Effects of light curing method and resin composite composition on composite adaptation to the cavity wall

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This study aimed to evaluate the effects of the light curing method and resin composite composition on marginal sealing and resin composite adaptation to the cavity wall. Cylindrical cavities were prepared on the buccal or lingual cervical regions. The teeth were restored using Clearfil Liner Bond 2V adhesive system and filled with Clearfil Photo Bright or Palfique Estelite resin composite. The resins were cured using the conventional or slow-start light curing method. After thermal cycling, the specimens were subjected to a dye penetration test. The slow-start curing method showed better resin composite adaptation to the cavity wall for both composites. Furthermore, the slow-start curing method resulted in significantly improved dentin marginal sealing compared with the conventional method for Clearfil Photo Bright. The light-cured resin composite, which exhibited increased contrast ratios during polymerization, seems to suggest high compensation for polymerization contraction stress when using the slow-start curing method.

Keywords: Resin composite, Marginal sealing, Cavity wall adaptation, Resin composite composition, Contrast ratio

INTRODUCTION

Adhesive dentistry is an important aspect of dental practice. Resin composite polymerization results in volumetric shrinkage, and this stress leads to greater gap formation between the resin and cavity surfaces^{1–6}. Such marginal gaps and subsequent microleakage may cause marginal staining, postoperative sensitivity^{7,8}, and secondary caries. In addition, cavity-wall gap formation may lead to pain on biting and failure of adhesion after repeated occlusal loading. The polymerization reaction of light-cured composites is rapid, which leads to the development of higher levels of stress in cured materials compared with that in self-activated materials⁹. Furthermore, the maximum interfacial stress generated at the cavity wall in light-cured composite restorations is twice as large as that observed in self-cured composite restorations¹⁰. Therefore, this stress leads to greater gap formation between the resin and cavity surfaces with light-cured resin composites than with self-cured resin composite¹.

When the bond strength exceeds polymerization shrinkage stress, a crack is initiated in the tooth structure, usually the enamel^{11,11–13}. We previously reported that the white margins represented cracks in the enamel surrounding the resin composite restorations; these cracks were located 30–50 μm from the composite–enamel interface, as observed using environmental scanning electron microscopy under a 100% saturated water vapor condition¹³.

There are several ways to overcome the curing stresses generated by light-cured, bulk-filled resin composites. One technique to decrease curing stresses is to use a flowable resin composite as the lining

material^{14–16}. The low shrinkage stress contributes to improved resin composite adaptation to the cavity wall^{17,18}. However, the low mechanical property of flowable composite materials decreases the bond strength to the dentin wall^{19,20}.

Incremental filling techniques are believed to decrease the curing stress at the tooth–resin interface that occurs when a cavity is bulk filled with light-cured resin composites. However, Versluis *et al.*²¹ conducted a theoretical study using the finite element analysis method and reported that compared with the bulk filling techniques, incremental filling techniques resulted in a higher frequency of polymerization shrinkage effects at the restoration–enamel interface. In addition, incremental filling does not increase the bond strength of the cavity floor of a box-like cavity²².

Alternatively, the internal hardness of cured resins increased with argon ion laser output along with increasing intensity, although the maximum hardness was not always increased²³. The use of an intense light source may lead to a higher frequency of marginal and wall gap formation^{3–6,24,25}. When a composite was cured with initial low-intensity light followed by high-intensity light, excellent marginal sealing and cavity adaptation were achieved^{3–6,26,27}. Previous work has shown that when a composite was light cured with an initial light intensity of 270 mW/cm^2 for 10 s followed by a light intensity of 600 mW/cm^2 for 50 s after a 5-s interval, decreased the curing stress in the resin composite^{3–6}. This method has been termed the slow-start curing method^{5,6}. We already reported that the slow-start curing method improved resin composite marginal sealing and adaptation to the all dentin cavity wall for various adhesives^{3–6}.

In contrast, the composition of a composite influences its capacity for refractive index mismatch between the matrix and filler²⁸⁾, direct transmittance²⁹⁾ and contrast ratio^{30,31)}. We previously reported that the light-cured resin composite, which had increased contrast ratios during polymerization, showed an accelerated curing rate at the bottom surface when using the slow-start curing method³²⁾. The purpose of this study was to test the hypothesis that the light curing method (conventional or slow-start curing) and resin composite composition will affect marginal sealing at the dentin and adaptation to the cavity wall on enamel and dentin cavity.

MATERIALS AND METHODS

Specimen preparation

The materials, components, manufacturers, batch numbers, and bonding procedures used in this study are listed in Table 1. Extracted intact human molars were used in this study. The teeth were collected under protocol no. 725, which was and approved by the appropriate institutional review board. Cylindrical cavities with 2/3 enamel and 1/3 dentin margin, 2 mm depth and 3 mm-diameter, with a C-factor of 3.7, were prepared on the buccal or lingual cervical regions of each lower molar using a diamond point (# B12, GC Corp., Tokyo, Japan) under copious air-water irrigation (Fig. 1).

Each of the 24 cavities was treated with the adhesive Clearfil Liner Bond 2V (Table 1). After curing of the adhesive, the cavities were bulk filled with

Clearfil Photo Bright resin composite or Palfique Estelite resin composite.

The resin composites were then polymerized using the conventional light curing method at 600 mW/cm² for 60 s or the slow-start curing method at 270 mW/cm² for 10 s + 5-s interval+600 mW/cm² for 50 s. For light curing, an experimental quartz-tungsten halogen light curing unit (GC Corp, Tokyo, Japan) was employed, which was connected to a slide regulator and equipped with a control system for lamp voltage, and light intensity. Light intensity was measured using a Curing radiometer (model 100, Demetron Research, Danbury, CT, USA). After light curing, the specimens were stored in the dark for 24 h in water maintained at 37°C. Resin composite restorations were finished with wet 600-grit SiC paper. The specimens were thermocycled for 500 cycles between 5°C and 55°C with a 30-s dwell time.

Fig. 1 Preparation of bonding substrate.

Table 1 Study materials

Material/Manufacturer	Components ^a	Batch No.	Bonding Instruction ^b
Clearfil Liner Bond 2V (Kuraray Noritake Dental Inc., Tokyo, Japan)	Primer A: MDP, HEMA, dimethacrylates, photoinitiator, water, others	00002A	a, b, c, d, e, f
	Primer B: HEMA, dimethacrylates, accelerator, water	00002A	—
	Bond A: MDP, HEMA, Bis-GMA, dimethacrylates, photoinitiator, microfiller, others	00003A	—
Clearfil Photo Bright (Kuraray Noritake Dental Inc., Tokyo, Japan) shade (US)	Silanated colloidal silica, prepolymerized organic filler containing colloidal silica, Bis-GMA, dimethacrylates, photoinitiator, others Filler load: 82 weight %	0036	—
Palfique Estelite (Tokuyama Dental Corp., Tokyo, Japan) shade (A3)	Silica-zirconia filler, Bis-GMA, TEGDMA, photo initiator Filler load: 82 weight %	15597	—

^aAbbreviations: MDP, 10 methacryloyloxydecyl dihydrogen phosphate; HEMA, 2-hydroxyethylmethacrylate; Bis-GMA, bisphenol A diglycidylmethacrylate; TEGDMA, triethyleneglycol dimethacrylate

^bProcedures: (a) mix equal volumes of primers A and B, (b) apply primer for 30 s, (c) dry with gentle air-blowing, (d) apply adhesive, (e) gently blow air, (f) light-cure for 20 s.

Evaluation of marginal sealing and cavity wall adaptation

To determine the degree of adaptation to the cavity margins and walls, a dye penetration test was performed by placing a 1.0 % acid red propylene glycol solution (Caries Detector, Kuraray Noritake Dental Inc., Tokyo, Japan) at the margins of the restorations for 5 s. The solution was then rinsed with water and gently blown dry. The degree of dye penetration was observed using a stereomicroscope at 20× magnification. A photographic record of each specimen was obtained at this stage. Subsequently, the specimens were longitudinally cut in half using a diamond saw microtome (Leitz 1600 saw microtome, Ernst Leitz, Wetzlar, Germany) under running water, and the dye was reapplied to the cavity walls examined to determine gaps and photographed. From the photographs, the length of dye penetration along the cavity margins and cavity walls was measured using a Digitizer (KD4300 model, Graphtec Co., Tokyo, Japan). The degree of dentin marginal leakage was determined as the length of dye penetration, which was expressed as a percentage of the total length of the dentin cavity margin. Dye penetration along the cavity walls was calculated as a percentage of the total length of the cavity wall. This area was referred to as the cavity-wall gap. Dye penetration scores were compared and analyzed using Mann-Whitney U and Kruskal-Wallis tests. Areas of marginal dye penetration in the enamel were considered to be enamel cracks.

RESULTS

The results for marginal leakage and cavity-wall gap formation are shown in Table 2. Light curing using the slow-start curing method showed complete dentin marginal sealing for both Clearfil Photo Bright and Palfique Estelite resin composites. This method also resulted in significantly better cavity wall adaptation compared with the conventional method for both resin composites ($p<0.05$). Furthermore, the slow-start curing method resulted in significantly better dentin marginal sealing compared with the conventional method for Clearfil Photo Bright ($p<0.05$). In contrast, the conventional method resulted in poor dentin marginal sealing and poor wall adaptation for both resin

composites. Enamel crack formation was observed in all specimens using either of the two curing methods.

DISCUSSION

In the present study, the conventional light curing method resulted in poor marginal integrity and cavity wall adaptation, whereas the slow-start light curing method resulted in complete dentin marginal sealing for both Clearfil Photo Bright and Palfique Estelite resin composites. The slow-start method also showed significantly better cavity wall adaptation compared with the conventional method for both resin composites. Recent resin composite is designed to promote curing speed in order to save treatment time. However, increasing the velocity of light-cured resin decreases composite adaptation to the cavity wall when a different composition was used³³. The polymerization rate has a significant effect on strain development. Therefore, we selected old type resin composite in this study.

A previous report indicated that a certain light intensity, which represents, the amount of activated starter radicals, was optimal for formation of cross-linked long-chain molecules²⁷. A higher concentration of radicals leads to an earlier termination of the reaction with short-chain molecules. This suggests that curing with a high-intensity light is more likely to lead to marginal gaps and poor adaptation of resin composite to the cavity walls. On the other hand, the decreased rate of surface hardness³⁻⁶ development due to the prolongation of the gel state and the accompanying absence of dye penetration suggests that this particular protocol may result in increased material flow, thereby providing stress relief despite the high elastic modulus and photosensitivity of the resin composite¹². Previous studies have shown that when a composite was light cured using the slow-start curing method, a higher rate of hardening of the resin composite occurred at the cavity base than at the surface³⁻⁶. In addition, this method allowed most polymerization contraction to be completed during the initial flowable stage of resin composite polymerization. Moreover, this method decreased curing stresses by delaying the hardening of the resin composite and permitted more time for relief of the stress induced

Table 2 Dentin marginal leakage and cavity-wall gap formation [%: mean (SD)]

Light curing method	Clearfil Photo Bright		Palfique Estelite	
	Dentin marginal leakage	Dentin cavity-wall gap formation	Dentin marginal leakage	Dentin cavity-wall gap formation
600 mW/cm ² 60 s	38.3 (30.1) ^a	42.3 (9.4)	10.3 (16.0) ^a	38.6 (9.2)
270 mW/cm ² 10 s + 5-s interval + 600 mW/cm ² 50 s	0	12.8 (6.7)	0	18.0 (9.6)

^aIntragroup data connected by a vertical line are significantly different ($p<0.05$).^bIntergroup data designated with same superscript letters for each resin composite are significantly different ($p<0.05$).

by polymerization contraction³⁻⁶). Furthermore, the rate of curing of the resin directly adjacent to the cavity wall may be enhanced by the free radicals present in the bonding resin. The initial low light intensity may have boosted the polymerization rate at this location than at the surface of the resin. The process of polymerization is then completed by high-intensity radiation, allowing for a more uniform rate of cure throughout the bulk of the resin composite. The radiation allows most of the polymerization contraction to be completed during the initial flowable stage of the resin composite, enabling the resin to flow toward the cavity walls⁴).

The slow-start curing method resulted in a more effective dentin marginal sealing compared with the conventional method only for the Clearfil Photo Bright composite. Light transmission through the light-cured resin composite is strongly affected by the opacity of the resin composite, which changes before and after resin composite curing. The opacity of the resin composite is indicated by the refractive index mismatch between the matrix and filler²⁸) or contrast ratio^{30,31}). Optimizing filler/resin refractive index mismatch increases curing depth²⁸). The greater the transparency of the resin composite shows the smaller the value of the ratio. A completely opaque material has a contrast ratio of 1, while that for a translucent material is within the range of 0–1³⁰). Almost all resin composite materials have a property of decreasing the contrast ratio (increasing transparency) during polymerization³¹). The contrast ratio of Clearfil Photo Bright increases during polymerization (increasing opacity), whereas that of Palfique Estelite slightly decreases during polymerization (slightly increasing transparency)³¹). We previously reported that the light-cured resin composite, which had increased contrast ratios during polymerization, showed acceleration of curing at the bottom surface when using the slow-start curing method³²). Therefore, for Clearfil Photo Bright, the delay in the hardening of the resin composite, particularly at the top surface, may apparently decrease curing stresses and permit more time for relief of the stress induced by polymerization contraction³²). This allows most of the polymerization contraction to be completed during the initial flowable stage of polymerization, enabling the resin to flow within itself and preventing it from pulling away from the marginal cavity walls³⁻⁶).

The light curing method and resin composite composition affected marginal sealing at the dentin and adaptation to the cavity wall. Therefore, tested hypothesis were accepted.

Enamel crack formation was observed in all specimens. Further research is required on the prevention of enamel crack initiation and the propagation for light-cured resin composite restorations. We will confirm the effect of self-cured adhesive and light-cured adhesive on the enamel crack formation using light-cured resin composite in future research.

CONCLUSION

The slow-start curing method showed better cavity wall adaptation compared with the conventional method for both Clearfil Photo Bright and Palfique Estelite resin composites. Furthermore the slow-start curing method improved dentin marginal sealing compared with the conventional method for Clearfil Photo Bright. The light-cured resin composite, which exhibited increased contrast ratios during polymerization, seems to suggest high compensation for polymerization contraction stress when the slow-start curing method was used.

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