

# Quality Resource Guide

## Dental Adhesives

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MetLife designates this activity for **2.0 continuing education credits** for the review of this Quality Resource Guide and successful completion of the post test.

### Educational Objectives

Following this unit of instruction, the practitioner should be able to:

1. Identify differences between enamel and dentin as substrates for bonding.
2. Identify the advantages and disadvantages of etch-and-rinse adhesives.
3. Identify the advantages and disadvantages of self-etch adhesives.
4. Identify the advantages and disadvantages of universal adhesives.
5. Recognize the importance of selective enamel etching when using adhesives in self-etch mode, including universal adhesives.
6. Identify the clinical steps needed to restore bond strengths after contamination with saliva or blood during the adhesive procedure.
7. Recognize that the outcomes of clinical studies with universal adhesives suggest that enamel etching is necessary for the success of restorations in class V lesions.

The following commentary highlights fundamental and commonly accepted practices on the subject matter. The information is intended as a general overview and is for educational purposes only. This information does not constitute legal advice, which can only be provided by an attorney.

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## Introduction

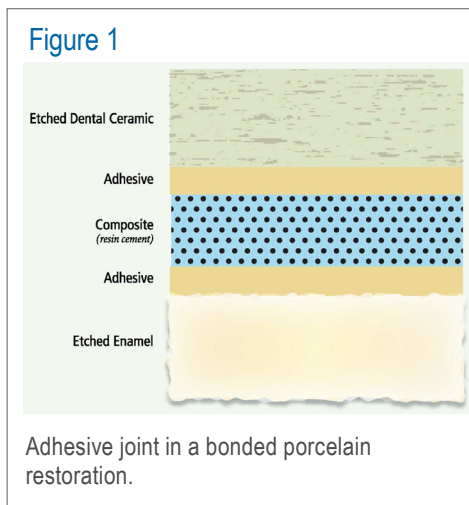
Adhesion or bonding is the process of forming an adhesive joint, which consists of two substrates joined together. In Dentistry, the adherend is the substrate to which the adhesive is applied – enamel or dentin, rarely cementum. Dentin adhesives are solutions of resin monomers that join substrates and solidify. While most adhesive joints involve only two interfaces, dental adhesive joints are more complex, for example, the joint formed when a clinician bonds a porcelain veneer - enamel-adhesive-composite-adhesive-porcelain (**Figure 1**). A bonded composite restoration is another example of a complex adhesive joint. The adherend or substrate is usually dentin or enamel. While enamel is composed of 96%/weight hydroxyapatite (mineral), dentin contains a significant amount of water and organic material, mainly type I collagen. The hydrated and organic nature of dentin makes this hard tissue extremely difficult to bond to.

## Indications for Dental Adhesives

- Direct anterior composite restorations
- Direct posterior composite restorations
- Indirect composite restorations
- All-porcelain restorations, including zirconia
- Orthodontic brackets
- Pit and fissure sealants
- Fiber-reinforced posts
- Splints for periodontally-involved teeth and luxated teeth
- Root desensitization
- Reattachment of fractured tooth fragments
- Endodontic sealer
- Internal reinforcement of fragile endodontically treated teeth

## Contraindications for Dental Adhesives

- Patients with known allergies to resin-based materials and other components
- Direct application in deep preparations of vital teeth (<0.5mm from the pulp)
- Contamination of the operating field - use of rubber dam may optimize the outcome



## Advantages of Dental Adhesion

- Wide range of clinical applications
- Increased resistance to recurrent caries lesions when dental tissues are impregnated with the adhesive
- More conservative procedures (lesion-specific preparations)
- Reinforcement of residual tooth structure
- Reduced microleakage
- Some adhesives have antibacterial properties, which may prevent recurrent caries lesions
  - Clearfil SE Protect (Kuraray Noritake) contains MDPB (12-methacryloyloxydodecylpyridinium bromide)
  - Peak Universal Bond (Ultradent Products, Inc.) contains chlorhexidine

## Disadvantages of Dental Adhesion

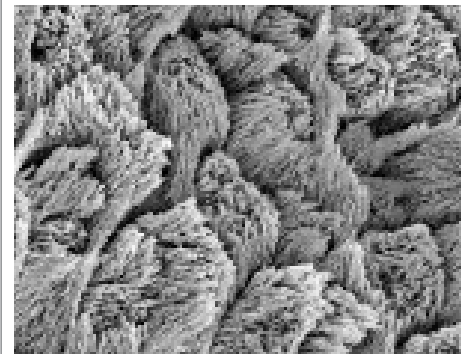
Dentists may mistakenly rely solely on adhesion as the source of primary retention, even in clinical situations in which there is not enough residual tooth structure, such as a preparation for a core build-up without enamel margins. Other forms of mechanical retention, such as slots, coves, and retention locks, may be needed when more than half of the coronal tooth structure has been compromised.

## Consequences of Inadequate Adhesion

- Bacterial leakage
- Pulpal inflammation
- Recurrent caries
- Marginal gaps
- Fractured restorations
- Dental sensitivity
- Compromised esthetics
- Compromised function

Etching enamel with phosphoric acid<sup>1</sup> has been considered the gold standard<sup>2</sup> for bonding resin-based materials to tooth structure since Dr. Buonocore described the technique in 1955.<sup>1</sup> The micro-mechanical nature of the interaction of adhesives with enamel is a result of the infiltration of resin monomers into the numerous microporosities left by the acid dissolution of enamel (**Figure 2**).<sup>2</sup>

**Figure 2**



SEM image of enamel etched with 34% phosphoric acid for 15 seconds. Note the multitude of microporosities created by the dissolution of hydroxyapatite by the etch making the substrate extremely retentive. Original magnification = X5,000.

When the tooth structure is prepared with a bur or with a spoon excavator, residual components form a “smear layer” of debris on the surface.<sup>3</sup> The smear layer (**Figures 3 and 4**) obstructs the entrance of dentin tubules, decreasing dentin permeability. This smear layer is a barrier that must be removed or made permeable, so that monomers in the adhesive can flow into the dentin collagen structure. In spite

of different classifications of adhesive systems, current adhesion strategies depend on how the adhesive interacts with this smear layer; etch-and-rinse (ER) adhesives remove the smear layer through acid-etching, while self-etch (SE) adhesives make the smear layer permeable without removing it completely (Table 1, Figures 3 and 4).

The ultimate goal of a bonded restoration is to obtain an intimate and durable adaptation of the restorative material with the dental structure.<sup>4</sup> This task is difficult to achieve, as dentin is more hydrated and more organic than enamel.<sup>5</sup> The treatment of dentin with phosphoric acid or with acidic primers is followed by the application of hydrophilic monomers (that is, primer or primer/adhesive), which infiltrate the small spaces within the dentin's dense network of collagen fibrils, resulting in the formation of a hybrid layer.<sup>6</sup> (Figure 3). The improved sealing provided by the hybrid layer may result in decreased post-operative sensitivity and may even act as an elastic buffer that compensates for the polymerization shrinkage stress during contraction of the restorative composite.<sup>7-9</sup>

### Etch-and-Rinse Adhesives

Three-step etch-and-rinse (ER) adhesives involve a separate etching and rinsing step followed by a hydrophilic primer and the application of a hydrophobic bonding resin (Table 1). Two-step ER adhesives (Table 1) combine primer and bonding resin into one solution and usually need more than one coat to achieve an acceptable micro-mechanical interlocking of monomers into the collagen-rich etched dentin (Figure 3).<sup>10,11</sup> Three-step ER adhesives result in better laboratory performance (high immediate enamel and dentin bond strengths) and better clinical performance than 2-step ER adhesives.<sup>12,13</sup>

Etching and priming are considered technique-sensitive application procedures. Air-drying of etched preparations used to be taught as a method to check for the etched aspect of enamel. Some clinicians still dry the preparation after rinsing the etching gel. As a result of air-drying enamel, dentin is also dried, which may cause dentin collagen fibrils to collapse. In vitro studies have demonstrated that drying dentin upon etching results in low bond

Figure 3 - Diagram showing how etch-and-rinse adhesives interact with dentin

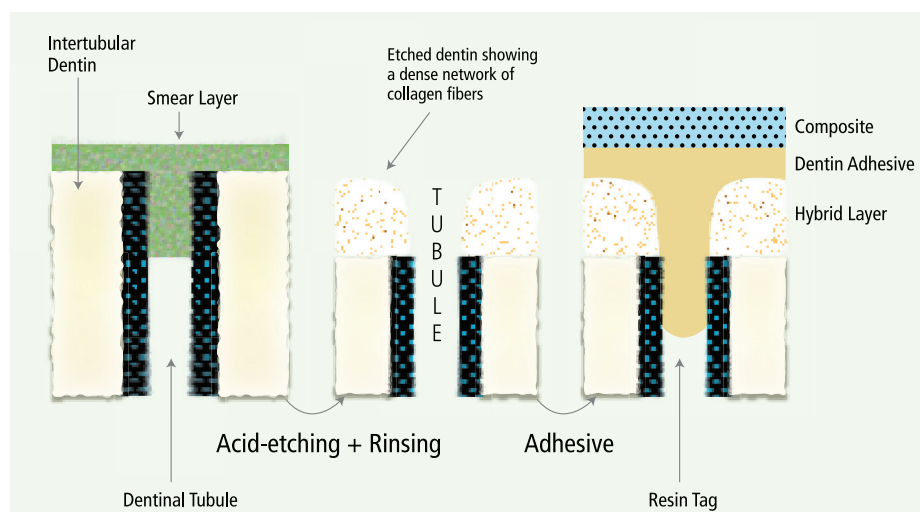
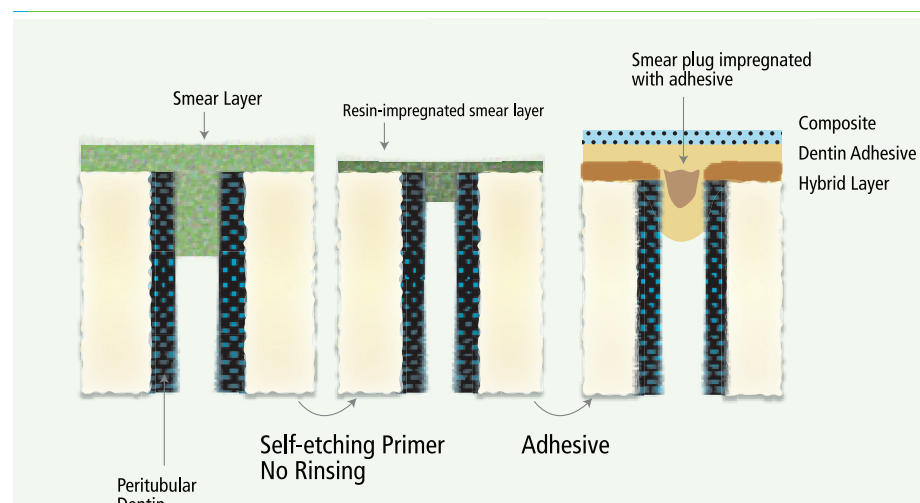


Figure 4 - Diagram showing how self-etch adhesives interact with dentin







strengths.<sup>14-16</sup> Therefore, keeping the preparation moist (glistening) after rinsing off the etching gel has been recommended. However, leaving the dentin moist may not be so crucial with current adhesives, as agitation of the adhesive during application improves infiltration of the monomers into etched dentin. A clinical study in non-carious cervical lesions (NCCs) found that passive application of the adhesive resulted in 82.5% retention rate after 2 years compared to 92.5% retention rate of the restorations in which the adhesive was scrubbed vigorously.<sup>17</sup>

### Advantages of Etch-and-Rinse Adhesives

- Ability to bond composite, porcelain, fiber posts, etched or sandblasted metals, or amalgam
- High immediate dentin and enamel bond strengths in laboratory studies
- Clinical studies over 4 years with very good results
- As these adhesives contain organic solvents such as ethanol or acetone, minor dentin contamination with saliva does not decrease bond strengths *in vitro*.

Table 1

	Type	Brand Names (Manufacturer)	Components		
			1	2	3
Etch-and-Rinse	3-Step  Multi-Bottle	Adper Scotchbond Multi-Purpose (3M Oral Care) All-Bond 2 (Bisco) All-Bond 3 (Bisco) GLUMA Solid Bond (Kulzer) OptiBond FL (Kerr) Solobond Plus (Voco)	Phosphoric acid	Hydrophilic primer	Hydrophobic bonding resin
	2-Step 	Adper Single Bond Plus (3M Oral Care) Excite F (Ivoclar Vivadent) iBOND Total Etch (Kulzer) Excite F (Ivoclar Vivadent) One Coat Bond (Coltene) One-Step Plus (Bisco) OptiBond SOLO Plus (Kerr) Prime&Bond XP (Dentsply Sirona)	Phosphoric acid	Combined (hydrophilic primer + bonding resin)	
Self-Etch (no etch)	2-Step 	All-Bond SE (Bisco) Clearfil SE Bond 2 (Kuraray Noritake) Clearfil SE Protect (Kuraray Noritake) One Coat Self-Etching Bond (Coltene) OptiBond eXTRa Universal (Kerr)	Self-etching primer	Hydrophobic bonding resin	
	1-Step 	Futurabond M (Voco) Futurabond NR (Voco) iBond Self Etch (Kulzer) One Coat 7.0 (Coltene) OptiBond All-in-One (Kerr)	Self-etching hydrophilic primer/bonding resin		
Etch-and-Rinse  OR  Self-Etch	Universal Adhesives	Adhese Universal (Ivoclar Vivadent) All-Bond Universal (Bisco) Clearfil Universal Bond Quick (Kuraray Noritake) Futurabond U (VOCO) Futurabond M+ (VOCO) G-Premio Bond (GC Co.) iBond Universal (Heraeus Kulzer) One Coat 7 Universal (Coltene) OptiBond Universal (Kerr) Prime&Bond Elect (Dentsply Sirona) Prime&Bond Active (Dentsply Sirona) Scotchbond Universal Adhesive (3M Oral Care)	Phosphoric acid	Hydrophilic bonding resin	
			Self-etching hydrophilic primer/bonding resin		

**Disadvantages of Etch-and-Rinse Adhesives**

- Acetone-based adhesives need more applications than those recommended by the respective manufacturers
- Over-etching decreases bond strengths
- Bond strengths may vary with the degree of moisture
- Hydrolytic degradation of the bonds may occur when margins are in dentin.

**Self-Etch Adhesives**

The development of non-rinsing adhesives (also known as SE adhesives) has changed the traditional concept of bonding. SE adhesives do not require a separate acid-etch step as they condition and prime enamel and dentin simultaneously. SE adhesives rely on their ability to infiltrate through smear layers (**Figure 4**) and partially dissolve hydroxyapatite to generate a hybrid layer with minerals incorporated.<sup>11</sup>

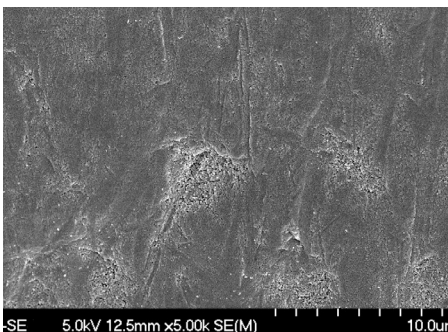
As the preparation is not rinsed, these materials are more user-friendly because their application time is reduced as compared to ER adhesives.<sup>11</sup> All SE adhesives contain water, which is required to ionize the respective monomers. Once ionized, the monomers are able to interact with enamel and dentin substrates. The difference between 1-step SE and 2-step SE adhesives is that for the latter an extra hydrophobic bonding resin is applied over the acidic primer.

Two-step SE adhesives have the potential to form a hybrid layer and seal dentin.<sup>18</sup> In contrast with ER adhesives, the hybrid layer formed by SE adhesives is not completely demineralized (hydroxyapatite not completely removed).<sup>18</sup> Clinical studies have reported that mild SE adhesives (pH>1.5) result in better adhesion to dentin than strong SE adhesives (pH<1.5).<sup>13</sup>

For enamel, the respective bond strengths are lower than those associated with ER adhesives (that rely on a separate etching step).<sup>19</sup> Because of their higher pH, SE adhesives result in a shallow enamel demineralization compared to that of phosphoric acid (**Figure 5**).<sup>19</sup> However, roughening enamel to remove prismless enamel improves the enamel bonding ability of SE adhesives.<sup>20</sup> A separate phosphoric acid enamel etching step (known as 'selective enamel etching') also enhances the efficacy of SE adhesives.<sup>21</sup> A drawback of 'selective enamel etching' is that the clinician may inadvertently etch dentin. For some SE adhesives, dentin bond strengths decrease when they are applied on acid-etched dentin compared to the same adhesive applied in SE mode.<sup>22,23</sup>

Aggressive SE adhesives (pH<1.5) may be used for pit-and-fissure sealants in pediatric patients to shorten treatment time and reduce the procedure complexity.<sup>24,25</sup>

**Figure 5**



Enamel etching pattern of All-Bond Universal (Bisco) applied to enamel as SE adhesive. Compare with the etching pattern of phosphoric acid in Figure 2.

### Advantages of Self-Etch Adhesives

- Extremely easy to apply, no etch, no rinsing
- Most are available in unidose to help the dental professional comply with infection control guidelines
- Some 2-step SE adhesives (for example, Clearfil SE Bond, Kuraray Noritake) result in high dentin bond strengths in vitro and excellent clinical results.<sup>26,27</sup> Clearfil SE Bond is still the reference against which all other SE adhesives are compared.<sup>27</sup>
- Although clinical evidence demonstrates that SE adhesives do not cause less post-operative sensitivity than ER adhesives,<sup>28,29</sup> some clinicians claim that SE adhesives cause lower incidence of post-operative sensitivity.

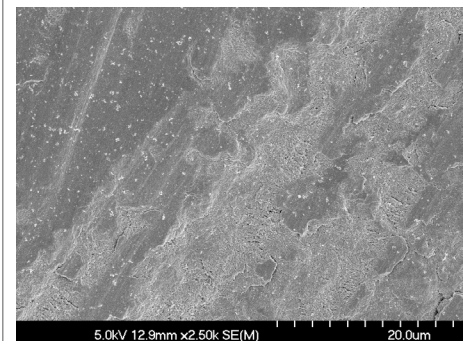
### Disadvantages of Self-Etch Adhesives

- Acidic primer is not as acidic as phosphoric acid; therefore, SE adhesives do not etch enamel to the same depth as phosphoric acid
- Some 1-step SE adhesives result in clinical signs of enamel leakage at 1 year
- The acidity of 1-step SE adhesives inhibits the polymerization of chemically-cured composites. Special attention may be required to the utilization of self- or dual-cure cured composite buildup materials and self- or dual-cured luting cements with 1-step SE adhesives
- One-step SE adhesives behave as permeable membranes after polymerization, allowing the permeation of fluids through the adhesive layer to the surface and subsequent degradation of the resin-dentin interface by hydrolysis
- On enamel, 1-step SE adhesives result in the formation of water blisters on the surface of the adhesive, which compromises durability of enamel bonding
- One-step self-etch adhesives undergo phase separation very rapidly
- Water in their composition may become entrapped if not properly evaporated, which results in dentin leakage.

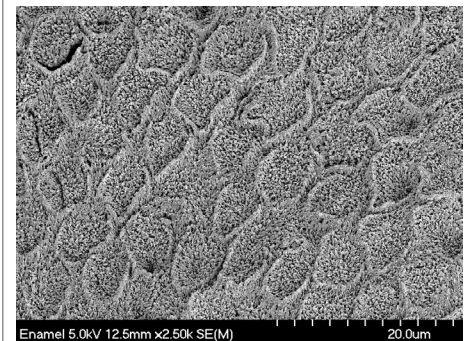
## Universal Adhesives

In the past, dentists have used dentin adhesives following one specific adhesion strategy, ER or SE. However, dentists now demand more versatile materials. As a result, manufacturers have developed adhesives that are more user-friendly and provide dentists with the possibility of selecting the adhesion strategy. With the advent of these universal adhesives (**Table 1**) dentists are now use the same adhesive according to each specific clinical situation, or under different adhesion strategies recommended by the respective manufacturers (*i.e.*, SE, ER, or as SE adhesives on dentin and ER adhesives on enamel, a technique commonly referred to as "selective enamel etching"). This new generation of 1-bottle dental adhesives has become very popular in Dentistry.<sup>30</sup>

**Figure 6**



**A** - Enamel etching pattern of Scotchbond Universal Adhesive (3M Oral Care) applied as a 1-step SE adhesive. Original magnification = X2,500.



**B** - Enamel etching pattern after etching with Scotchbond Universal etchant (34% phosphoric acid, 3M Oral Care). Original magnification = X2,500

Universal adhesives are indicated for a variety of clinical procedures, including direct composite restorations, indirect restorations, and zirconia primers. The major difference between traditional 1-step SE adhesives and universal adhesives is that most universal adhesives contain 10-MDP monomer (methacryloyloxydecyl dihydrogen phosphate), which has been shown to bond chemically to calcium in hydroxyapatite through a mechanism known as nano-layering.<sup>31</sup> This molecule may be responsible for the excellent long-term clinical success of the 2-step SE adhesive Clearfil SE Bond (Kuraray Noritake).<sup>27</sup> Nevertheless, chemical bonding provided by 10-MDP depends on the concentration of the molecule. As a result, the extent of chemical bonding in universal adhesives is weak compared to that observed for the 2-step SE adhesive Clearfil SE Bond.<sup>32</sup>

Enamel etching with phosphoric acid is still required for these new universal adhesives (Compare **Figures 6A and 6B**). Consequently, the recommended adhesive strategy for most clinical applications of universal adhesives is selective enamel etching (no dentin etching). In Pediatric Dentistry it is sometimes difficult to etch and rinse enamel. It has been shown that the active application (scrubbing) of universal adhesives on enamel results in higher bond strengths to intact enamel for some universal adhesives compared to the bond strengths obtained with passive application, except for Adhese Universal and Scotchbond Universal. For these two adhesives enamel bond strengths are identical when applied passively or with scrubbing action.<sup>33</sup>

Clinical and laboratory evaluations have demonstrated that some universal adhesives form a hybrid layer (**Figure 7A**) and may perform at the same level of existing materials.<sup>34,35</sup> In case universal adhesives are used as ER adhesives, it is not necessary to leave dentin moist for two reasons:

(1) As for traditional SE adhesives, water is required for the ionization of the acidic monomers in universal adhesives to enable them to interact

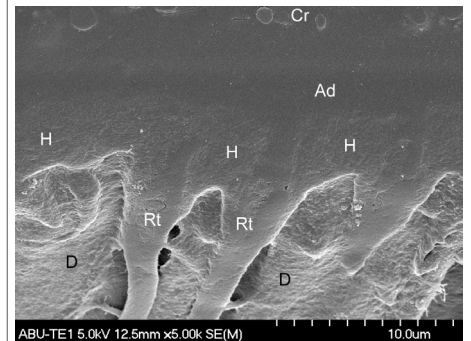
with dentin and enamel. This is the reason why universal adhesives contain 10-20% water. The drawback is that residual water may trigger hydrolytic degradation of polymers and collagen, especially under acidic pH

(2) As residual water is always present, the evaporation time after the application of the adhesive may be a very crucial clinical step. Manufacturers recommend evaporation of the solvent with air for 5 sec after the application of the universal adhesive (10 sec for All-Bond Universal). However, 5 sec is not enough to evaporate the water added to the composition of the adhesive and/or the residual water from leaving the dentin moist.<sup>36</sup> If dentists leave dentin moist prior to applying universal adhesives, the amount of residual water left into the dentin substrate may hamper the formation of a hybrid layer for some universal adhesives (**Figure 7B**), reduce bond strengths, and substantially increase hydrolytic degradation of the bonded interface.<sup>36,37</sup>

Although laboratory studies indicate that the adhesive strategy (*i.e.*, SE vs. ER) does not affect immediate dentin bond strengths of universal adhesives, artificial aging methods, such as storage in water for periods of 6 months to 1 year, cause a significant decrease in bond strengths when the ER strategy is used. Dentin bonding durability increases when universal adhesives are applied as SE adhesives.<sup>30</sup>

For traditional ER and SE adhesives a separate silane solution is usually recommended for ceramic bonding. The intaglio is etched with hydrofluoric acid, rinsed with water and air-dried, followed by the application of a silane solution. Some universal adhesives, namely Clearfil Universal Bond Quick (Kuraray Noritake Dental Inc.) and Scotchbond Universal Adhesive (3M Oral Care), contain a silane in their composition, therefore the application of a separate silane solution is not recommended by the respective manufacturer. However, the efficacy of the combined adhesive and silane solution for luting lithium disilicate ceramic restorations is questionable.<sup>38,39</sup> For this reason, the application of a separate silane solution is still recommended.

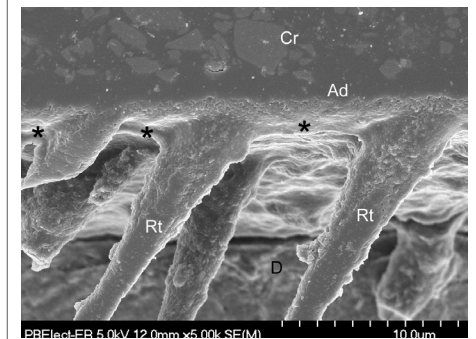
Figure 7



**A** - Enamel etching pattern of Scotchbond UniA - SEM image of the adhesive interface formed with All-Bond Universal applied on human dentin as ER adhesive.

Cr = Composite resin; Ad = Adhesive; Rt = Resin tag; D= Dentin. The hybrid layer (H) was resistant to the deproteinizing effect of sodium hypochlorite.

Original magnification = X5,000



**B** - SEM image of the adhesive interface formed with Prime & Bond Elect (Dentsply Sirona) applied on human dentin as ER adhesive.

Cr = Composite resin; Ad = Adhesive; Rt = Resin tag; D= Dentin. The asterisks (\*) correspond to the areas in which part of the hybrid layer is missing as a result of deficient permeation of the adhesive around the collagen fibers.

Original magnification = X5,000

### **Advantages of Universal Adhesives**

- They are indicated for a wider variety of restorative procedures and adhesion strategies
- Bond chemically to hydroxyapatite in dentin when used in SE mode
- Seal dentin margins well when used in SE mode
- Application of the adhesive in SE mode with a scrubbing movement increases enamel bond strengths.
- No need to leave dentin moist when used in ER mode

### **Disadvantages of Universal Adhesives**

- The highest enamel bond strengths are only achieved after phosphoric acid etching
- Most universal adhesives require mixing with the respective dual-cure activator when used with self- or dual-cure composite materials, such as build-up materials and resin cements
- They do not seal dentin margins well when dentin is etched with phosphoric acid.
- Since etching dentin is not recommended with universal adhesives, a separate enamel acid-etching step is necessary, which increases the clinical application time.

## **Contamination of the Bonding Surface**

Contamination with blood or saliva may occur during the bonding procedure especially when absolute isolation is not used. Contamination with blood reduces bond strengths significantly for both ER and SE adhesives. However, when blood is rinsed followed by the application of the adhesive, bond strength significantly increases to control levels.<sup>40</sup> If surface contamination with saliva occurs with ER adhesives after etching, drying the saliva followed by the application of the adhesive, results in bond strengths similar to those of the uncontaminated surfaces.<sup>41</sup> For SE adhesives, contamination with saliva decreases bond strengths.<sup>42</sup> As a general guideline for

1-step SE adhesives, if saliva contamination occurs before light curing, then washing, drying and reapplying the adhesive followed by light curing is recommended. If saliva contamination occurs after light curing, then re-application of the adhesive after washing and drying is not necessary.<sup>42</sup>

For universal adhesives several decontamination methods have been proposed to restore dentin bond strengths. Dentin bond strengths of universal adhesives decrease with saliva contamination, but water rinsing and reapplication of the adhesive improve bond strength to control levels.<sup>43</sup> When All-Bond Universal adhesive (ER mode) was contaminated with saliva after the adhesive was cured, significantly higher bond strengths were obtained when the preparation was rinsed, dried, re-etched, and the adhesive was re-applied and cured, compared to decontamination with rinsing and drying only, and decontamination with rinsing, drying, and application of the adhesive without re-etching.<sup>44</sup>

Regarding blood contamination, decontamination methods do not prevent the decrease in bond strengths when contamination occurs after light curing. Drying the blood contaminants and reapplying the adhesive may restore dentin adhesion if contamination occurs before light curing. Alternatively, rinsing and drying contaminants followed by adhesive re-application may be effective depending on adhesive type.<sup>45</sup>

For adhesion to zirconia, such as when luting a zirconia crown, if saliva contamination occurs after the application of an MDP-based zirconia primer, rinsing off the saliva with water will preserve bond strengths. If saliva contamination occurs prior to MDP-based zirconia primer application, sandblasting with alumina will preserve bond strength.<sup>46</sup> Saliva contamination also has a deleterious effect on the long-term durability of restorations of CAD/CAM resin blocks luted with resin cement. Sandblasting or phosphoric acid cleaning recover bonding effectiveness by 75–85%.<sup>47</sup>

## **Clinical Studies with Recent Adhesives**

While laboratory studies usually assess immediate bonding characteristics, the durability of adhesion under aged conditions is considered more clinically relevant.<sup>48</sup> Nevertheless, the ultimate test for a dental material is its clinical effectiveness and durability, which is only measurable in clinical trials. In the small number of published clinical studies and systematic reviews available, Clearfil SE Bond, a 2-step SE adhesive, has shown excellent retention rates in non-carious class V lesions for up to 13 years.<sup>27</sup> Additional enamel etching resulted in improved marginal adaptation.<sup>27</sup>

Some one-step SE adhesives have not performed well in laboratory studies and clinical studies.<sup>12,26,49,50</sup> (Figure 8). The clinical behavior of 1-step SE adhesives improves considerably when the clinician adds an extra coat of a hydrophobic bonding resin. In a clinical study in class V lesions,<sup>51</sup> a 1-step SE adhesive, (iBond, Heraeus Kulzer), resulted in 40% retention rate at 18 months. For the group to which an extra layer of a hydrophobic bonding resin was applied over the cured iBond, transforming it in a 2-step SE adhesive, the retention rate increased to 83% at 18 months. These findings demonstrate that 2-step SE adhesives are clinically more efficient than 1-step SE adhesives.<sup>13</sup>

**Figure 8**



Class II composite restorations on teeth #4 and #5 two years post-insertion. Teeth were restored with a SE adhesive without additional enamel etching. Note the degradation of the marginal integrity caused by the inadequate enamel bonding provided by the SE adhesive.

Although the application of an extra hydrophobic bonding resin over universal adhesives seems to increase the longevity of the bonds in laboratory studies,<sup>52,53</sup> one randomized clinical trial in NCCLs reported that Scotchbond Universal may not benefit from the application of the extra bonding resin, regardless of the adhesion strategy.<sup>54</sup>

Regarding other clinical studies with universal adhesives, a systematic review and meta-analysis of restorations in NCCLs reported that ER and selective enamel etching strategies resulted in higher retention rate and lower incidence of restoration fractures compared to SE.<sup>55</sup> There was no significant difference between any of the clinical parameters when the ER strategy was used with dry versus moist dentin.<sup>55</sup> A clinical trial reported no difference in retention rate between the ER and the SE strategies after 18 months of clinical use in NCCLs, but reported a high incidence of marginal discoloration when one of the universal adhesives was used with the SE strategy.<sup>56</sup> Another recent clinical trial involving NCCLs reported that ER and selective enamel etching strategies resulted in better 2-year restoration retention than the SE strategy for the two universal adhesives tested.<sup>57</sup> The results of these projects highlight the need to etch enamel when using universal adhesives.

### MMP Inhibitors

Dentin collagen fibrils contain inactive proforms of proteolytic enzymes called matrix metalloproteinases (MMPs).<sup>37</sup> These enzymes have been identified in both odontoblasts and

mineralized or demineralized human dentin and have been claimed to play a role on the degradation of resin-dentin bonds.<sup>37,58</sup>

Dentin MMPs are activated by SE or by ER adhesives during bonding procedures.<sup>37,59</sup> If collagen fibrils are incompletely infiltrated with resin monomers MMPs may degrade the collagen within incompletely resin-infiltrated hybrid layers, decreasing the longevity of bonded restorations.<sup>37,60</sup>

The use of exogenous MMP inhibitors as part of the bonding sequence, such as chlorhexidine, has been advocated to help improving the longevity of adhesive restorations.<sup>37</sup> In spite of numerous *in vitro* and *in situ* studies demonstrating the benefits of applying chlorhexidine as an adjunct to dentin bonding,<sup>37</sup> only a few clinical studies with follow-up over 2 years have been published.<sup>61,62</sup> These clinical studies do not show any benefit from using chlorhexidine as an MMP inhibitor. In fact, a meta-analysis concluded that there is insufficient evidence to recommend or refute the degradation inhibitory effect of MMP inhibitors used for cavity pretreatment prior to inserting adhesive restorations.<sup>63</sup>

### Summary and Recommendations

Numerous simplified adhesives have been introduced to the dental market within the last few years, sometimes without comprehensive testing to validate the performance claimed by the respective manufacturers. In spite of their user-friendliness and lower technique sensitivity

when compared to ER adhesives, 1-step SE adhesives have resulted in low enamel and dentin bonding effectiveness *in vitro*,<sup>11,18</sup> while their clinical reliability has been questioned.<sup>51</sup> Another drawback that has been associated with 1-step SE adhesives is their behavior as semi-permeable membranes. These materials allow the movement of water across the enamel and dentin bonded interface, which potentially leads to hydrolytic degradation of the bonds.<sup>64,65</sup> The transformation of 1-step SE adhesives into 2-step SE adhesives through the addition of an extra coat of a hydrophobic bonding resin may improve their clinical behavior.

Universal adhesives have become very popular in recent years. They provide dentists the versatility to select the adhesion strategy tailored to their clinical preferences or to a certain clinical application. Manufacturers recommend their use with etch-and-rinse (ER), self-etch (SE) or selective enamel etching strategies. While etching enamel with phosphoric acid results in significantly better bonding performance of universal adhesives, etching dentin results in degradation of the bonds overtime. Subsequently, the recommended adhesion strategy is selective enamel etching (without dentin etching). Other recommendations to enhance the clinical performance of universal adhesives included active application (scrubbing) of the adhesive on enamel and dentin, followed by gentle air-drying for 15-20 sec to evaporate the water that is present in all universal adhesives.

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## POST-TEST

Internet Users: This page is intended to assist you in fast and accurate testing when completing the “Online Exam.” We suggest reviewing the questions and then circling your answers on this page prior to completing the online exam.

(2.0 CE Credit Contact Hour) Please circle the correct answer. 70% equals passing grade.

1. **One of the following characteristics is NOT an advantage of etch-and-rinse adhesives:**
  - a. Usually only indicated for bonding to enamel and dentin
  - b. High enamel bond strengths
  - c. Low failure rate at 4 years
  - d. High immediate dentin bond strengths
2. **Bonding to dentin is more challenging than bonding to enamel. Which of the following characteristic is responsible for that challenge?**
  - a. Enamel is rich in organic components
  - b. Dentin is more organic but less hydrated than enamel
  - c. Dentin contains hydroxyapatite and silica
  - d. None of the above
3. **The results of laboratory research with universal adhesives after artificial aging show:**
  - a. A significant decrease in dentin bonding durability when the universal adhesive is used as self-etch adhesive
  - b. A significant decrease in dentin bond strengths when the adhesive is used as etch-and-rinse adhesive
  - c. A substantial increase in post-operative sensitivity
  - d. 'a' and 'b'
4. **Universal adhesives may be used without enamel etching in specific clinical situations if:**
  - a. The adhesive is mixed with water
  - b. The adhesive is mixed with a self-cure activator
  - c. The adhesive is scrubbed vigorously on enamel
  - d. The adhesive is warmed to body temperature
5. **Regarding the use of MMP inhibitors, such as chlorhexidine, clinical evidence shows:**
  - a. Chlorhexidine prolongs the longevity of adhesive restorations
  - b. Controlled clinical studies do not show any benefit from using MMP inhibitors
  - c. MMP inhibitors decrease post-operative sensitivity in posterior composite restorations
  - d. 'b' and 'c'
6. **There are methods to improve the clinical behavior of self-etch adhesives, including universal adhesives applied in self-etch mode. Example:**
  - a. Roughen intact dentin to remove the smear layer
  - b. Etch enamel with phosphoric acid
  - c. Etch dentin with phosphoric acid
  - d. 'a' and 'b'
7. **Regarding the clinical behavior in class V (NCCLs) composite restorations with universal adhesives:**
  - a. Self-etch and selective enamel etching strategies result in better retention rate than the etch-and-rinse strategy
  - b. All strategies result in similar clinical retention rate
  - c. Selective dentin etching is the recommended adhesion strategy
  - d. Etch-and-rinse and selective enamel etching result in better clinical outcomes than the self-etch adhesion strategy
8. **For etch-and-rinse adhesives, leaving the dentin moist may not be so crucial, because**
  - a. Dentin is not etched prior to applying the adhesive
  - b. The respective manufacturers recommend air-drying for 30 sec prior to applying the adhesive
  - c. Agitation of the adhesive during application improves adhesive infiltration into etched dentin even if dentin is not moist
  - d. Residual water must remain in the hybrid layer over time to prevent desiccation
9. **If surface contamination with saliva occurs with etch-and-rinse adhesives after etching...**
  - a. The saliva must be rinsed off, the preparation re-etched, followed by the application of the adhesive
  - b. The saliva must be dried, followed by the application of the adhesive
  - c. The adhesive must be applied immediately
  - d. None of the above
10. **One of the following characteristics is NOT an advantage of universal adhesives**
  - a. They bond chemically to dentin when used in self-etch mode
  - b. Dentin must be left moist when universal adhesives are used in etch-and-rinse mode
  - c. Their enamel bond strengths increase after separate enamel etching with phosphoric acid
  - d. They seal dentin margins well when used in self-etch mode

