clearly removed (Figure 6-3B). However, dentinal tubules were patent at some areas (arrows), shown in Figure 6-3C.
Figure 6-4 SEM image at 2,000X magnification shows that the occluding substances at tubular entrances of caries-affected dentin subjacent to rapidly progressing caries were partially removed after acid etching (arrow, Figure 6-4A). In contrast, some dentinal tubules of acid-etched, caries-affected dentin beneath to slowly progressing caries were still completely occluded (arrow, Figure 6-4B).
Figure 6-5 A longitudinal section of acid-etched, caries-affected dentin shows that the dentinal tubule was occluded along the tubule (arrow, Figure 6-5A). Dentinal tubules of normal dentin in non-carious tooth were funnel-shaped and patent after acid etching (arrow, Figure 6-5B). Lateral branches of dentinal tubules were observed at the tubular walls (block arrow).
Figure 6-6 Color images of the sectioned restored teeth (at the centre) obtained from light microscopy show fluorescent dye diffused through dentinal tubules and deposited at bonded interfaces (XT- Filtek Supreme XT; FLC- Fuji Lining LC; ND- normal dentin; CD- caries-affected dentin).
Figure 6-6 (caption)

Color images obtained from light microscopy show fluorescent dye diffused through dentinal tubules and deposited at bonded interfaces. Of non-carious tooth, fluorescent dye penetrated entirely in restoration with GIC lining (Figure 6-6A), and similar appearance was found in restoration with lining. In contrast, dye diffusion was inhibited in some areas of caries-affected dentin, in which some alterations such as discoloration were observed (arrows, Figures 6-6B to 6-6E). Dye penetrations at bonded interfaces of restored carious teeth were clearly less than of restored non-carious teeth, whether without lining (Figures 6-6B and 6-6C) or with GIC lining (Figures 6-6D and 6-6E).
Figure 6-7 Color and corresponding grey images simultaneously photographed from CLSM at 40X magnification.
Color and corresponding grey images simultaneously photographed from CLSM at 40X magnification. In restored non-carious teeth, fluorescent dye diffused through dentinal tubules and entirely stained at bonded interfaces (Figure 6-7A - bonded with the TE adhesive without lining, and Figure 6-7B - with GIC lining). Dye absorption into the bulk of the GIC lining was observed in Figure 6-7B. In contrast, fluorescent dye penetrations were limited in restored carious teeth (Figure 6-7C for TE-C, and Figure 6-7D for GIC-C). In carious teeth, there was no dye staining detected in the bulk of the GIC lining (Figure 6-7D). However, fluorescent dye could diffuse through dentinal tubules in some areas of restored carious tooth and was able to accumulate at the interface, as found in restored non-carious tooth (Figure 6-7E).
Table 6-1 Materials, components, batch numbers and manufacturers

<table>
<thead>
<tr>
<th>Materials</th>
<th>Compositions</th>
<th>Batch no.</th>
<th>Manufacturers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuji Lining LC</td>
<td>Paste A- Alumino silicate glass 70-80%, HEMA 10-15%, Urethane dimethacrylate 5-10%;</td>
<td>0611082</td>
<td>GC Corp., Tokyo, Japan</td>
</tr>
<tr>
<td>Paste Pak</td>
<td>Paste B- HEMA 30-40%, Polyacrylic acid 25-35%, Proprietary Ingredient 5-10%, Silica powder 1-5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(FLC)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single Bond 2</td>
<td>Etchant- 35% phosphoric acid</td>
<td>5FE</td>
<td>3M ESPE, St. Paul, MN, USA</td>
</tr>
<tr>
<td>(SB2)</td>
<td>Bonding- Bisphenol-A diglycidyl ether dimethacrylate, HEMA, dimethacrylate, colloidal nanofiller 10%, solvent, water</td>
<td>6JR</td>
<td></td>
</tr>
<tr>
<td>Filtek Supreme XT</td>
<td>BIS-GMA, UDMA, TEGDMA, Bis-EMA, inorganic fillers 59.5% (by volume)</td>
<td>6GY</td>
<td>3M ESPE, St. Paul, MN, USA</td>
</tr>
<tr>
<td>(XT)- shade A2B</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HEMA- 2-hydroxyethyl methacrylate; BIS-GMA- Bis-phenol A diglycidyl methacrylate; UDMA- urethane dimethacrylate; TEGDMA- triethylene glycol dimethacrylate; Bis-EMA- Bisphenol-A polyethylene glycol dimethacrylate
Table 6-2 Cavity lengths, widths and depths in mm (mean ± standard deviation) of carious and intact teeth groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of teeth</th>
<th>Length</th>
<th>Width</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carious</td>
<td>16</td>
<td>4.13±0.69</td>
<td>3.06±0.74</td>
<td>2.69±0.48</td>
</tr>
<tr>
<td>(Group 1 and 3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intact</td>
<td>16</td>
<td>4.20±0.64</td>
<td>2.95±0.62</td>
<td>2.70±0.43</td>
</tr>
<tr>
<td>(Group 2 and 4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cavity length, width and depth were not significantly different between carious and intact teeth groups ($p > 0.05$).
Table 6-3 Means and standard deviations of baseline flow rates and changes in fluid flow rates (nL.s\(^{-1}\)):
(1) after caries removal, (2) after acid etching and (3) during setting of the GIC in the carious group categorized by caries activity (slowly or rapidly progressing). The changes were slightly different between slowly progressing and rapidly progressing groups.

<table>
<thead>
<tr>
<th>Caries activity</th>
<th>Baseline flow rate</th>
<th>Change after caries removal</th>
<th>Change after acid etching</th>
<th>Change during GIC setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slowly progressing</td>
<td>0.31±0.08 (n=6)</td>
<td>0.10±0.20 (n=6)</td>
<td>-0.05±0.05 (n=3)</td>
<td>0.53±0.31 (n=3)</td>
</tr>
<tr>
<td>Rapidly progressing</td>
<td>0.37±0.09 (n=10)</td>
<td>-0.03±0.07 (n=10)</td>
<td>0.16±0.09 (n=5)</td>
<td>0.75±0.41 (n=5)</td>
</tr>
</tbody>
</table>
Table 6-4 Means and standard deviations of fluid flow rates (nL.s\(^{-1}\)) after caries removal in carious teeth or after cavity preparation in intact teeth

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of teeth</th>
<th>Before removal</th>
<th>After removal</th>
<th>Change (after-before)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carious</td>
<td>16</td>
<td>0.35±0.09</td>
<td>0.40±0.09</td>
<td>0.05±0.14(^a)</td>
</tr>
<tr>
<td>(Group 1 and 3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intact</td>
<td>16</td>
<td>0.06±0.05</td>
<td>0.42±0.12</td>
<td>0.36±0.10(^b)</td>
</tr>
<tr>
<td>(Group 2 and 4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significant different was found between the changing fluid flow rate of carious teeth and of intact teeth \((p < 0.001)\).
Table 6-5 Means and standard deviations of fluid flow rates (nL.s\(^{-1}\)) after acid etching in the groups without lining (TE) (n=8)

<table>
<thead>
<tr>
<th>Group</th>
<th>Before etching</th>
<th>After etching</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>TE-C</td>
<td>0.40±0.09</td>
<td>0.46±0.16</td>
<td>12.5±30.9 %(^a)</td>
</tr>
<tr>
<td>TE-I</td>
<td>0.37±0.14</td>
<td>0.77±0.48</td>
<td>101.8±84.1 %(^b)</td>
</tr>
</tbody>
</table>

Significant different was found between the changing fluid flow rates after acid etching of carious teeth and of intact teeth (\(p = 0.014\)).
Table 6-6 Means and standard deviations of fluid flow rates (nL.s$^{-1}$) during setting of the GIC in the groups with lining (GIC) (n=8)

<table>
<thead>
<tr>
<th>Group</th>
<th>Before GIC</th>
<th>During GIC</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIC-C</td>
<td>0.39±0.09</td>
<td>1.06±0.39</td>
<td>173.7±101.1 %$^a$</td>
</tr>
<tr>
<td>GIC-I</td>
<td>0.47±0.08</td>
<td>1.47±0.31</td>
<td>225.9±102.8 %$^a$</td>
</tr>
</tbody>
</table>

There was no significant difference in the changing fluid flow rates during setting of the GIC between the two groups ($p > 0.05$).
Author/s:
Banomyong, D.

Title:
Effects of glass-ionomer cement lining on sealing ability and postoperative tooth sensitivity after resin composite restoration of posterior teeth

Date:
2009

Citation:

Publication Status:
In Press

Persistent Link:
http://hdl.handle.net/11343/35095

File Description:
Chapter 6