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

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Purpose: This study aimed to evaluate the effects of light-curing method on the marginal seal and resin composite adaptation to the cavity wall, and the formation of enamel cracks around resin composite restorations.
Materials and Methods: Cylindrical cavities were prepared on the buccal or lingual cervical region of human molars. The teeth were restored with Clearfil Liner Bond 2 V and filled with Clearfil Photo Bright or Palfique Estelite resin composite. The resins were cured with the conventional light-curing method (600 mW/cm^2 for 60 s) or the slow-start curing method (270 mW/cm^2 for 10 s+5-s interval+600 mW/cm^2 for 50 s). After thermal cycling, the specimens were subjected to a dye penetration test with a caries detector.
Results: Light curing with the slow-start curing method resulted in a complete dentin marginal seal with both Clearfil Photo Bright and Palfique Estelite resin composites. This method also resulted in significantly better cavity wall adaptation of both resin composites compared with that achieved by the conventional method ($p<0.05$). The conventional method resulted in a poor dentin marginal seal and poor wall adaptation of both resin composites. Enamel crack formation was observed in all specimens.
Conclusion: The slow-start curing method improved the marginal sealing and resin composite adaptation to the cavity wall. However, enamel crack formation could not be avoided, even with the slow-start curing method. The dye penetration test using a caries detector can be used to evaluate resin composite adaptation to the cavity wall both in vitro and in vivo.
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Key Words: cavity wall adaptation, dye penetration test, marginal sealing, resin composite

Introduction

Adhesive dentistry is an important aspect of dental practice, particularly because of recent increases in cases of abrasion and erosion attributed to an aging society, eating disorders, and reflux esophagitis. Teeth with abrasion and erosion cannot be treated using metal inlays placed for conventional Black's cavities; such teeth can be restored only using resin composites with a direct bonding technique.

However, resin composite polymerization results in volumetric shrinkage, and the stress created leads to greater gap formation between the resin and cavity wall.[1-4] Such marginal gaps and subsequent microleakage may cause marginal staining, postoperative sensitivity,[5] 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 stresses in the cured materials compared with that in self-activated materials.[6] Furthermore, the maximum interfacial stress generated at the wall of cavities filled with light-cured composites is twice that generated with self-cured composites.[7] Therefore, this stress lead to greater gap formation between the resin and cavity walls when light-cured materials are used compared with that when self-cured materials are used.[1] On the other hand, when the bond strength exceeds polymerization shrinkage stress, a crack is initiated in the tooth structure, usually the enamel,[1,8-10] leading to direct communication with the oral cavity.

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 a lining material.[11,12] The low shrinkage stress contributes to improved resin composite adaptation to the cavity wall.[13]

However, the low mechanical property of flowable composites materials decreased the bond strength to the dentin wall.[14,15]

Furthermore, an incremental filling technique for the insertion of resin composite is widely used by many clinicians.[16] This technique is thought 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.[17] performed a theoretical study using the finite element analysis method and reported that incremental filling techniques caused increased polymerization shrinkage effects at the restoration-enamel interface compared with the bulk filling techniques. In addition Yoshikawa et al.[18] demonstrated that incremental filling was unable to increase the bond strength to the cavity floor of a box-like cavity.

Alternatively, increasing the velocity of light-cured resin composite decreased in composite adaptation to the cavity wall when a resin composite of a different composition was used.[19] Composite flow decreased the amount of tensile force exerted by the hardening resin. Therefore, the polymerization rate has a significant effect on strain development. The internal hardness of cured resins increased with argon ion laser output along with increasing intensity, but the maximum hardness was not always increased.[20] The use of an intense light source may lead to more frequent marginal and wall gap formation.[3,4,21,22] When a composite was cured with an initial low-intensity light followed by high-intensity light, excellent marginal sealing and cavity adaptation were achieved.[3,4,21-23] 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, it helped in decreasing the curing stress in the resin composite.[3,4] This method has been termed the slow-start curing method.[4]

The purpose of this study was to evaluate the effects of light-curing method on the marginal seal and resin composite adaptation to the cavity wall, and the formation of enamel cracks around resin composite restorations.

Materials and Methods

Specimen preparation

The materials, components, manufacturers, batch numbers, and bonding procedures used in this study are listed in Table 1. Erupted intact human molar after extraction were employed in this study. The teeth were collected under protocol no. 725 approved by the appropriate institutional review board. Cylindrical cavities with 2/3 enamel and 1/3 dentin margins, 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 molar using a diamond point (# B12, GC Corp., Tokyo, Japan) under copious air-water irrigation.

Each of the 20 cavities was treated with an adhesive, Clearfil Liner Bond 2 V (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; 600 mW/cm^2 for 60 s or the slow-start curing method; 270 mW/cm^2 for 10 s+5-s interval+600 mW/cm^2 for 50 s. The light curing unit used was an experimental quartz-tungsten halogen light curing unit (GC Corp., Tokyo, Japan) connected to a slide regulator. This light curing unit has a control system for lamp voltage, and the light intensity was adjustable. The light intensity was measured using a curing radiometer (Curing Radiometer, model 100, Sybron Kerr Corp., Milwaukee, WI, USA). After light curing, the specimens were stored in the dark for 24 h in 37°C water. The resin composite restorations were finished with wet 600-grit SiC paper.

Specimens were thermocycled for 500 cycles between 5°C and 55°C with a 30 s dwell time.

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.) shade (US)	silanated colloidal silica, prepolymerized organic filler containing colloidal silica, Bis-GMA, dimethacrylates, photoinitiator, others Filler load: 82 wt%	0036	
Palfique Estelite (Tokuyama Dental Corp., Tokyo, Japan) shade (A3)	silica-zirconia filler, Bis-GMA, TEGDMA, photo initiator Filler load: 82 wt%	15597	

[a]Abbreviations: MDP, 10-methacryloyloxydecyl dihydrogen phosphate; HEMA, 2-hydroxyethylmethacrylate; Bis-GMA, bisphenol A diglycidylmethacrylate; TEGDMA, triethyleneglycol dimethacrylate
[b]Procedures: (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 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. Then, the specimens were longitudinally cut in half with a diamond saw microtome (Leitz 1600 Saw Microtome, Ernst Leitz, Wetzlar, Germany) under running water, and the dye reapplied to the cavity walls and observed 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). Areas of marginal dye penetration in the enamel were considered to be enamel cracks. Then, the degree of enamel crack was determined as the ratio of the margin stained with the dye divided by the total length of the enamel cavity margin and converted to a percentage. The degree of dentin marginal leakage was determined as the length of dye penetration 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 cavity wall length. 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.

Results

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

Furthermore, the slow-start curing method resulted in a significantly better dentin marginal seal compared with the conventional method with Clearfil Photo Bright ($p<0.05$). The conventional method resulted in a poor dentin marginal seal and poor wall adaptation with both resin composites.

Enamel crack formation was observed in all specimens. There were no significant differences in the degree of enamel crack formation between the two light-curing methods ($p>0.05$).

Table 2. Enamel crack formation, dentin marginal leakage, and cavity-wall gap formation [%: mean (SD)]

	Clearfil Photo Bright			Palfique Estelite		
Light curing method	Enamel crack	Dentin marginal leakage	Dentin cavity-wall gap formation	Enamel crack	Dentin marginal leakage	Dentin cavity-wall gap formation
600 mW/cm^2 60 s	46.7 (39.6)	45.9 (26.3) [A, a]	44.9 (7.7) [B]	81.3 (12.3)	12.3 (17.0) [a]	41.1 (7.6) [C]
270 mW/cm^2 10 s + 5-s (interval) + 600 mW/cm^2 50 s	61.2 (22.1)	0 [A]	11.5 (6.5) [B]	85.4 (17.7)	0	16.3 (9.7) [C]

[a]Intragroup data with same superscript capital letters for each light curing method are significantly different ($p<0.05$).
[b]Intergroup data designated with same small letters for each resin composite are significantly different ($p<0.05$).

Discussion

In this study, the conventional light curing method resulted in poor marginal integrity and cavity wall adaptation, whereas the slow-start light curing method resulted in a complete dentin marginal seal with 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 with both resin composites.

A previous report indicated that at a certain light intensity, the amount of activated starter radicals is optimal to form cross-linked long-chain molecules.[23] A higher concentration of radicals leads to an earlier reaction stop with short-chain molecules. This suggested 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 hardness[3-6] 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, providing stress relief despite the high elastic modulus and photosensitivity of the resin composite examined.[9] Previous work has shown that when a composite was light cured with the slow-start curing method, the resin composite hardened earlier at the cavity base than at the surface.[3,4] In addition, this method allowed most polymerization contraction to be completed during the initial flowable stage of resin composite polymerization. Moreover, this method apparently decreases curing stresses by delaying the hardening of the resin composite and permits more time for relief of the stress induced by polymerization contraction.[3,4] Furthermore, the rate of cure of the resin directly adjacent to the cavity wall may be enhanced by the free radicals that already exist in the bonding resin. The initial low light intensity was thought to boost the polymerization rate at this location rather than at the surface of the resin. The process of polymerization is then completed by the 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 walls.[3]

The slow-start curing method resulted in a significantly better dentin marginal seal compared with the conventional method for Clearfil Photo Bright resin. Light transmission through the light-cured resin composite is strongly affected by the opacity of the resin composite. This opacity is different before and after the resin composite is cured.[24] Almost all resin composite materials have the property of increasing transparency during polymerization.[25] The opacity of Clearfil Photo Bright increases during polymerization, whereas that of Palfique Estelite slightly decreases during polymerization.[25] Therefore, with Clearfil Photo Bright, the delay in the hardening of the resin composite, particularly at the top surface,[26] may apparently decrease curing stresses and permit more time for relief of the stress induced by polymerization contraction.[27] 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 walls.[3,4] The dye penetration test using a caries detector can be used to evaluate resin composite adaptation to the cavity wall both in vitro and in vivo.

Enamel crack formation was observed in all specimens. There were no significant differences between the slow-start method and the conventional method in terms of the degree of enamel crack formation. Enamel is a highly mineralized tissue and has a modulus of elasticity higher than that of dentin. Enamel prisms are very fragile. The tensile strength of enamel is 7.4 MPa when pulled vertical to the enamel prisms.[28] The enamel cavosurface reportedly exhibits disruption even when a decreased power density of 100 mW/cm^2 is used.[9] Therefore, enamel crack formation could not be avoided, even with the slow-start curing method, when the cavities were prepared with butt-joint margins. Further research is required to prevent enamel crack initiation and propagation.

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