Effect of delayed light polymerization of a dual-cured composite base on microleakage of Class 2 posterior composite open-sandwich restorations

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Objective: To determine the effect of delayed start of light polymerization of a dual-cured composite base on the microleakage of Class 2 open-sandwich composite restorations. **Method and Materials:** Fifty extracted human molars were used to prepare Class 2 mesio-occlusal and disto-occlusal slot preparations. Teeth were randomly divided into 2 groups and restored with a base of dual-cured composite in the proximal box and a top layer of light-cured composite. Group I was restored with a 1-step dual-cured bonding agent; group II was restored with a 2-step dual-cured bonding agent. Five subgroups were created according to the method of polymerization of the dual-cured composite: (A) self-cured, (B) light-cured immediately, (C) light-cured 30 seconds after placement, (D) light-cured 60 seconds after placement, and (E) light-cured 120 seconds after placement. Restorations were stored for 1 week at 37°C and 100% relative humidity, thermocycled (2,000 times, 5°C to 55°C, 15-second dwell), and immersed in a 1% aqueous solution of methylene blue for 24 hours at 37°C. Samples were sectioned mesiodistally, and dye penetration at enamel, dentin, and cementum margins was scored under a stereomicroscope using an ordinal scoring system. **Results:** Statistical analysis using analysis of variance (ANOVA) on ranks showed that the dual-cured composite light polymerized 1 minute after placement exhibited the lowest microleakage ($P < .05$) in both bonding agent groups. **Conclusion:** Delayed, rather than immediate, light polymerization of the dual-cured composite base reduced microleakage in Class 2 open-sandwich restorations. *(Quintessence Int 2009;40:471–477)*

Key words: Class 2, delayed curing, dual-cured, microleakage, open-sandwich restoration, polymerization shrinkage, posterior composite

Numerous dental materials and methods proposed for placement of direct composite resins have been hypothesized to improve marginal adaptation and reduce polymerization shrinkage stress by using incremental composite placement,[1] low elastic modulus liners,[2] and stepped or ramped light curing.[3] In the direct Class 2 posterior composite restoration, the rationale behind each choice should be to apply materials that reduce polymerization shrinkage and shrinkage stress and work effectively on enamel, as well as in the proximal box of deep restorations where dentin and cementum become primary concerns for long-term success. The problems caused by polymerization shrinkage and

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shrinkage stresses include gap formation and microleakage at the tooth-composite interface that may result in secondary decay, postoperative sensitivity, and clinical failure of the restoration.[4]

For successful clinical outcomes, a nonshrinking composite resin would be the ideal material used to deal with the problems caused by polymerization shrinkage and shrinkage stress.[5] Because no direct composite material currently exists that is truly nonshrinking, these problems may be overcome by the optimal combination of placement technique, material choice, and curing method. Therefore, use of specific materials and light-curing techniques to control the rate of polymerization may reduce the shrinkage stress.[6]

The open-sandwich technique for placement of a Class 2 posterior composite restoration has all layers of restorative material exposed to the oral cavity at the proximal margins, which are areas of primary concern for long-term clinical success. A self- or dual-cured composite resin material, glass ionomer, or resin-modified glass ionomer is placed as a base that covers the entire proximal box including all the dentin and cervical margin up to about one-third to one-half of the height of the matrix band. After an initial polymerization period of this base, a top layer of a light-cured composite resin is placed to complete the restoration to full anatomic form and function.

The type of composite resin used in the proximal box may play a critical role in the marginal adaptation of a Class 2 posterior composite restoration. Light-cured composites, when light-polymerized, develop high stresses when bonded to the cavity wall.[7] The polymerization of dimethacrylate-based composites results in considerable volumetric shrinkage in the range of 2% to 6%.[8] During the polymerization process, composites shrink as a result of the change from a liquid to a solid state by the conversion of monomer molecules into a polymer network linked through shorter covalent bonds. Bulk contraction results from the reduction in free volume within the monomer structure as it transforms into a tightly packed polymer.[9]

Reduced shrinkage and polymerization contraction stress at the tooth-restoration border have been identified as key factors for improved marginal cavity adaptation.[10] In vitro studies demonstrate that polymerization shrinkage stress may be a primary factor for marginal leakage and adhesive failure.[11] Modification of the composite formulation can diminish stress by altering the concentration of the polymerization promoters or inhibitors to slow the kinetics of the curing reaction.[9] Chemically or self-cured composites demonstrate the lowest amount of internal stress to the tooth structure when polymerizing and a lower polymerization rate, which may result in better adaptation of the restoration.[12]

The directed shrinkage technique is described as the use of a self-cured resin as the first increment in the base of a Class 2 composite followed by a light-cured composite resin to complete the open-sandwich restoration.[13] The hypothesis of this clinical method suggested that the warmth of the tooth would enhance polymerization closest to the tooth and inhibit shrinkage from the preparation walls as seen in light-cured composite resins.

The technique proposed in this study instead uses dual-cured composites as the initial base or liner for direct Class 2 posterior composite restorations.[14,15] This material is used mainly for core buildup procedures. Updated delivery systems, lower viscosity, and control over placement and setting times simplify the adaptation of dual-cured composite resin materials to the pulpal floor and proximal box. Dual-cured systems have been demonstrated in vitro to have better properties, such as improved bond strength, modulus of elasticity, hardness, color stability, and low solubility, than self-cured systems.[16] These enhanced properties play a significant role when considering selection of materials exposed to the oral environment for posterior composite restorations. A recent study demonstrated that the self-cure mode produces a lower polymerization contraction stress than the light-cure mode when using the same dual-cured composite material.[6]

Table 1 Materials, composition, and manufacturer's instructions

Materials	Compositions (batch no.)	Manufacturer's instructions
Adhesive systems		
I. DC Bond (1-step self-etch dual-cured bonding agent, Kuraray America)	Adhesion monomer (MDP); hydrophilic monomer; hydrophobic monomer; photoinitiators; self-curing catalyst; nanofiller; water; ethanol; Liquid A: Lot DCA-T1; Liquid B: Lot DCB-T1	Mix 1 drop each A+B, apply 2 coats agitated to tooth surface for 20 s, air dry with high pressure for 8 s and light cure 20 s.
II. Clearfil Liner Bond 2V (2-step self-etch dual-cure bonding agent, Kuraray America)	Adhesion monomer (MDP); 2-hydroxyethyl methacrylate (HEMA); di-camphorquinone Lot no. 61197	Mix 1 drop each Primer A+B. Apply to tooth surfaces. Leave in place 30 s. Air dry lightly 5 s. Apply 1 coat Bond A+B, dry with light air stream, light cure 20 s.
Composite resins		
I. DC Core Automix (Kuraray America)	Silanated silica; silanated glass; bis-GMA; TEGMA; hydrophobic aromatic dimethacrylate; di-camphoroquinone; benzoylperoxide Ref no. 362 KA Lot no. 020AA	Dual-cured radiopaque 2-component core buildup material supplied in an automix delivery system.
II. Clearfil AP-X (Kuraray America)	Silanated barium glass; silanated colloidal silica; silanated silica; bis-GMA; TEGDMA; dicamphoroquinone Ref no. 1731-KA Lot no. 453BA	Light-cured composite resin.

(MDP)10-methyl-acryloxydecyl dihydrogen phosphate; (bis-GMA) bisphenol A- glycidyl methacrylate; (TEGDMA) triethylene glycol dimethacrylate.

Delaying light polymerization of a dual-cured composite and allowing for some initial conversion by the self-cure mode of the material may reduce the polymerization rate, polymerization shrinkage, and associated stresses of light curing and therefore improve the marginal seal of Class 2 composite resin restorations. The aim of this in vitro study was to determine the effect of delayed light polymerization of a dual-cured composite base material on the microleakage of Class 2 composite restorations.

The null hypothesis of this study was that placement of a dual-cured composite resin material as the initial base increment in the gingival box of direct Class 2 composite restorations restored with the open-sandwich technique would not reduce microleakage at the gingival and proximal margins if light polymerization were delayed instead of performed immediately following placement. There would be no difference in microleakage between the immediate light-cure and delayed light-cure groups.

METHOD AND MATERIALS

Fifty extracted human molars were used to prepare Class 2 mesio-occlusal and disto-occlusal slot preparations. Gingival margins were placed at the cementoenamel junction (CEJ). The teeth were restored using an open-sandwich technique with a 2-mm base increment of dual-cured composite (DC Core Automix, dentin shade, Kuraray America) in the proximal box and a 2-mm top layer of light-cured composite (Clearfil AP-X, shade-XL, Kuraray America). Teeth were randomly divided into 2 groups based on the bonding agent used. Group I was restored with 1-step self-etch dual-cured bonding agent (DC Bond, Kuraray America); group II was restored with 2-step self-etch dual-cured bonding agent (Clearfil Liner Bond 2V, Kuraray America). Each group was further divided into 5 subgroups according to the delay in the start of light polymerization of the dual-cured composite base: (A) self-cured after placement; (B) light-cured immediately

Table 2 Microleakage scores

Subgroups	Scores 0	1	2	3
Group I				
IA	0	7	7	6
IB	0	4	7	9
IC	2	7	7	4
ID	4	9	6	1
IE	2	5	9	4
Total	8	32	36	24
Group II				
IIA	0	4	11	5
IIB	0	2	8	10
IIC	3	6	8	3
IID	4	8	7	1
IIE	3	7	8	2
Total	10	27	42	21

See text for explanation of scores and subgroups.

Table 3 Pairwise multiple comparison of cure mode (Tukey test)

Group comparison	Difference of ranks	q statistic	Significant difference (*P* value)
B vs D	2,655.00	7.25	< .001
B vs C	1,752.50	4.79	< .001
B vs E	1,745.50	4.77	< .001
B vs A	834.50	2.28	.052
A vs D	1,820.50	4.97	< .001
A vs C	918.00	2.51	.057
A vs E	911.00	2.49	.056
E vs D	909.50	2.49	.057
E vs C	7.00	0.02	.980
C vs D	902.50	2.47	.057

after placement; (C) light-cured 30 seconds after placement; (D) light-cured 60 seconds after placement; and (E) light-cured 120 seconds after placement. Details of the adhesive systems and composite materials are listed in Table 1.

The Optilux 400 light (Demetron Research) with a continuous mode of polymerization (600 mW/cm^2 continuous energy output for 40 seconds) was used to cure each composite resin layer. Restorations were stored for 1 week at 37°C and 100% relative humidity, thermocycled (2,000 times, 5°C to 55°C, 15-second dwell), and immersed in a 1% aqueous solution of methylene blue for 24 hours at 37°C. Samples were sectioned mesiodistally, and dye penetration at enamel, dentin, and cementum margins was scored under a stereomicroscope (Global Surgical) using an ordinal scoring system: 0 = no penetration; 1 = enamel penetration; 2 = gingival dentin penetration; 3 = axial dentin penetration.

Because the data are not normally distributed, Kruskal Wallis 1-way analysis of variance (ANOVA) on ranks was performed to compare the effects of bonding agent and curing modes on microleakage scores. A *P* value less than .05 was used to determine statistical significance.

RESULTS

Microleakage scores of the subgroups are listed in Table 2. There was no statistically significant difference between the leakage of the 2 bonding agents used ($P = .947$). There was a statistically significant difference between microleakage at different levels of cure mode ($P < .001$). Pairwise multiple comparisons were performed using the Tukey test.

The highest degree of leakage was obtained for samples that were light-cured immediately after placement (group B). Leakage of these samples (group B) was significantly higher ($P < .05$) than all other cure modes except for samples that were allowed to self-cure (group A). The lowest degree of microleakage was obtained for samples that had a 60-second delay (group D) before light curing, followed by those that had a 30-second delay (group C), a 120-second delay (group E), and those that were self-curing (group A). Microleakage recorded from samples light-cured after a 60-second delay (group D) was significantly lower ($P < .05$) than immediate light-cured (group B) and self-cured (group A) groups. The difference between the microleakage of the samples light-cured after 60 seconds (group D), 30 seconds (group C), and 120 seconds (group E) was not statistically significant. Table 3 shows the result of pairwise multiple comparisons of cure mode.

DISCUSSION

The results of this study support rejection of the null hypothesis that use of a dual-cured composite resin material as the base increment in the proximal box for Class 2 open-sandwich composite restorations would not reduce microleakage if the start of light polymerization was delayed instead of done immediately following placement. A statistically significant difference in microleakage was found between the immediate light-cure and delayed light-cure groups.

The modification of the light polymerization time interval of a dual-cured composite played an important role in the results obtained. A dual-cured composite resin material placed in the proximal box for Class 2 open-sandwich composite restorations and light-cured 1 minute after placement resulted in the lowest microleakage at the CEJ margin. The same dual-cured material light-cured immediately after placement demonstrated the highest leakage, indicating behavior similar to a light-cured composite in regard to polymerization shrinkage stresses. It has been suggested that upon polymerization of a light-cured composite in a large Class 2 composite restoration, the greatest stresses occur in the proximal box and dentinoenamel junction.[18] In addition, the increased size of the restoration may amplify microleakage due to shrinkage.[19]

A reduced amount of polymerization shrinkage stress may result from letting the self-polymerization mode of the dual-cured composite initiate, thereby slowing the polymerization reaction velocity before the final light-polymerization procedure. The results of this study support a recent study suggesting that choice of a low contraction-stress composite resin and modification of its placement are significant determinants in reduction of microleakage and better clinical outcomes in Class 2 direct restorations.[20] Delayed light polymerization may reduce polymerization shrinkage and stresses at final conversion and therefore enhance clinical success of posterior composite resin restorations. Additionally, final light polymerization would enhance significant mechanical properties, making the selection of a dual-cured composite an improvement over a self-cured or a light-cured composite at the gingival margin.

The dual-cured composite used in this study, DC Core automix, was reported to have higher dentin bond strengths when light-cured as compared to self-curing.[16] All of the delayed light-cured groups in this study had significantly lower microleakage than the self-cured group, which may be explained by the improvement in material properties when the composite was ultimately light-polymerized. The immediate light-cured samples had higher microleakage than the self-cured samples, but a statistically significant difference between these 2 groups could not be demonstrated.

Given that the physical properties of the dual-cured material are enhanced by light polymerization, delayed light curing of the dual-cured composite optimizes the best qualities of the self-cure mode and light-cure mode, which may result in improved clinical performance. The present samples were subjected to thermocycling to evaluate microleakage of the restoration over time rather than immediately after placement. The lower microleakage among the delayed light-cured samples was therefore a clinically significant finding.

Samples that were light-cured after a 60-second delay had the lowest degree of microleakage. This study did not show a statistically significant difference between microleakage scores of samples that were light-cured after 30 seconds, 60 seconds, and 120 seconds. However, all 3 groups performed better than the immediate light-cured and self-cured groups, clearly underlining the importance of delaying the start of light polymerization. It is not known whether dual-cured composites from different manufacturers would yield diverse results when light-cured at varied time intervals; this would be the subject of a subsequent study.

Long-term clinical trials and micromorphologic analysis of the bonded surfaces will be necessary to validate existing in vitro studies on this subject matter.

Other techniques proposed for reducing polymerization shrinkage of light-cured composites use specialized curing lights, incremental placement, and flowable composite liners. Ramped curing intensity lights, stepped curing lights, and pulse curing lights vary light intensity over the curing time in different ways. The results in the literature for the application of these lights have been mixed, with some studies reporting improved marginal adaptation,[21] reduced polymerization contraction stress,[3] and reduced shrinkage,[22] while others did not find any improvement in marginal seal,[23] shrinkage, or shrinkage stress.[24] It has been concluded that clinically unusable applications of low light power for protracted periods of time are required to significantly lessen contraction stresses.[25]

While there is evidence that incremental fill techniques may improve marginal adaptation, the use of flowable composites as stress-relieving liners to improve marginal adaptation on enamel margins cannot be recommended.[18] The other variable in the microleakage results of this study—the bonding agent—did not demonstrate any statistical differences between groups. The 1-step self-etch bonding agent used in this study showed a performance equivalent to the traditional 2-step self-etch bonding agent in the microleakage results.

CONCLUSION

Delayed light polymerization of the dual-cured composite base rather than immediate light polymerization reduced microleakage at the gingival margin and proximal walls in Class 2 open-sandwich restorations.

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