Quality Resource Guide

Dental Adhesives

Author Acknowledgements

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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.

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Introduction

Enamel is composed of 96%/weight hydroxyapatite (mineral). Dentin, on the other hand, contains a significant amount of water and organic material, mainly type I collagen. While bonding to enamel through the micromechanical interlocking of resin tags within the array of microporosities in acid-etched enamel can be reliably achieved, and can effectively seal the restoration margins against leakage, bonding to dentin remains the greatest challenge in adhesive dentistry.

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 a rubber dam may optimize the outcome

Advantages of Dental Adhesion

- Wide range of clinical applications
- Reliable micromechanical retention to etched enamel without macro-retention features
- Increased resistance to recurrent caries lesions when dental tissues are fully infiltrated with the adhesive
- Recent adhesives used in self-etch mode are very reliable for treating root sensitivity
- More conservative procedures (lesion-specific preparations)
- Reinforcement of residual tooth structure
- Reduced microleakage
- Some dental adhesives result in stable chemical adhesion to hydroxyapatite when dentin is not etched with phosphoric acid
- 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

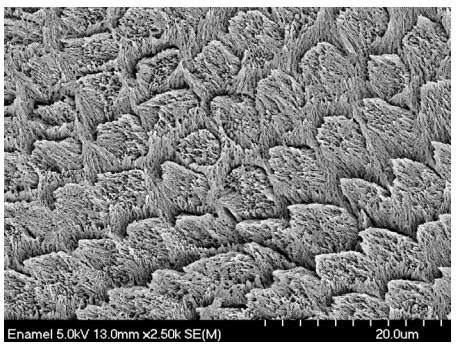
- Dentists may mistakenly rely solely on adhesion as the source of primary retention, even in clinical situations in which there is not enough residual tooth structure. Other forms of mechanical retention, such as slots, coves, and retention locks, may be needed when more than half of the coronal tooth structure has been compromised
- Small uncured monomers, such as HEMA, may seep into the pulp space and cause pulp inflammation
- Potential for marginal bacterial leakage when the cavo-surface margin is located in dentin/cementum
- Moisture contamination of the operatory field may be more detrimental for adhesive than for non-adhesive restorations.

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[1] has been considered the gold standard[2] for bonding resin-based materials to tooth structure since Dr. Michael Buonocore used 85% phosphoric acid in 1955 to make the enamel surfaces more suitable for mechanical adhesion.[1] Buonocore later expanded the acid-etch technique to seal pits and fissures, as reported in 1967.[3] The micromechanical 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 1**).[2]

Figure 1



SEM image of enamel etched with 35% 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 = X2,500.

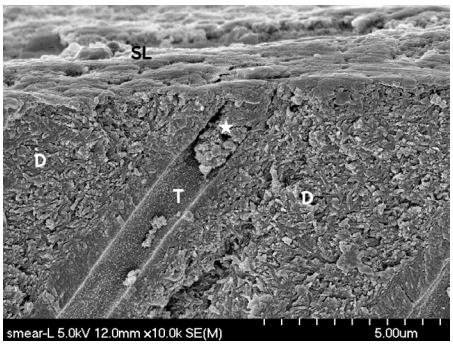
Residual components form a "smear layer" of debris on the surface when the tooth structure is prepared with a bur or with a spoon excavator.[4] (**Figure 2**). The smear layer obstructs the entrance of dentin tubules decreasing dentin permeability. The smear layer is a barrier that must be removed or made permeable, so that monomers in the adhesive can flow into the dentin collagen. Despite several current classifications of adhesive systems, the adhesion strategy depends on how the adhesive interacts with this smear layer. Adhesives that include a phosphoric acid-etching step are known as *etch-and-rinse* (ER) adhesives. They dissolve and remove the smear layer and smear plugs (**Table 1, Figure 3**). Adhesives that do not use a separate etching step are known as *self-etch* (SE) adhesives, as they do not remove the smear layer, but incorporate it into the adhesive interface (**Table 1, Figure 4**). *Self-adhesive* (SA) materials (adhesive and restorative all-in-one material) belong in a different category (**Table 1**). There are two types of SA materials, self-adhesive composite resins and GI (glass-ionomer) restorative materials.

Table 1

Etch-and-rinse (ER)  Include universal adhesives used as **ER** adhesives		3-Step **ER**
		2-Step **ER**
Self-tch (SE) *No separate etchant* Include universal adhesives used as **SE** adhesives		2-Step **SE**
		1-Step **SE**
Self-adhesive (SA) *No separate etchant* *No separate adhesive*	SA composite resin	Adhesive and restorative are the same material
	GICs and RMGICs	

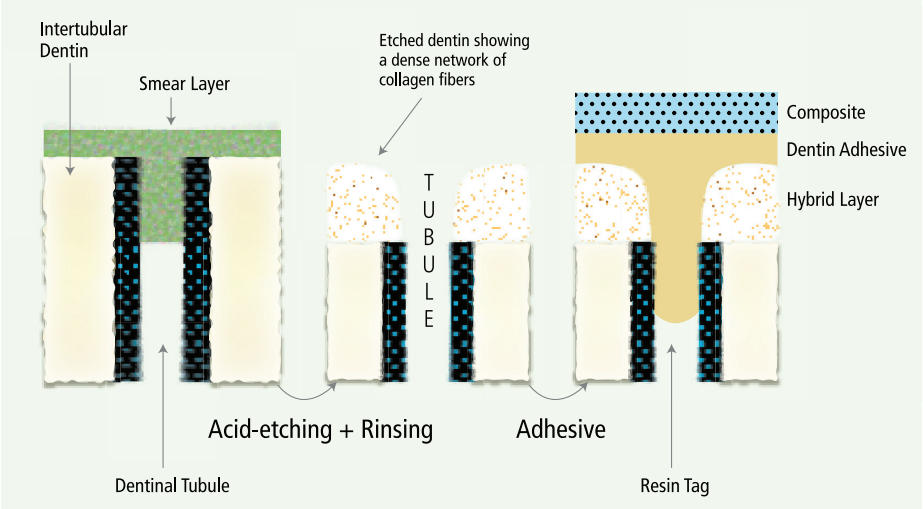
The goal of any adhesive restoration is to achieve a tight and long-lasting adaptation of the restorative material to enamel and dentin.[5] This task is difficult to achieve, as dentin is more hydrated and more organic than enamel.[6] The treatment of dentin with phosphoric acid or with acidic primers 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.[7] (**Figure 3**). The improved sealing provided by the hybrid layer may result in decreased post-

Figure 2



SEM image of the lateral view of dentin after crating a smear layer with a carbide. SL = Smear layer on the occlusal surface. T = Dentin tubule. D = Intertubular dentin. Asterisk = Smear plug blocking the entrance of the tubule. Original magnification = X10,000.

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



operative sensitivity and may even act as an elastic buffer that compensates for the polymerization shrinkage stress during contraction of the restorative composite.[8-10]

Etch-and-Rinse Adhesives

The advantages and disadvantages of ER adhesives are listed in **Table 2**. *Three-step* ER adhesives involve separate etching and rinsing steps followed by a hydrophilic primer and the application of a hydrophobic bonding resin (**Table 1**). *Two-step* ER adhesives 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**).[11,12] *Three-step* ER adhesives result in better laboratory performance (high immediate enamel and dentin bond strengths) and better clinical performance than *two-step* ER adhesives.[13,14]

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 off the etching gel. Dentin is also dried as a result of air-drying enamel, which may cause dentin collagen fibrils to collapse. In vitro studies have demonstrated that drying dentin upon etching results in low bond strengths.[15-17] However, leaving the dentin moist may not be so crucial with current adhesives, as agitation of the adhesive during application improves the infiltration of the resin monomers into etched dentin. A clinical study in non-carious cervical lesions (NCCLs) found that passive application of the adhesive resulted in an 82.5% retention rate after 2 years compared to a 92.5% retention rate of the restorations in which the adhesive was scrubbed vigorously.[18]

Self-Etch Adhesives

The advantages and disadvantages of SE adhesives are listed in **Table 3**. The development of SE adhesives (also known as non-rinsing 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.[12] As the preparation is not rinsed, these materials are more user-friendly because their application time is reduced as compared to ER adhesives.[12] All SE adhesives contain water, which is required to ionize the monomers in the primer. Once ionized, the monomers can 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.[19] The hybrid layer formed by SE adhesives is not completely demineralized as the dentin is not etched.[19] Clinical studies have reported that mild SE adhesives (pH>1.5) result in better adhesion to dentin than very acidic or strong SE adhesives (pH<1.5).[14]

Table 2 - Etch-and-rinse adhesives

Advantages	*Disadvantages*
3-step ER adhesives have been available since the 1990s giving them a long-track record	Acetone-based ER adhesives need more applications than those recommended by the respective manufacturers
They bond to virtually all substrates, including composite, porcelain, fiber posts, etched or sandblasted metals, and amalgam	The recommended solvent evaporation time may be insufficient and must be extended
High immediate dentin and enamel bond strengths in laboratory studies	Over-etching dentin may decrease bond strengths
Excellent bonding to enamel in vitro and durable restorations in clinical studies. However, retention rates for 2-step ER adhesives are lower than for 3-step ER adhesives	More technique sensitive than SE adhesives, as the potential for incomplete infiltration of the adhesive into the etched dentin depends on several contributing factors occurring simultaneously in a very short time
Clinical studies over 10 years with excellent results, specifically for the 3-step ER adhesive Optibond FL (Kerr), which is still the reference for all ER adhesives	Hydrolytic degradation of the bonds occurs when margins are located in the dentin
They contain organic solvents such as ethanol or acetone, therefore minor dentin contamination with saliva does not always decrease bond strengths *in vitro*	The clinical and in vitro performance of 2-step ER adhesives undergo degradation faster than that of 3-step ER adhesives
3-step ER adhesives contain a hydrophobic bonding resin that prevents or delays the degradation of the resin-dentin interface by making the interface impermeable and increasing the film thickness	Bond strengths may vary with the degree of moisture, depending on the specific adhesive
ER adhesives may result in mechanical interlocking with etched dentin provided that the dentin is not over-etched	Although ER adhesives do not cause more post-operative sensitivity than SE adhesives in clinical studies, clinicians have reported that ER adhesives cause a higher incidence of sensitivity with posterior composite restorations.

For enamel, the bond strengths obtained with SE adhesives are lower than those associated with ER adhesives.[20] Because of their less acidic pH, SE adhesives result in a shallow enamel demineralization compared to that of phosphoric acid (**Figure 5**).[20] However, roughening enamel to remove prismless enamel and scrubbing the adhesive vigorously improve the enamel bonding ability of SE adhesives.[21] A separate phosphoric acid enamel etching step (known as 'selective enamel etching') also enhances the efficacy of SE adhesives.[22] A drawback of

Table 3 - Self-etch adhesives

Advantages	*Disadvantages*
Extremely easy to apply, no etching, no rinsing.	SE adhesives do not etch enamel to the same depth as phosphoric acid because the acidic primer is not as acidic.
Some 2-step SE adhesives have been available since the late 1990s, therefore they have a long track record.	1-step SE adhesives need more applications than those recommended by the respective manufacturers.
SE adhesives can be used with selective enamel etching to improve clinical performance.	On enamel, some 1-step SE adhesives result in the formation of water blisters or droplets on the surface of the adhesive, which may compromise the durability of enamel bonding.
Some contain the monomer 10-MDP which bonds chemically to calcium and promotes stable dentin-resin interfaces.	1-step SE adhesives result in clinical signs of enamel leakage at 1 year, and unacceptable marginal discoloration at 2 years.
Clinical studies over 10 years with excellent results, specifically for the 2-step SE adhesive Clearfil SE Bond (Kuraray Noritake), which is still the reference for all other SE adhesives.	Residual water (from their composition) may become entrapped if not properly evaporated, which results in nanoleakage.
Mild 2-step SE adhesives create a calcium-rich hybrid layer allowing for simultaneous micromechanical and chemical bonding.	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 buildups and self- or dual-cured luting cements.
2-step SE adhesives (for example, Clearfil SE Bond, Kuraray Noritake) contain a hydrophobic bonding resin that prevents or delays the degradation of the resin-dentin interface.	1-step SE adhesives behave as permeable membranes on dentin, allowing the permeation of fluids through the adhesive layer to the surface and subsequent degradation.
Several SE adhesives are available in unidose to help comply with stricter infection control guidelines in some countries.	

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

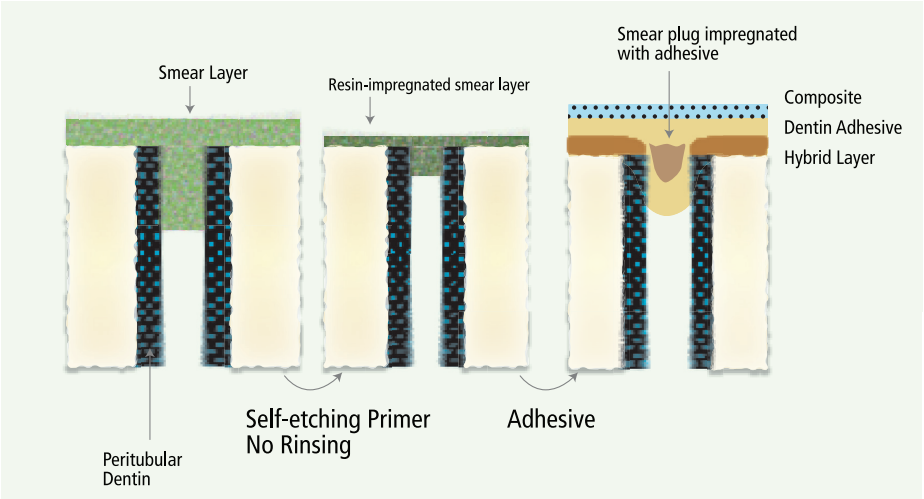


Figure 5

Enamel etching pattern of Prime & Bond Elect (Dentsply Sirona) applied to enamel as a SE adhesive (without previous phosphoric acid etching). Compare with the etching pattern of phosphoric acid in Figure 1. Original magnification = X2,500.

'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.[23,24]

Strong 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.[25]

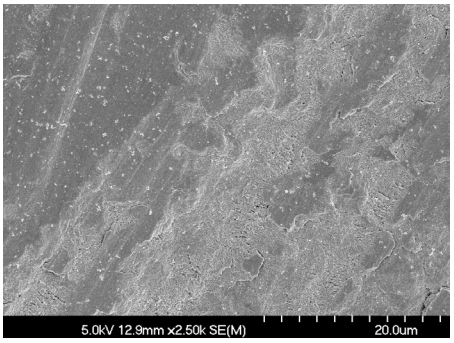
Universal Adhesives

The advantages and disadvantages of universal adhesives are listed in **Table 4.** Dentists have used dentin adhesives following one specific adhesion strategy, ER or SE. As dentists demand more versatile materials, manufacturers have developed adhesives that are more user-friendly and provide clinicians with the possibility of selecting their own adhesion strategy. With the advent of these *universal adhesives* (**Table 1**), dentists 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.[26]

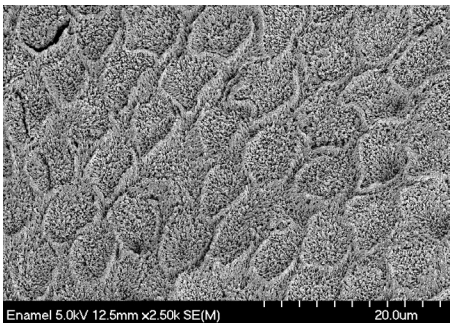
Universal adhesives are indicated for a variety of clinical procedures, including direct composite restorations, indirect restorations, and zirconia primers. The major difference between traditional 1-step SE adhesives and universal adhesives is that most universal adhesives contain 10-MDP (MDP) monomer (methacryloyloxydecyl dihydrogen phosphate), which has been shown to bond chemically to calcium in hydroxyapatite through a mechanism known as nano-layering.[27] This MDP molecule may be responsible for the excellent long-term clinical success of the 2-step SE adhesive Clearfil SE Bond (Kuraray Noritake).[28] As the chemical bonding provided by MDP depends on the concentration of the molecule, the chemical bonding in universal adhesives is slightly weaker compared to that of the 2-step SE adhesive Clearfil SE Bond.[29]

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

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.

Table 4 - Universal adhesives

Advantages	*Disadvantages*
Extremely versatile, as they are recommended as ER and SE adhesives in addition to selective enamel etching.	As etching dentin is not recommended with universal adhesives, a separate enamel acid-etching step is necessary, which increases the clinical application time.
Potential for chemical bonding to hydroxyapatite when used in SE mode.	Clinical studies have reported that the SE strategy results in a worse retention rate compared to ER and selective enamel etching.
Application of the adhesive in SE mode with a scrubbing movement increases enamel bond strengths.	The first universal adhesives required mixing with the respective dual-cure activator when used with self- or dual-cure composite materials, such as build-up composites and resin cements with tertiary amines.
No need to leave dentin moist when used in ER mode.	They do not seal dentin margins well in vitro when dentin is etched with phosphoric acid.
Indicated for a wider variety of restorative procedures by the respective manufacturers, including zirconia primers.	Solvent evaporation time must be extended to remove the residual water that is in the composition of the adhesive.
The newest generation contains effective silane molecules for bonding glass-matrix ceramics.	The incorporation of a silane in the adhesive solution in the first generation of universal adhesives did not improve the bond strengths to glass-matrix ceramics.

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 a 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.[30]

Laboratory evaluations have demonstrated that some universal adhesives form a hybrid layer[31] (**Figure 7A**) and result in excellent clinical outcomes.[32] When universal adhesives are used as ER adhesives it is not necessary to leave dentin moist for two reasons:

(1) 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) The evaporation time after the application of the adhesive may be a very critical clinical step due to the presence of water. 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 long enough to evaporate the water added to the composition of the adhesive and/or the residual water from leaving the dentin moist.[33] If dentists leave dentin moist prior to applying universal adhesives the amount of residual water left in 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.[33,34]

Laboratory studies indicate that storage in water for 6 months to 1 year causes a significant decrease in bond strengths of universal adhesives when the ER strategy is used. On the contrary, bonding durability to dentin increases when universal adhesives are applied under SE strategy.[26] However, the clinical outcomes at 5 years have demonstrated that universal adhesives provide excellent retention of composite restorations in NCCLs if the enamel is etched with phosphoric acid (ER or selective enamel etching).[35]

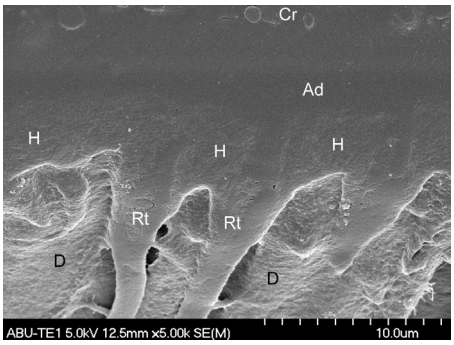
A separate silane solution is recommended for ceramic restorations when using traditional adhesives. The intaglio is etched with hydrofluoric acid, rinsed with water, and air-dried, followed by the application of a silane solution. For universal adhesives, some manufacturers have added a silane to the composition of their universal adhesives. Clearfil Universal Bond Quick (Kuraray Noritake) 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.[36,37] The silane may not be stable in the adhesive solution[37,38] and the low pH of the universal adhesive decreases the effectiveness of the incorporated silane.[37] A recent universal adhesive, Scotchbond Universal Plus (3M Oral Care), contains two silane molecules that are stable and reactive, without the need for a separate silane solution when bonding indirect restorations.[39]

Contamination of the Bonding Surface

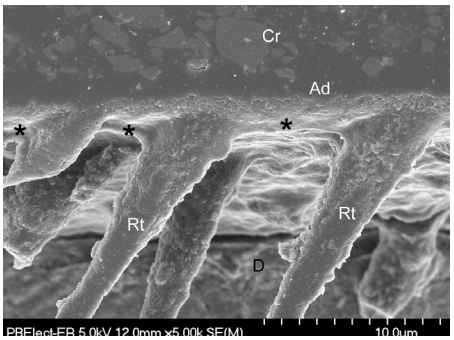
Contamination with blood or saliva may occur during the bonding procedure especially when absolute isolation is not used.

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.[40] When All-Bond Universal used as an ER adhesive 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.[41]

Figure 7



A - 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.

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 the adhesive type.[42]

For classical SE and ER adhesives, contamination with blood reduces bond strengths significantly for all adhesives. However, when blood is rinsed followed by the application of the adhesive, bond strength significantly increases to control levels.[43] 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.[44] For self-etch adhesives, contamination with saliva decreases bond strengths.[45] 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.[45]

For adhesion to zirconia, such as when luting a zirconia crown, if saliva contamination occurs after the application of an MDP/silane-based zirconia primer (such as Clearfil Ceramic Primer Plus, Kuraray Noritake; GC Multi Primer, GC Co.; and Monobond Plus, Ivoclar Vivadent), rinsing off the saliva with water will preserve bond strengths. If saliva contamination occurs prior to the MDP/silane-based zirconia primer application, sandblasting with alumina will preserve bond strength.[46] 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 recovers the bonding effectiveness by 75–85%.[47]

Clinical Studies with Recent Adhesives

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 (Kuraray Noritake), a 2-step self-etch adhesive, has shown excellent retention rates in NCCLs (class V lesions) for up to 13 years.[28] Additional enamel etching resulted in improved marginal adaptation.[28]

Classical one-step SE adhesives have not performed well in laboratory studies and clinical studies.[13,14,48] (**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,[49] a 1-step SE adhesive, (iBond, Kulzer), resulted in a 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 into 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.[14]

Although the application of an extra hydrophobic bonding resin over universal adhesives seems to increase the longevity of the bonds in laboratory studies,[50,51] the clinical behavior of Scotchbond Universal at 3- and 5-years is significantly worse when an extra hydrophobic bonding resin is used over the adhesive.[52,53] The use of the extra hydrophobic bonding resin is not recommended for universal adhesives.

Regarding other clinical studies with universal adhesives, the evidence shows that the ER and the selective enamel etching strategies improve the clinical outcomes of composite restorations in NCCLs. For Class II composite restorations the selective enamel etching strategy is recommended.[26] For glass-matrix ceramics, such as lithium disilicate, the adhesive strategy was not relevant.[26]

Figure 8

Class II composite restorations on tooth # 19 three years after the restoration was inserted. The tooth was restored with a 1-step SE adhesive without enamel phosphoric acid etching. The margins underwent degradation because of deficient bonding to enamel.

The Use of Chlorhexidine as an MMP Inhibitor

Strategies for preventing hybrid layer degradation in vitro involve pre-treatment of dentin with disinfectants, including chlorhexidine.[54] Dentin collagen fibrils contain inactive proforms of proteolytic enzymes called matrix metalloproteinases (MMPs).[34] These enzymes have been identified in both odontoblasts and mineralized or demineralized human dentin and have been claimed to play a role in the degradation of resin-dentin bonds.[34,55]

Dentin MMPs are activated by SE or by ER adhesives during bonding procedures.[34,56] 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.[34,57]

The use of exogenous MMP inhibitors as part of the bonding sequence, such as chlorhexidine, has been advocated to help improve the longevity of adhesive restorations.[34] Despite numerous in vitro and in situ studies demonstrating the benefits of applying chlorhexidine as an adjunct to dentin bonding,[34] only a few clinical studies with follow-

up over 2 years have been published.[58,59] These clinical studies do not show any benefit from using chlorhexidine as an MMP inhibitor. A systematic review and meta-analysis[60] concluded that there is insufficient evidence to recommend hybrid layer degradation inhibitory cavity pretreatment prior to placing adhesive resin restoration. We do not recommend using disinfectants as MMP inhibitors prior to inserting adhesive restorations.

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. Despite 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,[13,23] while their clinical reliability has been questioned.[14,48] 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. 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 provide dentists the versatility to select the adhesion strategy tailored to their clinical preferences or a certain clinical application. Manufacturers recommend their use with etch-and-rinse (ER), self-etch (SE), or selective enamel etching strategies. However, clinical studies in non-carious cervical lesions have demonstrated that etching enamel with phosphoric acid improves the longevity of these adhesive restorations. For posterior composite restorations, all the adhesions strategies (*e.g.*, ER, SE, and selective enamel etching) result in similar outcomes.

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. ***Etch-and-rinse* (ER) adhesives**
   a. Do not dissolve the smear layer
   b. Do not etch enamel
   c. They incorporate the smear layer into the adhesive interface
   d. None of the above

2. **One of the following characteristics is NOT an advantage of 2-step self-etch adhesives:**
   a. They contain a hydrophobic bonding resin that prevents or delays the degradation of the resin-dentin interface
   b. They do not etch enamel to the same depth as phosphoric acid
   c. They have a long track record
   d. Some of them bond chemically to dentin

3. **Bonding to dentin is not as reliable as bonding to enamel because:**
   a. Enamel is a humid substrate
   b. Dentin is rich in collagen and water
   c. Dentin contains fluoride
   d. None of the above

4. **The results of clinical research with universal adhesives at 5 years show:**
   a. Excellent clinical behavior in non-carious cervical lesions at 5 years when the enamel is etched
   b. Excellent clinical behavior in non-carious cervical lesions at 5 years when used as SE adhesives
   c. A substantial increase in post-operative sensitivity
   d. A very high failure rate

5. **There are methods to improve the performance of self-etch adhesives on enamel. Examples:**
   a. Remove the prismless enamel
   b. Etch enamel with polyacrylic acid
   c. Do not scrub the adhesive vigorously
   d. None of the above

6. **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. No need to dry saliva, just apply the adhesive
   c. The adhesive must be applied after 2 minutes
   d. None of the above

7. **Advantages of universal adhesives include:**
   a. They require most dentin
   b. They are versatile adhesives recommended for the ER, SE and selective enamel etching adhesion strategies
   c. They do not bond chemically to dentin
   d. Solvent evaporation time should be kept to a minimum

8. **Regarding the use of chlorhexidine as an MMP inhibitor to prevent the degradation of the bonding**
   a. Chlorhexidine prevents post-operative sensitivity
   b. Chlorhexidine prolongs the longevity of adhesive restorations
   c. Chlorhexidine prevents marginal staining
   d. None of the above

9. **Very acidic or strong SE adhesives (pH<1.5) may be used without a separate etching step for the following procedure**
   a. Composite buildups
   b. Porcelain veneers
   c. Pit-and-fissure sealants
   d. None of the above

10. **For self-adhesive (SA) materials**
    a. Adhesive and restorative are the same material
    b. They do not need a separate etching step
    c. They do not need a separate adhesive
    d. All of the above

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