Effect of light curing method and thermal cycling on resin composite adaptation to the cavity wall

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Purpose: This study evaluated the effects of the light curing methods and thermal cycling on adaptation to the cavity wall of different type of resin composite using a dye penetration test.
Materials and Methods: Cylindrical cavities with one-half enamel and one-half dentin margins were prepared on the labial cervical region of bovine incisors. Cavities were restored using Clearfil tri-S Bond ND Quick and filled with Clearfil AP-X or Clearfil Photo Bright composite. The resin composites were cured using the conventional or the slow-start curing method. Half of specimens were thermocycled.
Results: Clearfil AP-X showed significantly greater cavity-wall gap formation than that of Clearfil Photo Bright with both the conventional curing method and slow-start curing method with thermal cycling at 500 cycles ($p < 0.05$). The slow-start curing method showed significantly improved resin composite adaptation to the cavity wall compared with the conventional curing method for thermocycled Clearfil Photo Bright specimens ($p < 0.05$). Thermal cycling at 500 cycles significantly decreased cavity-wall gap formation compared with 0 cycle for Clearfil Photo Bright resin composites ($p < 0.05$). Clearfil Photo Bright using the slow-start curing method with thermal cycling at 500 cycles showed least cavity-wall gap formation.
Conclusion: Light-cured composite, increased contrast ratio during polymerization with thermal cycling at 500 cycles, improved adaptation to the cavity wall using the slow-start curing method. The slow-start curing method facilitated the high reduction for residual stress of composite that had increased contrast ratio.

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Key Words: adaptation, composite, dye penetration, polymerization, residual stress, slow-start curing method

Introduction

Resin composite polymerization results in volumetric shrinkage, and the resultant stress leads to the formation of gaps between the resin and cavity surfaces [1,2]. Such marginal gaps and the subsequent micro-leakage may cause marginal staining, postoperative sensitivity [3,4], and secondary caries. Light-cured resin composites are widely used in clinical practice. However, the polymerization reaction of light-cured composites is faster than that of self-cured composites, which has led to the development of higher stresses during setting than self-activated materials [5]. Therefore, the maximum stress to the interface generated at the cavity wall in light-cured resin composite restorations is twice that of self-cured composite [6]. This stress has been shown to lead to formation of greater gaps between the resin and cavity surfaces than self-cured resin composite. Moreover, contraction of resin composite polymerization leads to a cuspal deflection [7-9], a high-stressed tooth composite structure [10] and residual shrinkage stresses in a resin composite restoration and restored tooth [11,12].

There are several ways to overcome the curing stresses generated by light-cured, bulk-filled resin composites. One technique involves of using a flowable resin composite as a lining material [13,14]. The low polymerization stress [15] contributes to improved adaptation to the cavity wall [13,14,16]. However, the poor mechanical properties of flowable resin composite [16,17] decrease the bond strength to the dentin wall [18]. Many clinicians use the incremental filling technique [19]. This technique was thought to decrease the curing stress which occurs at the tooth-resin interface when a cavity is bulk-filled with light-cured resin composites. However, in a theoretical study using finite element analysis, it was reported that the incremental filling technique produced higher polymerization shrinkage effects at the restoration-enamel interface compared with bulk filling [20]. Previously, it was confirmed that incremental filling could not improve the bond strength to the floor of a box-like cavity.

Another study found that, increasing the curing velocity of light-cured resin composite decreased the adaptation to the cavity wall when a resin with a different composition was used [21]. Clearly, the polymerization rate has a significant effect on the development of stress. With argon ion laser output, the deep internal hardness of cured resin composites increase as the laser intensity increases, but the maximum internal hardness is reduced with the intense light intensity [22].

The use of an intense light source may lead to more frequent marginal and wall gap formation [2,23]. A slow-start light curing method with an initial low-intensity light followed by a high-intensity light has been used to cure resin composite with decreased stresses. This method was found to produce excellent marginal sealing and cavity adaptation [2,24-29]. Previous studies have reported that an initial light intensity of 270 mW/cm^2 for 10 s, followed by a 5 s interval, and then a light intensity of 600 mW/cm^2 for 50 s hardened the resin composite base faster than at the surface adjacent to the light source [2,30]. This procedure, known as the slow-start curing method [26,27], allowed most polymerization contraction to occur during the initial flowable stage of resin composite polymerization [2].

Bonding durability is an important factor for a long-lasting bonded restoration clinically. One of the degradation simulated techniques is the thermal cycling test. It was demonstrated that increased destruction occurs to bonds between tooth substrates and resin composite restorations after thermal stress [31,32]. High number of thermal cycling decrease resin composite adaptation to the cavity wall [33]. It is hypothesized that the slow-start curing method will improve cavity wall adaptation of different components of resin composites, thermal cycling decrease cavity wall adaptation of resin composite.

Materials and Methods

The materials, components, manufacturers, batch numbers, and bonding procedures used in this study are listed in Table 1. An experimental quartz-tungsten halogen light-curing unit (GC, Tokyo, Japan) that was connected to a slide regulator (Type SD-135, Matsunaga MFG, Yokohama, Japan) was used. This light-curing unit had a control system for lamp voltage and adjustable light intensity, which was measured using a curing radiometer (model 100, Sybron Kerr, Milwaukee, WI, USA).

Cylindrical cavities with 1/2 enamel and 1/2 dentin margins, 2 mm depth, 3 mm diameter, and a C-factor of 3.7 were prepared on the labial cervical region of extracted intact erupted bovine incisors using a diamond point (# B12, GC) under copious water spray. Each of the 40 cavities was treated with the adhesive Clearfil tri-S Bond ND Quick (Kuraray Noritake Dental, Tokyo, Japan). After this adhesive was cured (600 mW/cm^2 for 10 s) with light guide contacted at the cavity margin, the cavities were bulk-filled with Clearfil AP-X (shade A3; Kuraray Noritake Dental) resin composite or Clearfil Photo Bright (shade US; Kuraray Noritake Dental) resin composite. The resin composites were light-cured using the conventional curing method (600 mW/cm^2 for 40 s) or the slow-start curing method (270 mW/cm^2 for 10 s + 5 s interval + 600 mW/cm^2 for 30 s). The tip of the light guide placed at the resin composite surface.

The specimens were stored in water maintained at 37˚C in the dark for 24 h. Then, the restorations were finished and polished using wet 600-grit SiC paper, and half of specimens were thermocycled between 5˚C and

55˚C for 500 cycles [34] with a 30 s dwell time. The specimens were then longitudinally cut in half using a diamond saw microtome (MC-110, Maruto, Tokyo, Japan) under running water. The dye penetration test was used to determine the degree of adaptation to the cavity walls. This test was performed by placing a 1.0% acid red propylene glycol solution (Caries Detector, Kuraray Noritake Dental) at the cavity wall/restoration for 5 s, followed by rinsing with water and gentle blow-drying. The extent of dye penetration was observed with a mesoscope (20× magnification), and a photographic image of each specimen was acquired.

Table 1 Study materials

Material	Components[a]	Batch No.
Clearfil tri-S Bond ND Quick[b]	microfiller, Bis-GMA, MDP, HEMA, dimethacrylates, ethanol, photoinitiator, water, sodium fluoride, others	8N0022
Clearfil Photo Bright shade: US	prepolymerized organic filler, silanated silica filler, silanated colloidal silica, silanated silica glass filler, Bis-GMA, TEGDMA, urethane tetramethacrylate, hydrophilic aliphatic dimethacrylate, photoinitiator, catalysts, accelerators, pigments, others, Filler load: 82.0 wt%	450006
Clearfil AP-X, shade: A3	silanated barium glass filler, silanated silica filler, silanated colloidal silica, Bis-GMA, TEGDMA, photoinitiator, catalyst, accelerator, pigments, others Filler load: 84.5 wt%	6J0038

[a] Abbreviations: Bis-GMA, bisphenol A-glycidyl methacrylate; MDP, 10-methacryloyloxydecyl dihydrogen phosphate; HEMA, 2-hydroxyethylmethacrylate; TEGDMA, triethyleneglycol dimethacrylate

[b] Bonding instruction / Procedures: a, apply adhesive; b, dry with gently air-blowing (5 s); c, light-cure (10 s)

In these images, the length of dye penetration along the cavity walls was measured using a digitizer (KD4300 model, Graphtec, Tokyo, Japan). 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-resin gap. The dye penetration test scores were compared using the Mann-Whitney U test at a significant level of 5%.

Results

The results for cavity-wall gap formation are shown in Table 2. Clearfil AP-X showed significantly greater cavity-wall gap formation than that of Clearfil Photo Bright with both the conventional curing method and slow-start curing method with thermal cycling at 500 cycles ($p < 0.05$). The slow-start curing method showed significantly improved resin composite adaptation to the cavity wall compared with the conventional curing method for thermocycled Clearfil Photo Bright specimens ($p < 0.05$). Thermal cycling at 500 cycles significantly decreased cavity-wall gap formation compared with 0 cycle for Clearfil Photo Bright resin composites ($p < 0.05$). Clearfil Photo Bright using the slow-start curing method with thermal cycling at 500 cycles showed least cavity-wall gap formation.

Table 2 Cavity-wall gap formation

Light-curing method	Non-thermal cycling		500-thermal cycling	
Material	Clearfil AP-X	Clearfil Photo Bright	Clearfil AP-X	Clearfil Photo Bright
600 mW/cm^2	54.9 (21.6) ^{A}	36.8 (6.3) ^{B}	47.5 (16.2) ^{C}	17.6 (12.0) $^{a, A, B, C}$
270 / 600 mW/cm^2	56.2 (15.7) ^{A}	37.9 (10.6) ^{B}	33.4 (6.2) ^{C}	1.4 (3.1) $^{a, A, B, C}$

% means with standard deviations in parentheses. Intergroup data with the same superscripted lower-case letters for each light curing method are significantly different ($p < 0.05$). Intergroup data with the same superscripted upper-case letters for each thermal cycling number and each resin composite are significantly different ($p < 0.05$).

Discussion

Clearfil AP-X showed significantly greater cavity-wall gap formation than Clearfil Photo Bright with both conventional and slow-start curing methods with thermal cycling at 500 cycles. In a micro-computed tomography three-dimensional (μCT-3D) visualization analysis showed that the amount of polymerization shrinkage of Clearfil AP-X restoration was much larger than that of Clearfil Photo Bright restoration in a cavity with adhesive [35]. A significant correlation has been reported among polymerization shrinkage, flow, and gap formation [36]. Marginal integrity is inversely correlated with Young's modulus of the resin composite [37], and the marginal quality can be improved by the selection of resin composite with modulus of elasticity close to that of dentin [38]. However, flexural modulus of elasticity is not considered to be a significant determinant of gap formation [36]. Peutzfeldt *et al.* have attributed this to the fact that flexural modulus is determinant later after the gaps were formed [36]. The filler content of Clearfil AP-X is higher than that of Clearfil Photo Bright resin composite. Higher filler content decreased the flow and increased the modulus of elasticity [16,39] and stiffness. Therefore, large polymerization shrinkage, low flow and high modulus of elasticity of Clearfil AP-X [39] caused greater cavity-wall gap formation compared with Clearfil Photo Bright.

The slow-start curing method significantly improved resin composite adaptation to the cavity wall compared with the conventional curing method for thermocycled Clearfil Photo Bright specimens. Polymerization shrinkage that occurs after gelation or curing results in the buildup of large stresses in a resin composite [40]. Therefore, a decreased rate of development of surface hardness due to prolonged gel state and an accompanying absence of dye penetration suggest that this protocol results in increased material flow, which provides stress relief, despite its high elastic modulus and the photosensitivity of the resin composite [41]. Yodhikawa *et al.* reported on μCT-3D visualization analysis. In that study the slow-start curing method reduced the volume of polymerization shrinkage to half of that produced by the conventional curing method for both Clearfil AP-X and Clearfil Photo Bright resin composite restorations in the cavities with adhesive [35]. Moreover, it was reported that the time required for complete polymerization shrinkage after the slow-start curing method was less than half that required after the conventional curing method [2]. The slow-start curing method resulted in a lower microhardness at the top surface of Clearfil Photo Bright resin composite compared with the conventional curing method up to 60 s from the start of curing [2]. The viscosity of resin composite until 40 s from the start of curing was lower when initial low-intensity curing was used followed by high-intensity curing was used than when only high-intensity curing [42]. The use of a light intensity lower than the maximum resulted in a significant decrease in post-gel contraction without significantly affecting the degree of conversion [42,43]. This irradiation allowed for most of the resin composite polymerization shrinkage to occur during the initial flowable stage [2].

A high correlation between dye penetration test using caries detector and environmental scanning electron microscope observation of composite-cavity wall gap has been reported [29]. The slow-start curing method resulted in significantly decreased dye penetration, namely, better adaptation of Clearfil Photo Bright to the cavity wall compared with the conventional curing method. Previous studies have shown that, when Clearfil Photo Bright resin composite is light-cured using the slow-start curing method, the resin hardens faster at the bottom surface than at the top surface [2,30]. Light transmission through light-cured resin composites is strongly affected by the opacity and shade of the resin, and opacity changes during polymerization. The opacity of the resin composite is indicated by the mismatched refractive index between the matrix and filler [44] or the contrast ratio [45]. Optimizing the mismatched filler/resin refractive index increases the curing depth [44]. The contrast ratio decreases as the transparency of the resin composite increases. The ratio is equal to 1 for a completely opaque material and ranges between 0 and 1 for a translucent material [45]. Most resin composite materials tend to show a decrease in the contrast ratio during polymerization. However, the contrast ratio of Clearfil Photo Bright increases during polymerization (increased opacity), where as that of Clearfil AP-X decreases during polymerization (increased transparency) [35]. Therefore, the delay in hardening of Clearfil Photo Bright, particularly at the top surface [2,30], may decrease curing stresses and allow more time for relief.

The rate of curing for resin directly adjacent to the cavity wall may be enhanced by free radicals that are already present in the bonding resin. An initial low-intensity light may enhance the polymerization rate at this location, rather than at the resin surface. The process of polymerization is then completed by high-intensity radiation, which allows for more uniform curing throughout the bulk of the resin composite. Therefore, most of the polymerization shrinkage occurs during the initial flowable stage of the resin composite polymerization. This allow the resin to flow freely and presents it from pulling away from the cavity walls [2,24-29,35].

Thermal cycling at 500 cycles significantly decreased cavity-wall gap formation for Clearfil Photo Bright resin composites. Clearfil Photo Bright using the slow-start curing method with thermalcycling at 500 cycles showed least cavity-wall gap formation. The conventional curing method causes more internal stress in resin composite restoration than the soft-start curing method [25]. The slow-start curing method allows for more uniform curing throughout the bulk of the resin composite [2,30], especially for increased contrast ratio (Clearfil Photo Bright) during polymerization [35]. Therefore, the slow-start curing method seems to reduce residual stress especially for Clearfil Photo Bright resin composite restoration. It is thought that residual stress of resin composite is released during thermal cycling. When residual stress is high, high resin composite gap formation to the cavity wall occurs during thermal cycling. When residual stress is low, high resin composite adaptation to the cavity wall occurs because of accelerated adhesive polymerization with thermal cycling at 500 cycles. It appeared that Clearfil Photo Bright using the slow-start curing method with thermal cycling at 500 cycles showed the highest cavity wall adaptation.

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Conflict of Interest
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