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Shear Bond Strength of Dual-cured and Self-cured Resin Composites to Dentin Using Different Bonding Agents and Techniques

C Leevailoj • P Ua-wutthikrerk • S Poolthong

Clinical Relevance

When using resin composites as core buildup materials, dual-cured resin composites show higher shear bond strength to dentin than self-cured resin composites. Light activation of bonding agents prior to applying a resin composite core can improve the shear bond strength of resin composites to dentin.

SUMMARY

This study determined the effects of bonding agents on the shear bond strength of dual- and self-cured resin composites to dentin. Two light-cured dentin bonding agents (Excite and One-Step) and a dual-cured bonding agent (Excite DSC) were compared. Light activation of the bonding agents prior to placement of the resin composites was also evaluated. This *in vitro* study was performed on 120 extracted non-carious human third molars. The occlusal part of the crowns was removed to expose a flat dentin surface. The teeth were then randomly divided into three major groups for Excite, One-Step and Excite DSC as bonding agents. The specimens in each adhesive group were divided into four subgroups: with and without light activation of the bonding agent and with dual-cured (Luxacore Dualcure, DMG, Hamburg, Germany) or light-cured resin (Luxacore, DMG, Hamburg, Germany) composites. After placing the restorations, the specimens were kept in water at 37°C for 24 hours before being tested for shear bond strength on an Instron universal testing machine at a crosshead speed of 0.5 mm/minute. The results showed that the shear bond strength of dual-cured resin composite to dentin was significantly higher than that of self-cured resin composite (*p*=0.017). Light activation of the bonding agents prior to applying the resin composites led to a significantly higher shear bond strength of

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the resin composites to dentin, compared to no light activation (*p*<0.05).

INTRODUCTION

Currently, resin composites are commonly used as direct restorative materials. Although light-cured resin composites are generally used because of their numerous advantages,[1] self-cured and dual-cured resin composites still have important applications in contemporary restorative dentistry, including core buildup, luting of indirect restorations and post bonding.[2-4]

Three-step dentin bonding agents, which require etching, priming and bonding, had been the most successful dentin bonding system for several years.[5] However, they have been largely substituted by simplified bonding systems. In an effort to develop simpler, more user-friendly dentin bonding applications, simplified-step bonding systems, such as two-step total-etching, two-step self-etching and one-step self-etching adhesives have been introduced. Although these simplified-step adhesives bond well to light-cured resin composites,[6] their bonding to self-cured resin composites is questionable. There are reports of incompatibility between some simplified-step adhesives and self-cured resin composites.[3,7-10] The decrease in microtensile bond strength of self-cured resin composites to dentin was directly proportional to the acidity of these adhesives.[7] The acidity of resin monomers is known to retard the polymerization of self-cured resin composites.[11]

In addition, a study by Tay and others showed that single-step, self-etching adhesives permit the passage of fluid and behave as permeable membranes after polymerization.[12] Water permeation through the polymerized adhesive layer occurs via osmotic pressure. The water molecules that migrate to the composite-adhesive interface mechanically disrupt coupling between the adhesive and resin composites, thus decreasing bond strength. This is especially important for self-cured resin composites, because their slow rate of polymerization allows sufficient time for water permeation.

Some of the newer simplified-step adhesives include an additional activator in the package. The activator is mixed with an adhesive agent to allow the adhesive to cure chemically. This increases the bond strength of self-cured resin composites to dentin. One study reports that the adjunctive use of the activator with OptiBond Solo Plus slightly improves the microtensile bond strength of self-cured resin composites to dentin.[13] However, this is still lower than the strength obtained when using these adhesives with light-cured resin composites.[13] Nevertheless, there are other simplified-step adhesives that contain an activator, but their effects on bonding with self-cured resin composites are still questionable.

In some clinical situations, light activation of the bonding agent prior to placement of resin composites may not be possible. One example is when a bonding agent is used with a resin luting cement to fix a prefabricated post in an endodontically treated tooth; using this technique may interfere with seating of the post. Therefore, the effects of unpolymerized simplified-step adhesives to the bond strength of resin composites to dentin should be evaluated.

One of the main objectives of this study was to evaluate the shear bond strength of dual-cured and self-cured resin composites to dentin when bonding agents were or were not activated with light prior to placement of the resin composites. This study also determined the effects of different bonding agents to the shear bond strength of dual-cured and self-cured resin composites to dentin. For comparison purposes, light-cured dentin bonding agents and dual-cured bonding agents were included in the study.

METHODS AND MATERIALS

One hundred and twenty extracted, non-carious human third molars were stored in 0.01% thymol solution at 4°C and used within one month following extraction. The teeth were mounted in a polyvinyl chloride pipe with the use of self-cure acrylic resin. While the acrylic resin polymerized, the specimens were kept in a large cold-water bath to minimize any effects from the exothermic setting reaction of the acrylic. The occlusal surface of all the specimens was coarsely ground horizontally to expose fresh occlusal dentin at a depth of approximately 2 mm from the central pit. The samples were subsequently polished flat with 400- to 600-grit silicon carbide paper using a polishing machine at a speed of 250 rotations per minute for 10 seconds under running water, thus exposing a flat dentin surface.

The specimens were randomly divided into three groups (40 each). Each group was treated with one of three different single-bottle, total-etch adhesives: Excite (Ivoclar/Vivadent, Amherst, NY, USA), One-Step (BISCO, Schaumburg, IL, USA) and Excite DSC (Ivoclar/Vivadent). First, the bonding surfaces of occlusal dentin, 3 mm in diameter, were isolated, etched with 32% phosphoric acid for 15 seconds, rinsed with water for 15 seconds and dried gently to leave the dentin surface moist. The assigned adhesives were then applied to 40 specimens in each group according to the manufacturers' instructions (Table 1). Each adhesive group was divided into two subgroups of 20 specimens each. One subgroup was activated by visible light at an intensity of 500 mW/cm^2 (Elipar Trilight, 3M ESPE, St Paul, MN, USA) prior to placement of the resin composites. The other subgroup of 20 specimens was not activated with visible light prior to resin composite application.

Table 1: *Application Procedures of the Dentin Bonding Agents and Step of Preparation for Each Group*

Bonding Agent	Application Procedure	Group	Light Activation of the Bonding Agent	Resin Composite
Excite	Etch for 15 seconds, rinse, gently air dry, apply adhesive, gently agitate and add more adhesive every 5 seconds for 20 seconds, gently air dry for 5 seconds	1	Yes (20 seconds)	Dual-cured
		2	No	
		3	Yes (20 seconds)	Self-cured
		4	No	
Excite DSC	Etch for 15 seconds, rinse, gently air dry, press the applicator with initiator into the adhesive liquid for 5 seconds, apply to tooth substrate for 10 seconds	5	Yes (20 seconds)	Dual-cured
		6	No	
		7	Yes (20 seconds)	Self-cured
		8	No	
One-Step	Etch for 15 seconds, rinse, gently air dry, apply adhesive to tooth substrate for 10 seconds, gently air dry	9	Yes (20 seconds)	Dual-cured
		10	No	
		11	Yes (20 seconds)	Self-cured
		12	No	

Table 2: *Composition and pH Value of Dentin Bonding Agents*

Bonding Agent	Composition	pH
Excite	HEMA, dimethacrylates, phosphonic acid acrylate, highly dispersed silicon dioxide, initiators and stabilizers in an alcohol solution	2.3
Excite DSC	Liquid: HEMA, dimethacrylates, phosphonic acid acrylate, highly dispersed silicon dioxide, initiators and stabilizers in an alcohol solution Brush: coated with initiators	2.3
One-Step	BPDM, BIS-GMA, HEMA, and acetone	3.7

Table 3: *Mean Shear Bond Strength (MPa) and Standard Deviation for Each Group*

	Group	Number	Mean	SD
1	Exc L-DC	10	13.64	4.48
2	Exc NL-DC	10	6.85	2.18
3	Exc L-SC	10	7.37	2.11
4	Exc NL-SC	10	0	0
5	DSC L-DC	10	15.15	5.48
6	DSC NL-DC	10	11.20	4.34
7	DSC L-SC	10	8.22	2.78
8	DSC NL-SC	10	7.12	2.97
9	OS L-DC	10	9.89	3.62
10	OS NL-DC	10	5.78	1.63
11	OS L-SC	10	9.08	3.51
12	OS NL-SC	10	1.38	0.64

Ten specimens from each subgroup were restored with dual-cured resin composite (Luxacore dual-cure, DMG, Hamburg, Germany) and light activated for 40 seconds. The 10 remaining specimens from each subgroup were restored with self-cured resin composite (Luxacore) and allowed to polymerize for 10 minutes without light activation. Both resin composites were mixed using a mixing gun and tips supplied by the manufacturer, then injected into a silicone mold (3 mm in diameter and 3 mm in height). The details of specimen preparation and bonding procedures for all 12 subgroups are shown in Table 1.

All specimens were stored in distilled water at 37°C for 24 hours before being subjected to the shear bond strength test. The method for testing shear bond strength follows the 2003 ISO technical specification #11405, using an Instron universal testing machine (Model 8872, Instron Limited, Bucks, England) at a crosshead speed of 0.5 mm/minute until bond failure occurred. The shear bond strength was calculated from the peak load of failure divided by the specimen bonding surface area. The mode of failure was determined by observation under a stereomicroscope at 10x magnification and classified into adhesive (Ad), mixed (Mix) and cohesive (Co) failures in either dentin or resin. The pH of the bonding agents measured with a pH meter is shown in Table 2.

SEM Examination of Fractured Interfaces

Two fractured dentin sides and two fractured resin composite sides from each group were randomly selected for evaluation under a scanning electron microscope. Both the dentin and resin sides were air-dried and sputter-coated with gold before being examined with a scanning electron microscope at 3500x magnification.

RESULTS

Shear Bond Strengths

Shear bond strength data obtained from all 12 groups (as shown in Tables 3-8) were analyzed using three-way analysis of variance (ANOVA) using the computer pro-

Table 4: *Shear Bond Strength Analyzed Using Three-way ANOVA*					
Source	**Sum of Square**	**df**	**Mean square**	**F**	**Sig**
Corrected model	2132.297	11	193.845	19.594	0.000
Intercept	7625.696	1	7625.696	770.823	0.000
Factor "bonding agents"	363.617	2	181.809	18.378	0.000
Factor "resin composites"	717.950	1	717.950	72.572	0.000
Factor "Light activation at bonding agents"	802.074	1	802.074	81.076	0.000
Factor "bonding agents" * Factor "resin composites"	83.594	2	41.797	4.225	0.017
Factor "bonding agents" * *Factor "Light activation at bonding agents"	111.692	2	55.846	5.645	0.005
Factor "resin composites" * Factor "Light activation at bonding agents"	1.434	1	1.434	0.145	0.704
Factor "bonding agents" * Factor "resin composites" * Factor "Light activation at bonding agents"	51.936	2	25.968	2.625	0.077
Error	1068.436	108	9.893		
Total	10826.429	120			
Corrected total	3200.733	119			

gram SPSS version 10.0 (SPSS Inc, Chicago, IL, USA). The effects of bonding agents, resin composites and light activation of bonding agents were examined with the interaction of these three parameters on shear bond strength. Statistical significance was set at the 0.05 probability level. Multiple comparisons were performed using Bonferroni and Tamhane's T2.

The mean shear bond strength and standard deviations for all groups are presented in Table 3. Three-way ANOVA showed that significant differences in shear bond strength (Table 4) were observed for bonding agents ($p<0.001$), resin composites ($p<0.001$) and light activation of bonding agents ($p<0.001$). The interaction bonding agents and resin composites and the interaction between bonding agents and light activation at bonding agents were statistically significant ($p=0.017$ and $p=0.005$, respectively). However, the interaction between resin composites and the light activation of bonding agents and the interaction among all three factors were not statistically significant ($p=0.704$ and $p=0.077$).

Table 5: *The Shear Bond Strength for the Interaction Between Light Activated Bonding Agents and Resin Composites*			
Group	**Number**	**Mean (MPa)**	**SD**
(5) DSC L-DC	10	15.15[c]	5.48
(1) Exc L-DC	10	13.64[c,a]	4.48
(9) OS L-DC	10	9.89[b,a]	3.62
(11) OS L-SC	10	9.08[b,a]	3.51
(7) DSC L-SC	10	8.22[b]	2.78
(3) Exc L-SC	10	7.37[b]	2.11

The same superscript denotes no statistically significant difference among the groups.

Table 6: *The Shear Bond Strength for the Interaction Between Non-activated Bonding Agents and Resin Composites*			
Group	**Number**	**Mean (MPa)**	**SD**
(6) DSC NL-DC	10	11.20[a]	4.34
(8) DSC NL-SC	10	7.12[a,b]	2.97
(2) Exc NL-DC	10	6.85[a,b]	2.18
(10) OS NL-DC	10	5.78[b]	1.63
(12) OS NL-SC	10	1.38	0.64
(4) Exc NL-SC	10	0	0

The same superscript denotes no statistically significant difference among the groups.

The shear bond strength of samples from groups with light activation of bonding agents before placement of the resin composite was compared (Table 9). The shear bond strength of dentin to self-cured resin composite in the Excite and Excite DSC groups (groups 3 and 7) was significantly lower than that of dentin to dual-cured resin composite (groups 1 and 5). On the other hand, for One-Step, the shear bond strength of dentin to the self-cured resin composite (group 11) was not significantly different from that of dentin to dual-cured resin cements (group 9).

Without light activation, the shear bond strength of dentin to self-cured resin composite in the Excite and One-Step groups (groups 4 and 12) was significantly lower than that of dentin to the dual-cured resin composite (groups 2 and 10). Nevertheless, for Excite DSC, the shear bond strength of dentin to the self-cured resin composite (group 8) was not significantly different from dentin to the dual-cured resin composite (group 6) (Table 6).

Next, the shear bond strength among groups restored with dual-cured resin composite was compared (Table 7). In the groups with Excite as the bonding agent, the shear bond strength with light activation before placement of the resin composite (group 1) was significantly higher than the group without light activation (group 2). However, the shear bond strength of dentin to dual-cured resin composite, using Excite DSC and One-Step as bonding agents, showed no statistical difference in both the light activated (groups 5 and 9) and non-light activated groups (groups 6 and 10).

When shear bond strength is compared among groups restored with self-cured resin composite, the groups with Excite and One-Step with light activation (groups 3 and 11) showed significantly higher strength than those without light activation (groups 4 and 12). However, the bond strength of the Excite DSC groups showed no statistical difference between the light activated (group 7) and non-light activated (group 8) (Table 8).

Table 7: *The Shear Bond Strength for the Interaction Between Activated and Non-activated Bonding Agents and Dual-cured Resin Composites*

Group	Number	Mean (MPa)	SD
(5) DSC L-DC	10	15.15[a]	5.48
(1) Exc L-DC	10	13.64[a]	4.48
(6) DSC NL-DC	10	11.20[a,b]	4.34
(9) OS L-DC	10	9.89[a,b,c]	3.62
(2) Exc NL-DC	10	6.85[b,c]	2.18
(10) OS NL-DC	10	5.78[c]	1.63

The same superscript denotes no statistically significant difference among the groups.

Table 8: *The Shear Bond Strength for the Interaction Between Activated and Non-activated Bonding Agents and Self-cured Resin Composites*

Group	Number	Mean (MPa)	SD
(11) OS L-SC	10	9.08[a]	3.51
(7) DSC L-SC	10	8.22[a]	2.78
(3) Exc L-SC	10	7.37[a]	2.11
(8) DSC NL-SC	10	7.12[a]	2.97
(12) OS NL-SC	10	1.38	0.64
(4) Exc NL-SC	10	0	0

The same superscript denotes no statistically significant difference among the groups.

Modes of failures were examined using a stereomicroscope. The frequencies of different failure modes are summarized in Table 9.

Table 9: *The Frequency of Failure Modes of Each Group*

	Cohesive in Resin	Cohesive in Dentin	Adhesive	Mixed	Total
Exc L-DC	0	0	7	3	10
Exc NL-DC	0	0	9	1	10
Exc L-SC	9	0	0	1	10
Exc NL-SC	0	0	10	0	10
DSC L-DC	0	0	5	5	10
DSC NL-DC	0	1	9	0	10
DSC L-SC	1	0	5	4	10
DSC NL-SC	0	0	10	0	10
OS L-DC	0	0	9	1	10
OS NL-DC	0	0	10	0	10
OS L-SC	0	0	9	1	10
OS NL-SC	0	0	10	0	10
Total	10	1	94	15	120

SEM Examination of Fractured Interfaces

SEM examination at 3500x magnification of representative fractured specimens in all groups is showed in Figures 1-13 (A&B).

Fractured specimens from group 3, Excite with light activation before placement of self-cured resin composite (Exc L-SC), revealed microporous—soapsuds-like blister—features along the composite-adhesive interfaces (Figure 3A and 3B). However, SEM pictures of fractured specimens in group 11, One-Step with light activation before placement of self-cured resin composite (OS L-SC), do not show such microporous features (Figure 12A and 12B). In group 7, Excite DSC with light activation before placement of self-cured resin composite (DSC L-SC), there are small parts in some specimens that were microporous (Figures 7A and 7B and 8A and 8B).

Fractured specimens from group 1 (Exc L-DC), group 2 (Exc NL-DC), group 5 (DSC L-DC), group 6 (DSC NL-DC), group 8 (DSC NL-SC), group 9 (OS L-DC) and group 10 (OS NL-DC) showed failure along the adhesive-dentin interface. Microporous features were not found in these specimens (Figures 1A-B, 2A-B, 5A-B, 6A-B, 9A-B, 10A-B, 11A-B).

Fractured specimens in group 4, Excite with no light activation before placement of self-cured resin composite (Exc NL-SC), showed no bonding at the adhesive-dentin interface (Figures 4A and 4B). SEM pictures of fractured specimens in group 12, One-Step with no light activation before placement of self-cured resin composite (OS NL-SC), showed evidence of a partially bonded surface at the dentin-resin interface (Figures 13A and 13B).

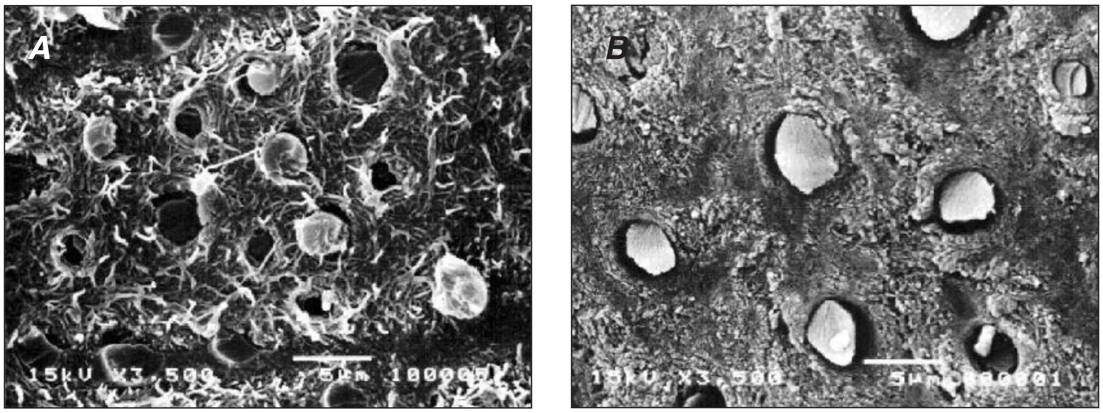


Figure 1: *SEM micrographs of the dentin and resin composite surfaces at fracture site of specimens from group 1. (A) the resin composite side. (B) the dentin side. Failure occurred along the adhesive-dentin interface.*

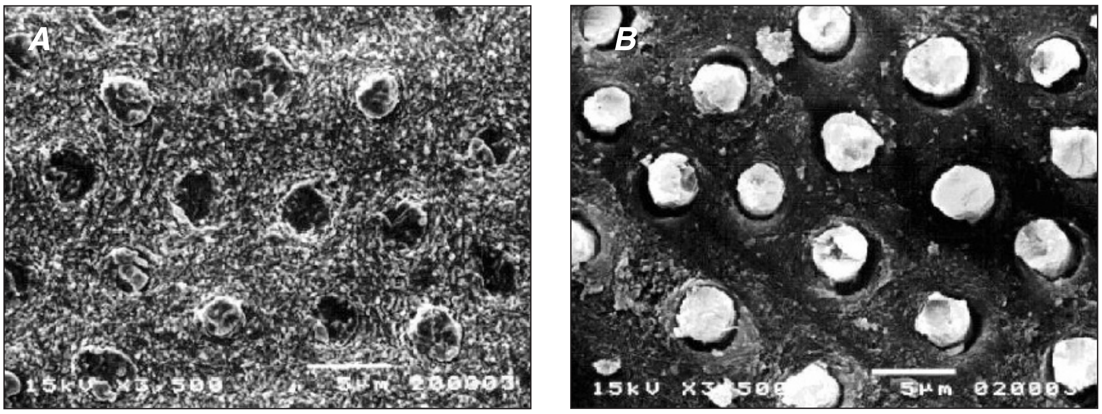


Figure 2: *SEM micrographs of the dentin and resin composite surfaces at fracture site of specimens from group 2. (A) the resin composite side. (B) the dentin side. Failure occurred along the adhesive-dentin interface.*

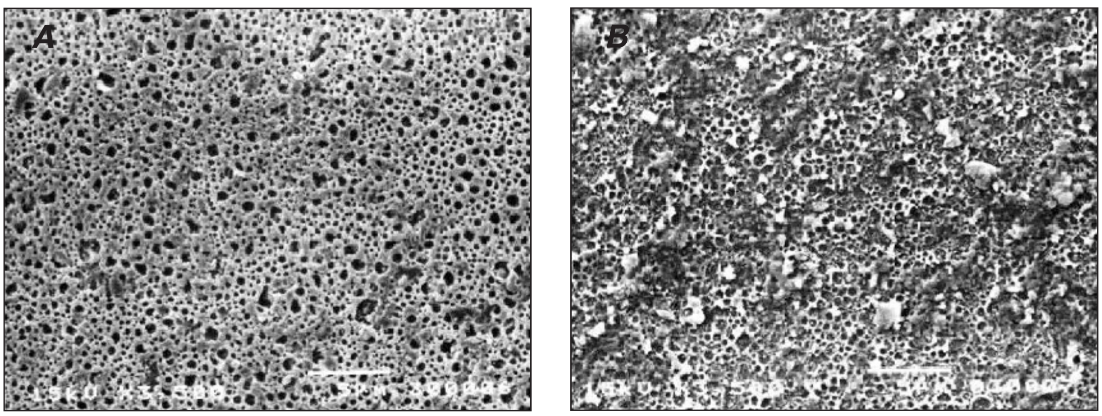


Figure 3: *SEM micrographs of the dentin and resin composite surfaces at fracture site of specimens from group 3. (A) the resin composite side. (B) the dentin side. Failure occurred within the composite. Microporous features were present.*

DISCUSSION

This study compared three total-etch and two-step bonding agents: Excite and One-Step, which are light-cured bonding agents, and Excite DSC, which is dual-cured. Excite DSC is manufactured by the same company as Excite; therefore, the components of both bonding agents are similar except that Excite DSC has an additional initiator coated on the brush supplied in the package. When stirred in the liquid component, this brush initiates the chemical curing mechanism.

The results in Table 3 show that Excite and Excite DSC with light activation prior to placement of dual-cured resin composite generated higher shear bond strengths than when bonded to a self-cured resin composite. However, there was no statistically significant difference in shear bond strengths between Excite and Excite DSC, although the later had an additional initiator. This might have resulted from the high acidity of Excite DSC (pH 2.3), which might have affected the chemical reaction between the bonding agent and the self-cured resin composite, thereby decreasing the shear bond strength of the resin composite to dentin. In addition, Excite DSC might not have achieved complete chemical curing, because the initiators were coated at the tip of the brush fiber and may not be incorporated sufficiently into the bonding mix. The manufacturer states that it is necessary to press the brush tip into the bonding liquid (which was typical for Excite) container for at least five seconds. In the group with light activation of bonding agents prior to application of chemical-cured resin composites, SEM micrographs showed small parts of some specimens harboring the same microporous fea-

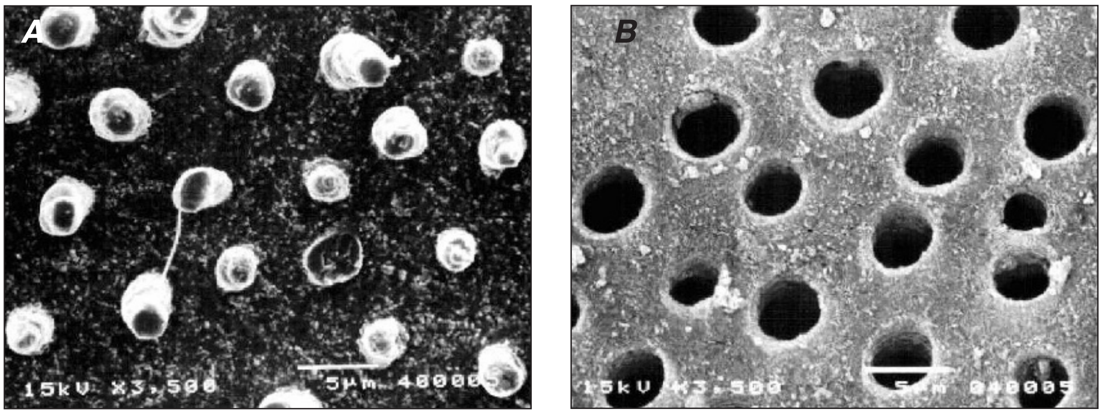


Figure 4: *SEM micrographs of the dentin and resin composite surfaces at fracture site of specimens from group 4. (A) the resin composite side. (B) the dentin side. Failure occurred along the adhesive-dentin interface. There was no bonding at the adhesive-dentin interface.*

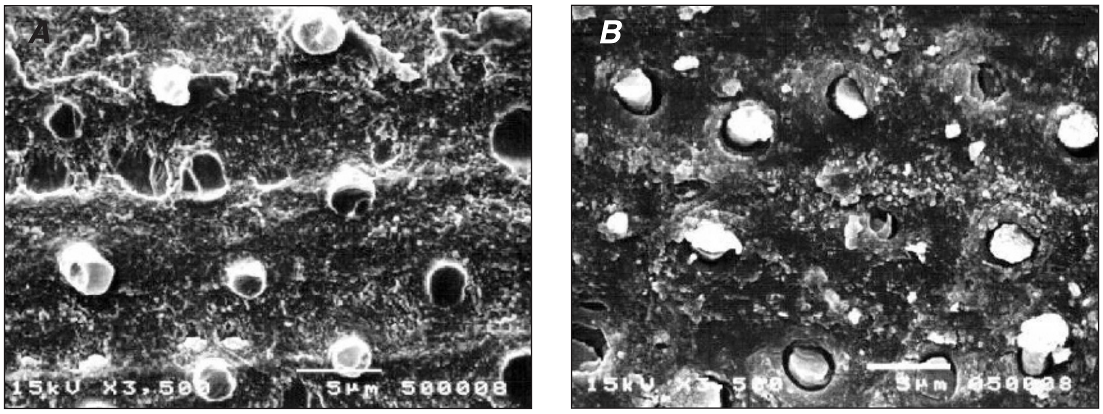


Figure 5: *SEM micrographs of the dentin and resin composite surfaces at the fracture site of specimens from group 5. (A) the resin composite side. (B) the dentin side. Failure occurred along the adhesive-dentin interface.*

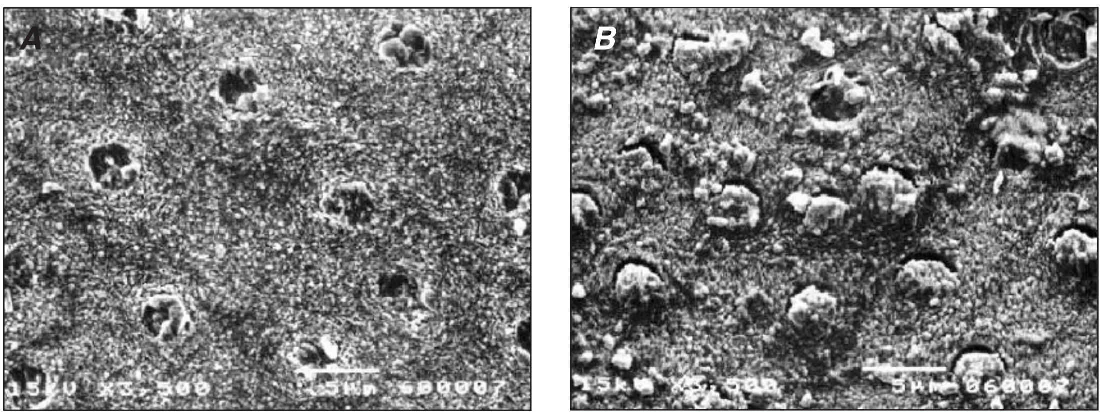


Figure 6: *SEM micrographs of the dentin and resin composite surfaces at fracture site of specimens from group 6. (A) the resin composite side. (B) the dentin side. Failure occurred along the adhesive-dentin interface.*

tures as found in the Excite group. This represents evidence of improper mixing of the initiator and bonding agent (Figures 8A and 8B).

The study also showed that, in group 3, Excite with self-cured resin composite (Exc L-SC), 90% of the failures were cohesive in the interface between the adhesive and resin composite, which indicated weak bonding. On the other hand, only 10% of the failures in group 7, Excite DSC with self-cured resin composite (DSC L-SC), were due to cohesive failure at the adhesive-composite interface. Fifty percent of the samples in group 7 showed adhesive failure at the adhesive-dentin interface and 40% were mixed failure. These results indicated that the weak areas at the adhesive-composite interface in group 7 were reduced. SEM micrographs of dentin and resin composite of a fractured specimen in group 3, Excite with light activation of the bonding agent before placement of self-cured resin composite (Exc L-SC), revealed microporous features along the adhesive-composite interfaces (Figures 3A and 3B). The results of this study were in accordance with those from other studies.[7,12] For group 7, only small areas in some specimens showed microporous features (see Figures 7A and B and 8A and B).

The shear bond strength of group 9, One-Step with light activation of the bonding agent prior to placement of dual-cured resin composite (OS L-DC), was not significantly different from the self-cured resin composite group (OS L-SC, group 11), as shown in Table 5. Though the One-Step bonding agent was a simplified-step bonding agent, the manufacturer claimed that it also bonds well to self-cured resin composites. According to the study, the bond strengths of One-Step used with self-cured resin composites were not different from those of One-Step used with light-activated resin composites, possibly due to low acidity, as its pH value was approximately 3.7.[11] From this study, groups that used One-Step as a bonding agent showed non-cohesive failure in resin, with some adhesive failures at the adhesive-dentin interface. Moreover, unlike Excite and Excite DSC, SEM micrographs of One-Step groups showed no microporous features on fractured specimens (Figures 12A and 12B).

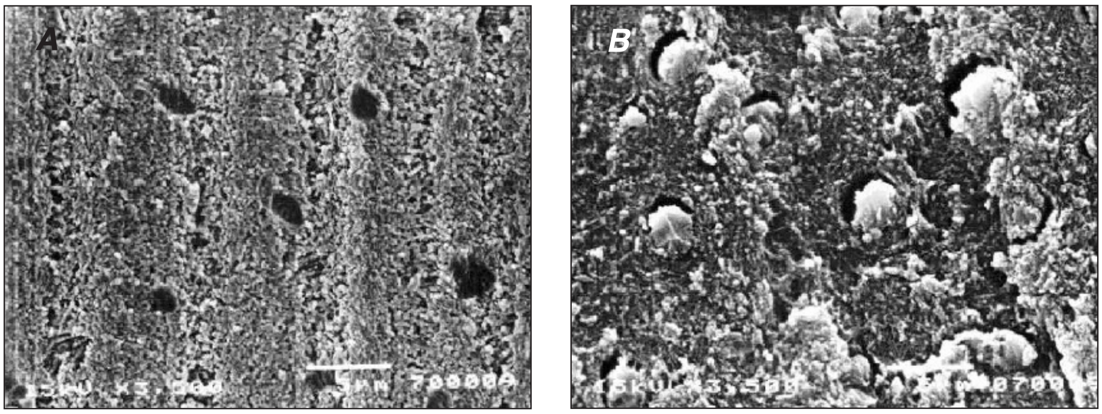


Figure 7: *SEM micrographs of the dentin and resin composite surfaces at the fractured side of specimens from group 7. (A) the resin composite side. (B) the dentin side. Failure occurred along the adhesive-dentin interface. There was no bonding at the adhesive-dentin interface.*

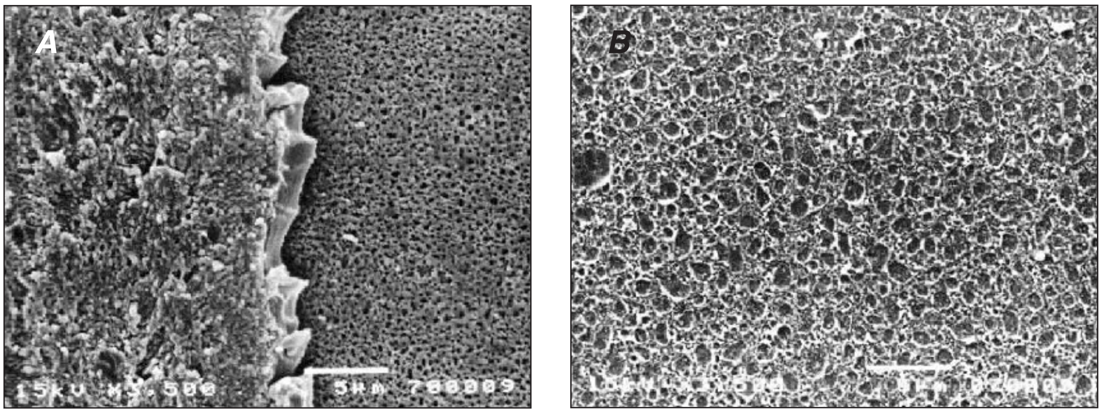


Figure 8: *SEM micrographs of the dentin and resin composite surfaces at the fractured side of specimens from group 7. (A) the resin composite side showing the adhesive interface and the underlying microporous feature. (B) the dentin side showing microporous features.*

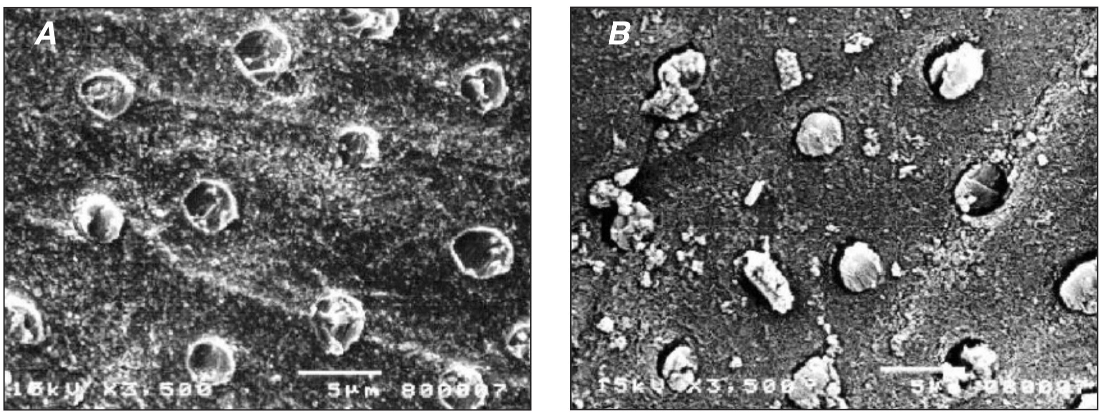


Figure 9: *SEM micrographs of the dentin and resin composite surfaces at the fractured side of specimens from group 8. (A) the resin composite side. (B) the dentin side. Failure occurred along the adhesive-dentin interface.*

Among the groups with no light-activation of bonding agents prior to placement of the self-cured resin composite, compared to those bonded to the dual-cured resin material, only the Excite DSC groups showed statistically different shear bond strengths (Table 6). It might be assumed that polymerization of Excite DSC can be performed without light activation. On the other hand, the shear bond strengths in the Excite and One-Step groups were significantly lower when bonded to the self-cured resin composite than when bonded to the dual cured resin composites. Especially in the Excite group, there was no bonding at the adhesive-dentin interface (Figures 4A and 4B). Excite is a light-cured bonding agent; therefore, its polymerization could not occur without light activation.

Even though One-Step was not light activated, its low acid condition might reduce the effect on polymeriza-

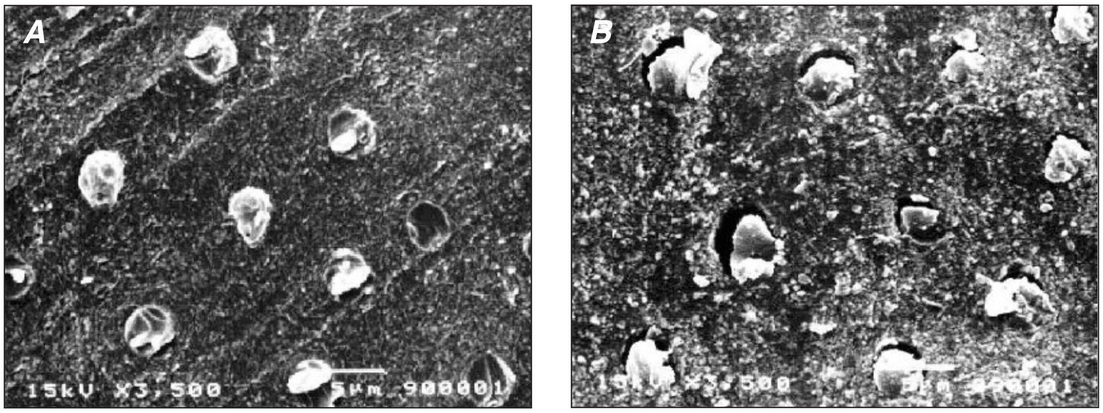


Figure 10: *SEM micrographs of the dentin and resin composite surfaces at the fractured side of specimens from group 9. (A) the resin composite side. (B) the dentin side. Failure occurred along the adhesive-dentin interface.*

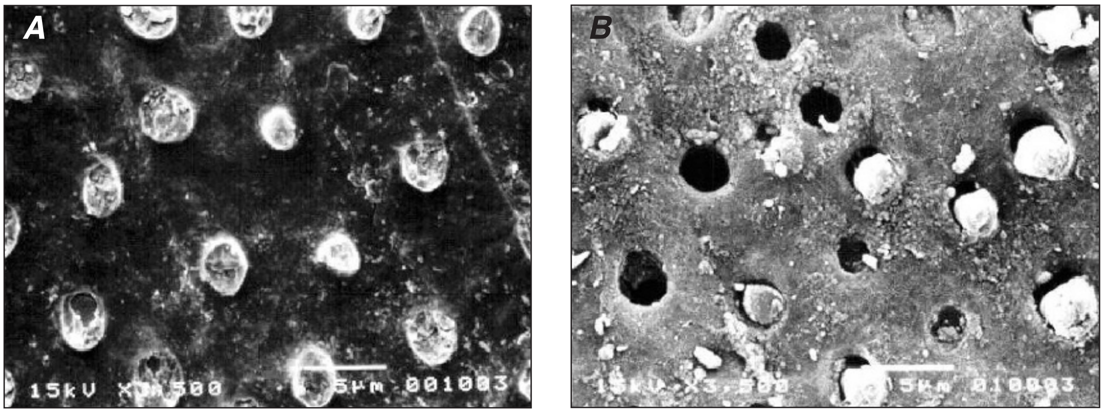


Figure 11: *SEM micrographs of the dentin and resin composite surfaces at the fractured side of specimens from group 10. (A) the resin composite side. (B) the dentin side. Failure occurred along the adhesive-dentin interface.*

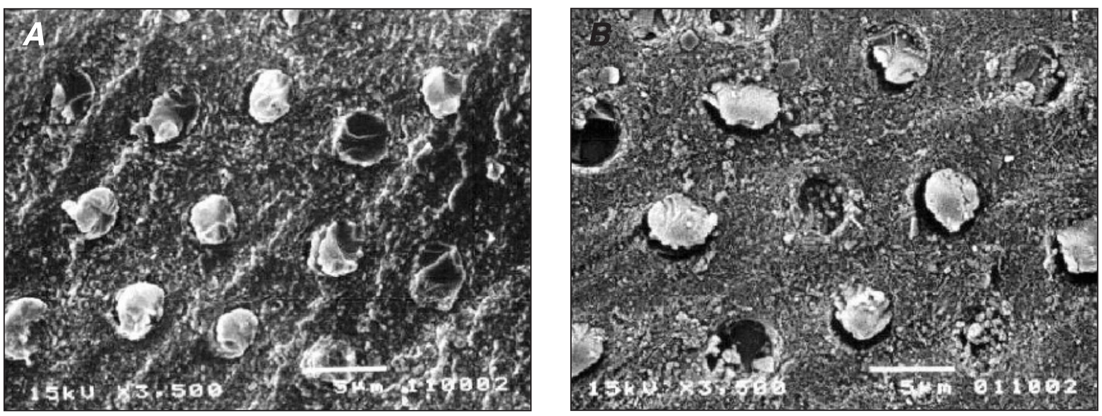
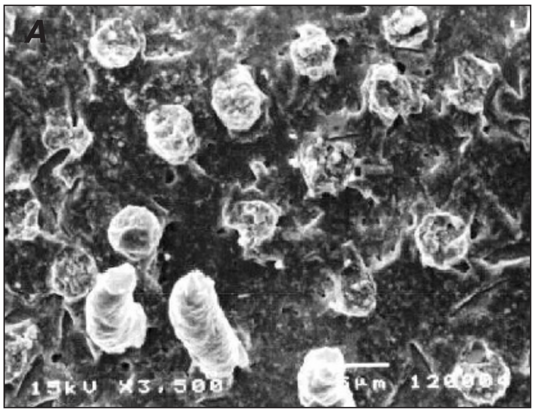


Figure 12: *SEM micrographs of the dentin and resin composite surfaces at the fractured side of specimens from group 11. (A) the resin composite side. (B) the dentin side. Failure occurred along the adhesive-dentin interface.*

tion of self-cured or dual-cured resin composites. Low shear bond strength from the One-Step group might correlate with parts of resin composites penetrating into dentinal tubules, as evidenced in SEM micrographs (Figures 13A and 13B). The polymerization of self-cured resin composites, which might be in contact with the bonding agent for a period of time prior to polymerization, might be retarded but not to the same extent as those in contact with bonding agents with high acidity. When the highly acidic bonding agent, Excite, contacted the self-cured resin composite for a long time prior to polymerization, the acid monomers of the bonding agent might destroy the amine initiators and slow down the polymerization reaction, resulting in decreased bond strength.

Table 7 shows the shear bond strength of dual-cured resin composite to dentin with light activation prior to placement, compared with groups without light activation. In the Excite DSC and One-Step groups, shear bond strength was not statistically different. However, the shear bond strength of Excite, with no light activation prior to placement of the dual-cured resin composite (Exc NL-DC), was significantly lower than the group with light activation (Exc L-DC). After placing dual-cured resin composite on an unpolymerized bonding agent, the resin composite was light activated on the top as soon as it was placed. The bonding agent underneath the resin composite might be exposed to light that passes through the 3-mm thick resin composite. However, the light intensity was decreased after passing through the resin composite;[14] therefore, the polymerization reaction of light-cured bonding agents might be lesser than the reaction



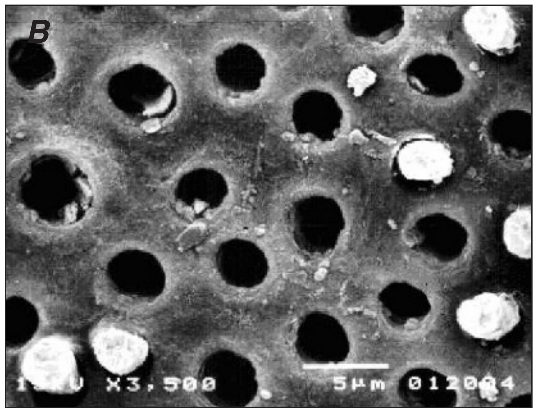


Figure 13: *SEM micrographs of the dentin and resin composite surfaces at the fractured side of specimens from group 12. (A) the resin composite side. (B) the dentin side. Failure occurred along the adhesive-dentin interface. There was partial bonding at the dentin-resin interface.*

for the adhesive that was light-activated prior to placement of the resin composite.

Table 8 shows the shear bond strength of self-cured resin composites with light activation prior to resin placement compared to groups without light activation. In the light-cured Excite and One-Step groups with no light activation of the bonding agent, the shear bond strengths were statistically significantly lower than in the groups with light activation. Generally, the self-cured resin composite was not exposed to light after placement of the resin composite, so that the bonding agent was not exposed to light in order to initiate polymerization. Therefore, its shear bond strength was very low. Unlike Excite and One-Step, the chemical-activated Excite DSC was able to carry out the polymerization process, although it was not exposed to light. Therefore, its shear bond strength with and without light activation before resin placement was not statistically different.

As the shear bond strength test was the most common method to evaluate bond strength,[15] this study evaluated shear bond strength by following ISO Technical Specification #11405. However, in the shear bond strength test, the surface area to be bonded was larger than the area used in the microtensile bond strength test. This could allow for greater opportunities for imperfect bonding due to defects on the bonded surface, which could give rise to higher variability in the shear bond strength value. In general, the coefficient of variation in the shear bond strength test is higher (20%-60%) than it is in the microtensile bond strength test (20%-40%).[16] In this study, the coefficient of variation was between 28.20% and 46.73%.

CONCLUSIONS

The bonding agent and resin composite selection, together with the operating techniques, were important factors contributing to dentin-resin bond strength. The main conclusions of this study are as follows:

First, types of bonding agents affect the shear bond strength of resin composites to dentin. The use of dual-cured bonding agents (Excite DSC) leads to higher shear bond strengths of self-cured or dual-cured resin composites to dentin.

Second, types of resin composites also affect the shear bond strengths of resin composite to dentin. This study revealed that the groups restored with dual-cured resin composite showed higher bond strength than the groups restored with self-cured resin composite.

Finally, light activation of the bonding agents prior to placement of self-cured and dual-cured resin composites showed higher shear bond strength than groups without light activation prior to resin composite placement.

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References

1. Lutz F, Setcos JC, Phillips RW & Roulet JF (1983) Dental restorative resins. Types and characteristics *Dental Clinics of North America* **27(4)** 697-712.
2. Cohen BI, Pagnillo MK, Musikant BL & Deutsch AS (1998) Shear bond strength of a titanium reinforced core material after using multi-step and single-step bonding agents *Journal of Prosthetic Dentistry* **80(3)** 307-310.
3. Hagge MS & Lindemuth JS (2001) Shear bond strength of an autopolymerizing core buildup composite bonded to dentin with 9 dentin adhesive systems *Journal of Prosthetic Dentistry* **86(6)** 620-623.
4. Hofmann N, Papsthart G, Hugo B & Klaiber B (2001) Comparison of photo-activation versus chemical or dual-curing of resin-based luting cements regarding flexural strength, modulus and surface hardness *Journal of Oral Rehabilitation* **28(11)** 1022-1028.
5. Swift EJ Jr, Perdigão J & Heymann HO (1995) Bonding to enamel and dentin: A brief history and state of the art *Quintessence International* **26(2)** 95-110.
6. Tay FR, Pashley DH, Yiu CK, Sanares AM & Wei SH (2003) Factors contributing to the incompatibility between simplified-step adhesives and self-cured or dual-cured composites. Part I. Single-step self-etching adhesive *Journal of Adhesive Dentistry* **5(1)** 27-40.
7. Sanares AM, Itthagarun A, King NM, Tay FR & Pashley DH (2001) Adverse surface interactions between one-bottle light-cured adhesives and chemical-cured composites *Dental Materials* **17(6)** 542-556.

8. Swift EJ Jr, Perdigão J, Combe EC, Simpson CH III & Nunes MF (2001) Effects of restorative and adhesive curing methods on dentin bond strengths *American Journal of Dentistry* **14(4)** 137-140.

9. O'Keefe KL & Powers JM (2001) Adhesion of resin composite core materials to dentin *International Journal of Prosthodontics* **14(5)** 451-456.

10. Dong CC, McComb D, Anderson JD & Tam LE (2003) Effect of mode of polymerization of bonding agent on shear bond strength of auto cured resin composite luting cements *Journal of the Canadian Dental Association* **69(4)** 229-234.

11. Suh BI (2003) A study of the compatibility of adhesives with composites *Compendium* **24(8) Supplement** 4-9.

12. Tay FR, Pashley DH, Suh BI, Carvalho RM & Itthagarun A (2002) Single-step adhesives are permeable membranes *Journal of Dentistry* **30(7-8)** 371-382.

13. Tay FR, Suh BI, Pashley DH, Prati C, Chuang SF & Li F (2003) Factors contributing to the incompatibility between simplified-step adhesives and self-cured or dual-cured composites. Part II. Single-bottle, total-etch adhesive *Journal of Adhesive Dentistry* **5(2)** 91-105.

14. Rueggeberg FA, Caughman WF & Curtis JW Jr (1994) Effect of light intensity and exposure duration on cure of resin composite *Operative Dentistry* **19(1)** 26-32.

15. Al-Salehi SK & Burke FJ (1997) Methods used in dentin bonding tests: An analysis of 50 investigations on bond strength *Quintessence International* **28(11)** 717-723.

16. Bayne S (2001) Bonding to dental substrates In: Craig RG and Powers JM (11th eds) *Restorative Dental Materials*.