Quality Resource Guide

Seventh Edition

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 current dental adhesives.
3. Recognize that enamel etching is necessary for the long-term success of restorations.
4. Understand the recommended adhesion protocols for lithium disilicate and zirconia restorations.
5. Identify the clinical steps needed to restore bond strengths after contamination during the adhesive procedure.

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Indications for Dental Adhesives

- Direct composite restorations
- Indirect composite restorations
- All-porcelain restorations
- Orthodontic brackets
- Pit and fissure sealants
- Fiber-reinforced posts
- Splints for periodontally involved teeth and luxated teeth
- Root desensitization with universal adhesives in self-etch mode
- 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 Adhesive Restorations

- Reliable micromechanical retention and reduced enamel microleakage when enamel is etched with phosphoric acid
- Increased resistance to recurrent caries lesions when dental tissues are fully infiltrated with the adhesive
- Conservative preparations, such as class II lesion-specific preparations
- Reinforcement of the residual tooth structure
- Recent dental adhesives result in stable chemical bonding to calcium in hydroxyapatite when dentin is not etched with phosphoric acid
- Some adhesives have antibacterial properties:
  - Clearfil™ SE Protect (Kuraray America Inc.) contains MDPB (12-methacryloyloxydodecylpyridinium bromide)
  - Peak™ Universal Bond (Ultradent Products Inc.) contains chlorhexidine
  - iBond® Total-Etch (Kulzer GmbH) contains glutaraldehyde

Disadvantages of Adhesive Restorations

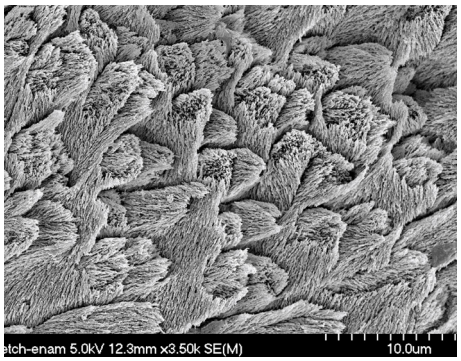
- Residual uncured monomers, such as HEMA (2-Hydroxyethyl methacrylate), may seep into the pulp space and cause inflammation especially in deep restorations
- Potential for marginal bacterial leakage when the cavosurface margin is located in dentin/cementum
- Moisture contamination of the operatory field may be more detrimental for adhesive than for non-adhesive restorations
- Postoperative sensitivity in posterior teeth may occur as a result of cusp deflection caused by shrinkage stress of composite resin
- Other forms of retention, such as slots, coves, and retention locks, may be needed when there are no enamel margins and more than half of the coronal tooth structure has been compromised, such as in extensive crown buildups.

Introduction

Dental adhesion had its genesis in the introduction of phosphoric acid for enamel etching by Dr. Michael Buonocore in 1955.[1] Enamel is composed of hydroxyapatite (96% by weight), a mineral formed by a lattice of calcium and phosphate ions. Bonding to enamel through the micromechanical interlocking of polymerized adhesive within the array of microporosities of acid-etched enamel (**Figure 1**) results in durable and reliable adhesion and can effectively seal the restoration margins against leakage. Dentin, on the other hand, contains a significant amount of water and organic material, mainly type I collagen, making it a challenging substrate for adhesion. Bonding to dentin is still the greatest challenge in adhesive dentistry. A listing of some of the available dental adhesives and associated products discussed in this QRG is provided in **Attachment 1.**

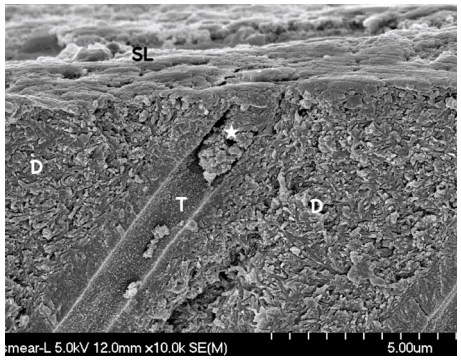
A "smear layer" of debris forms on the dentin surface[2] (**Figure 2**) when dentists use burs or spoon excavators for tooth preparation. Because it obstructs the entrance of dentin tubules (**Figures 2, 3, and 4**), the smear layer is a barrier

Figure 1



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 = X3,500.

Figure 2



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

that must be removed or made permeable, so that resin monomers in the adhesive can flow into dentin. Despite several current classifications of adhesive systems, the adhesion strategy depends on how the adhesive interacts with the smear layer. Adhesives that include a phosphoric acid-etching step are called 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**) restorative materials (all-in-one adhesive and restorative material) belong in a different category (**Table 1**). There are two types of SA materials, self-adhesive composite resins and glass-ionomer composite (GIC) restorative materials.

The goal of any adhesive restoration is to achieve a tight and long-lasting adaptation of the restorative material to enamel and dentin.[3] This task is difficult to achieve, as dentin is more hydrated and more organic than enamel.[4] The infiltration of resin monomers of the adhesive into the small spaces within the dentin's network of collagen fibrils results in the formation of a hybrid layer.[5,6] (**Figures 3** and **5**). The potential sealing provided by the hybrid layer may result in decreased postoperative sensitivity and may even act as an elastic buffer that compensates for the polymerization shrinkage stress during contraction of the restorative composite.[7,8]

Figure 3 - Diagram showing how ER adhesives interact with dentin

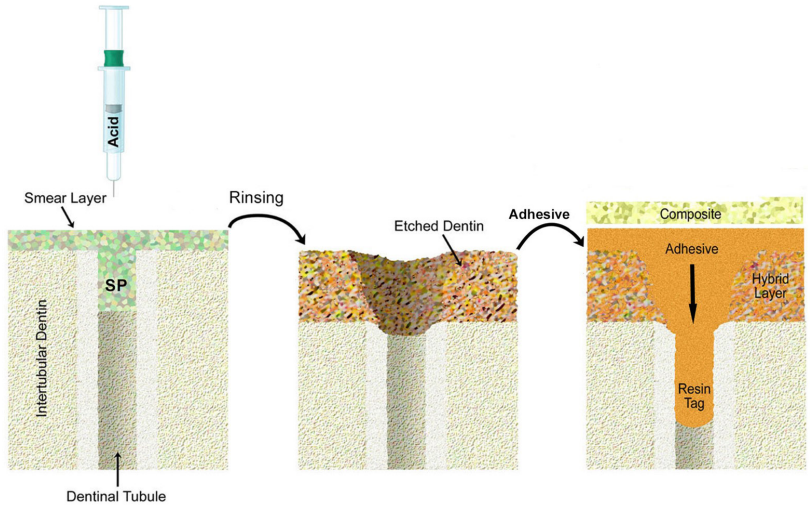
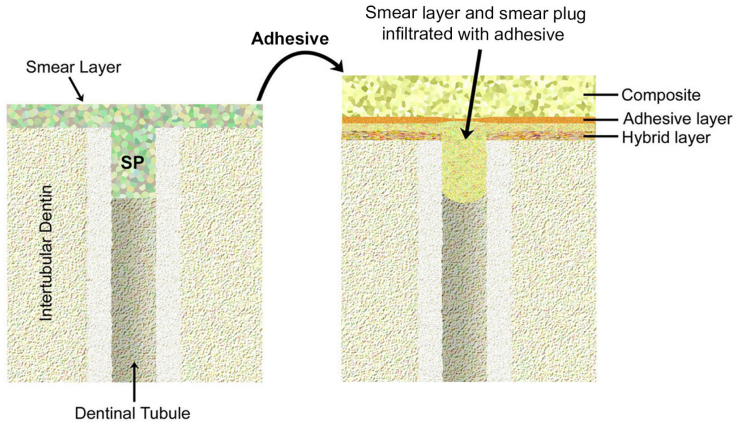


Figure 4 - Diagram showing how SE adhesives interact with dentin



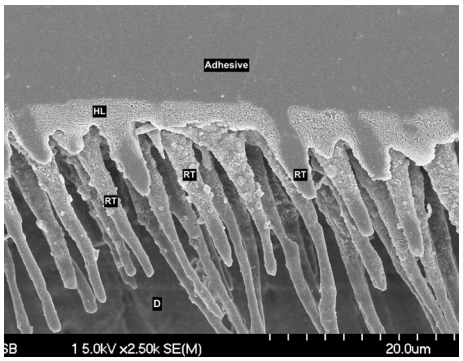
Adhesion Strategies

1. Etch-and-Rinse (ER) Adhesives

The advantages and disadvantages of ER adhesives are listed in **Table 2**. ER adhesives involve separate etching and rinsing steps (**Table 1**, **Figure 3**). Three-step ER adhesives result in better laboratory performance (higher immediate enamel and dentin bond strengths) and better clinical performance than other ER adhesives.[9]

Air-drying of etched preparations used to be taught as a method to check for the etched aspect of enamel. Clinicians still dry the enamel after rinsing off the etching gel, but dentin is also dried as a result of air-drying enamel. In vitro studies have demonstrated that drying dentin after rinsing the etching gel results in low bond strengths.[10,11] However, leaving the dentin moist may not be so essential with current adhesives, as they contain water in their composition. In addition, agitation of the adhesive during application improves the infiltration of the adhesive into etched dentin even without leaving the dentin moist. A clinical study in class V non-carious cervical lesions (NCCL) found that passive adhesive application 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.[12]

Figure 5



Section of the interface formed with Scotchbond™ Universal applied as ER adhesive on dentin (replica after dissolving dentin away) RT = Resin tag; D = Dentin (dissolved chemically to show the replica). The hybrid layer (HL) shows the collagen fibers (reticular pattern) enveloped with the polymerized dentin adhesive. Original magnification = X2,500.

2. Self-Etch (SE) Adhesives

Table 3 lists the advantages and disadvantages of SE adhesives. Their development has changed some concepts of dental adhesion. SE adhesives do not require a separate acid-etch step, as they condition and prime simultaneously due to their acidic pH. As the preparation is not rinsed, these materials are more user-friendly because their application time is reduced compared to ER adhesives.

SE adhesives rely on their ability to infiltrate through dentin smear layers (**Figure 4**) and partially dissolve hydroxyapatite to generate a hybrid layer that has residual calcium because dentin was not decalcified by etching.[6,13] This residual calcium plays an important role in chemical adhesion to dentin.[4] All SE adhesives contain water, which is required to ionize the resin phosphate monomers in the adhesive. Once ionized, these monomers

Table 1

Etch-and-rinse (ER) 	 Traditional 3-Step **ER**
	 2-Step **ER** Universal adhesives
Self-etch (SE) *No separate etchant*	 Traditional 2-Step **SE**
	 1-Step **SE** Universal adhesives
Self-adhesive (SA) *No separate etchant, No separate adhesive*	SA composite resins; restorative GICs/ RMGIC* (Adhesive & restorative are the same material)

** GIC - glass-ionomer cement; RMGIC - resin-modified glass ionomer cement*

Table 2 - ER adhesives

Advantages	Disadvantages
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 many substrates, including composite, porcelain, fiber posts, etched or sandblasted metals.	The recommended solvent evaporation time may be insufficient and must be extended.
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.	Over-etching dentin may decrease bond strengths. More technique sensitive than SE adhesives, as the potential for incomplete infiltration of the adhesive into the etched dentin depends on several factors.
Excellent bonding to enamel *in vitro* and durable restorations in clinical studies.	Degradation of the bonds occurs when margins are located in the dentin/ cementum.

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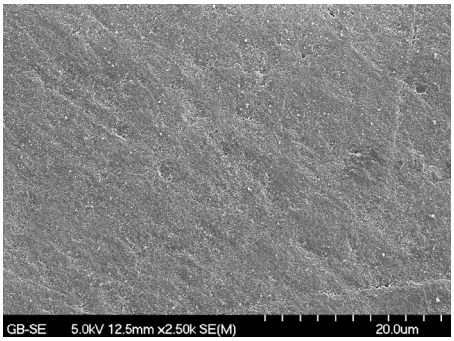
can etch enamel and dentin very slightly. Therefore, SE adhesives result in a shallow enamel demineralization compared to that created with phosphoric acid (**Figure 6**).[14] As a result, the enamel bond strengths obtained with SE adhesives are lower than those associated with ER adhesives.[14] A separate phosphoric acid enamel etching step is used to enhance the efficacy of SE adhesives.[15] Roughening enamel to remove prismless enamel and scrubbing the adhesive vigorously also improves the enamel bonding ability of SE adhesives, even without previous phosphoric acid etching.[16]

Two-step SE adhesives have the potential to form a hybrid layer and seal dentin.[13] Clinical studies have reported that mildly acidic 2-step SE adhesives, such as Clearfil™ SE Bond (pH of 2.0), result in better adhesion to dentin than very acidic or strongly acidic SE adhesives (pH<1.5).[9]

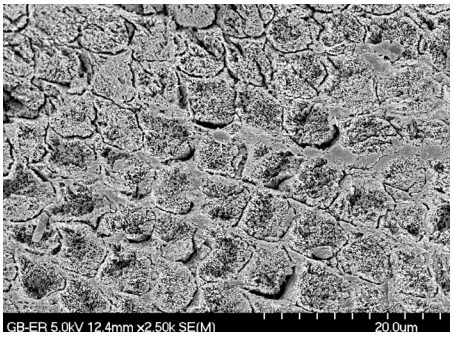
A drawback of etching enamel separately is that the clinician may inadvertently etch dentin. For some SE adhesives, dentin bond strengths decrease when applied to acid-etched dentin compared to the same adhesive applied to dentin that has not been etched.[17]

There has been some debate as to whether SE adhesives cause less post-operative sensitivity than ER adhesives in posterior composite restorations. There is strong clinical evidence that the adhesion strategy (*i.e.*, ER or SE) does not influence the postoperative sensitivity in posterior composite restorations.[18] In addition, the use of glutaraldehyde-based dentin desensitizers underneath posterior composite restorations does not prevent postoperative sensitivity.[19]

Figure 6



A - Enamel etching pattern of G-Premio Bond Universal applied as SE adhesive (no etching) with scrubbing. Adhesive was dissolved in acetone. Original magnification = X2,500.



B - Enamel etching pattern of G-Premio Bond Universal applied as ER adhesive (etching with 35% phosphoric acid for 15 sec). Adhesive was dissolved in acetone. Original magnification = X2,500.

3. Universal Adhesives

Fifteen years ago, dentists still used dentin adhesives that were exclusively indicated for one specific adhesion strategy, either ER or SE. With the demand for more versatile materials, manufacturers have developed simplified adhesives known as universal adhesives. This latest generation of dental adhesives has become very popular in Dentistry.[20] They are more user-friendly and allow clinicians to select a specific adhesion strategy, *i.e.*, SE, ER, or SE on dentin and ER on enamel, a technique commonly referred to as "selective enamel etching" (**Table 1**).

Universal adhesives are indicated for a variety of clinical procedures, including direct composite restorations and indirect restorations. The advantages and disadvantages of universal adhesives are listed in **Table 4**. The major difference between older 1-step SE adhesives and universal

Table 4 - Universal adhesives

Advantages	Disadvantages
Extremely versatile, as they are recommended as ER and SE adhesives. May also be used as selective enamel etching adhesives.	As etching dentin is not recommended with universal adhesives, a separate enamel acid-etching step is necessary, which increases the clinical application time.
Indicated for a wider variety of direct and indirect restorative procedures by the respective manufacturers	The incorporation of a silane in the adhesive solution does not improve the bond strengths to glass-based ceramics, such as lithium disilicate.
Potential for chemical bonding to hydroxyapatite when used in SE mode.	They do not seal dentin margins well in vitro when dentin is etched with phosphoric acid.
Application of universal adhesives in SE mode with a scrubbing movement increases enamel bond strengths.	Several universal adhesives required mixing with a dual-cure activator when used with self- or dual-cure composite materials, such as buildups and traditional resin cements that contain tertiary amines.
No need to leave dentin moist when used in ER mode.	Solvent evaporation time must be extended to remove the residual water that is in the composition of the adhesive.

adhesives is that most universal adhesives contain 10-MDP (methacryloyloxydecyl dihydrogen phosphate), a phosphate resin monomer molecule that has been shown to provide stable chemical bonds with calcium in hydroxyapatite through a mechanism known as nano-layering.[21] This 10-MDP molecule is responsible for the excellent long-term clinical success of the 2-step SE adhesive Clearfil™ SE Bond.[22]

Universal adhesives form a dentin hybrid layer[4] (**Figure 5**) and result in excellent clinical outcomes in NCCL.[25] Storage in water for 6 months to 1 year causes a significant decrease in dentin 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 the SE strategy.[20] For this reason, we recommend selective enamel etching (no dentin etching) to avoid removing calcium from dentin, which is crucial for chemical (ionic) bonding with 10-MDP, while providing strong enamel bonding from etching enamel with phosphoric acid.[23] (compare **Figures 6A** and **6B**).

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. For Adhese® Universal and Scotchbond™ Universal, enamel bond strengths are identical when applied passively or with scrubbing action.[24]

When universal adhesives are used as ER adhesives it is not necessary to leave dentin moist for two reasons:

(1) Universal adhesives contain 10-20% water because water is required to ionize the (acidic) phosphate resin monomers in universal adhesives, enabling them to interact with dentin and enamel. The drawback is that hydrolytic degradation of the polymerized adhesive and collagen may occur if residual water is left at the dentin-adhesive interface.[26,27]

(2) The evaporation time after applying the adhesive may be a critical clinical step due to the presence of residual water added to the composition of the adhesive or the residual water from leaving the dentin moist. Manufacturers recommend evaporation of the solvent with air for 5 seconds after applying the universal adhesive (10 seconds for All-Bond Universal®). However, 5 seconds is not long enough to evaporate the residual water.[26] It is recommended to gently air dry the adhesive for at least 15 seconds.[26] If dentin is left moist prior to applying a universal adhesive, the amount of residual water left on the dentin surface may hamper the formation of a hybrid layer and reduce bond strengths.[27]

Due to their acidity (pH <3), several universal adhesives deactivate the initiator component of self- or dual-cure composite materials that contain a tertiary amine, such as composite buildup materials.[28] As only a few dual-cure composite buildup materials are amine-free, these universal adhesives require mixing with a dual-cure activator when used with dual-cure composite buildup materials.

Scotchbond™ Universal Plus contains a copper salt that improves its compatibility with amine-containing dual-cure composite buildup materials, negating the need to mix it with a separate activator.[28,29]

4. Self-adhesive (SA) Restorative Materials

While some SA materials are currently indicated for luting procedures, the physical properties and adhesion potential of self-adhesive restorative composite resins are not ideal for clinical use.[30]

Restorative GIC (type II GIC) is indicated for situations where the dentin margin is wider than the enamel margins, as in root caries, class V lesions, and caries lesions around full coverage restorations. They are also widely used in pediatric dentistry and in endodontics to seal the entrance of the root canal.

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, a 2-step self-etch adhesive, has shown excellent retention rates in NCCL for up to 13 years.[22] Additional enamel etching resulted in improved marginal adaptation.[22]

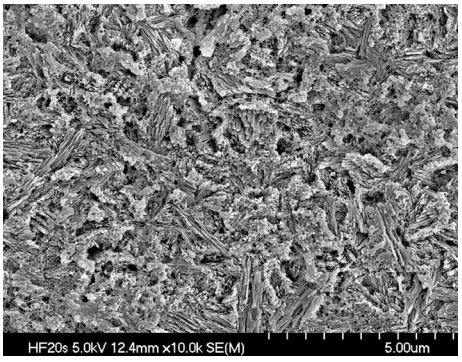
Regarding clinical studies with universal adhesives, the evidence shows that etching enamel improves the clinical outcomes of composite restorations in NCCL.[25] For Class II composite restorations, the selective enamel etching strategy is recommended.[20] However, the use of a universal adhesive in SE mode for posterior restorations has resulted in excellent clinical outcomes at 1 year.[31] This may be related to the chemical bonding between 10-MDP and calcium.

Bonding to Ceramics

1. Bonding to glass-based ceramics including lithium disilicate

Hydrofluoric acid (**HF**) is used to create microretentions in the ceramic. HF partially dissolves the glass phase of the lithium disilicate surface (**Figure 7**). For traditional adhesives, the HF is rinsed thoroughly with water for at least 60 seconds, followed by air drying and the

Figure 7



Lithium disilicate intaglio after etching with 5% HF for 20 sec. Note the resulting microporosities that provide microretention for the restoration. Original magnification = X10,000.

application of a silane solution. The silane increases the ceramic wettability while promoting chemical interaction between the silica (glass) in the ceramic and the methacrylate groups of the adhesive or luting resin.[20]

For universal adhesives, etching the intaglio with HF is still essential, followed by rinsing thoroughly with water. However, according to some manufacturers, applying a separate silane solution is unnecessary because their universal adhesive incorporates a silane molecule in the respective composition. Examples of these universal adhesives are Clearfil™ Universal Bond Quick and Scotchbond™ Universal Adhesive. The efficacy of the combined adhesive and silane solution for luting lithium disilicate restorations has been questioned,[32-34] as the silane is unstable when mixed in the adhesive solution.[36-38] Additionally, the universal adhesive's low pH (acidity) decreases the incorporated silane's effectiveness.[33]

A newer universal adhesive, Scotchbond™ Universal Plus, contains two silane molecules instead of one. The manufacturer claims that this adhesive carries an optimized mixture of silanes and that a separate silane solution for glass-based ceramics is not indicated. However, there have been conflicting reports on this claim.[33-35] Relying on the existing evidence, we recommend the use of a single silane solution with all universal adhesives when bonding glass-based ceramic restorations.

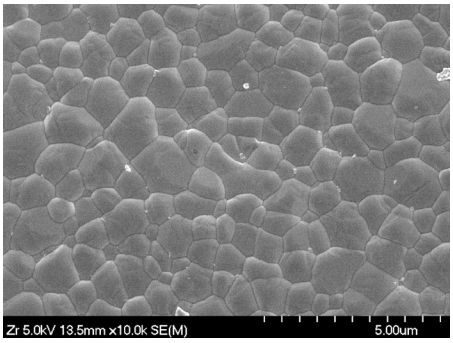
Several silane solutions are indicated for glass-ceramic restorations. Research has demonstrated that combining a silane with the molecule 10-MDP (previously discussed for dentin bonding) in the same solution is very effective for bonding lithium disilicate restorations.[34,39-42] Three commercial silane/10-MDP solutions are available: Clearfil™ Ceramic Primer Plus, G-Multi Primer™, and Monobond Plus® or Monobond® N.

Recommended sequence for luting lithium disilicate restorations:

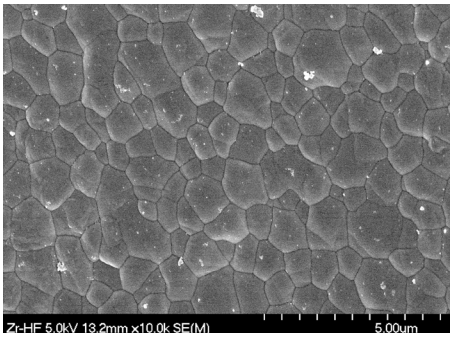
1. Intaglio is etched with 5% HF* for 20 seconds (this step is often carried out in the dental laboratory), followed by rinsing thoroughly for at least 60 seconds
2. Apply a silane/10-MDP solution to the intaglio with a small brush, leave undisturbed for 60 seconds
3. Apply a universal adhesive to the tooth preparation (selective enamel-etch preferred)
4. Remove excess adhesive from the preparation with a new small brush to avoid pooling of the adhesive
5. Light-cure the adhesive
6. Inject resin cement into the intaglio, seat restoration
7. Tack-cure for 2 seconds; remove cement excess; cure as indicated by the respective manufacturer

Hydrofluoric acid is toxic and corrosive; it is damaging to soft tissues

Figure 8



A - Zirconia intaglio as received from the dental laboratory. Original magnification = X10,000.



B - Zirconia intaglio after etching with 5% HF for 20 sec. Note that HF did not create micro-porosities for retention. Original magnification = X10,000.

Recent research has suggested that a separate adhesive does not need to be applied onto the restoration intaglio. The bond strengths are similar when only the silane/10-MDP solution is used.[34,41,42]

2. Bonding to zirconia

Zirconia does not contain glass; therefore, etching with HF does not create any retentive features (**Figures 8A and 8B**). Regardless of the adhesive protocol, the restoration intaglio must always be air abraded (sandblasted) with aluminum oxide particles to obtain micromechanical retention.[43] This step is often carried out by the dental laboratory.

The use of universal adhesives as zirconia primers has been recommended by the respective manufacturers. However, the resulting bond strengths undergo degradation within a few months.[44,45] A silane/10-MDP solution or primer, such as Clearfil™ Ceramic Primer, G-Multi Primer™, or Monobond Plus®, results in higher bond strengths to zirconia than other zirconia primers.[46,47] These 10-MDP/silane solutions, which are also recommended for bonding lithium disilicate restorations, are effective as zirconia primers due to the strong ionic and hydrogen bonding between zirconia and the 10-MDP molecule.[48]

Using 10-MDP-containing resin cements also results in high bond strengths to zirconia with no significant decrease after artificial aging, even without using 10-MDP-containing primers.[49] We currently teach the use of self-adhesive resin cements that contain 10-MDP to enhance the bonding to zirconia.[47,49] Some examples of dual-cure self-adhesive resin cements with 10-MDP: Clearfil™ SA Luting, also known as Panavia™ SA Cement; G-CEM One™; and RelyX™ Unicem 2.

A 3-step approach to achieve reliable bonding to zirconia is the APC concept.50 Step A (abrasion) includes air abrasion (sandblasting) with aluminum oxide particles; Step P (primer) refers to the application of a zirconia primer; Step C (composite resin cement) corresponds to the use of a dual-cure resin cement.

Recommendation:

1. Sandblast intaglio with alumina particles under a pressure <1 bar for 15 seconds; rinse, dry (this step is often carried out in the dental laboratory).
2. Apply a silane/10-MDP solution to the intaglio with a small brush, leave undisturbed for 60 seconds. This primer is not needed when the resin cement with 10-MDP is used, as noted above.
3. Clean and gently dry the tooth preparation. No etching or adhesive is needed when using a self-adhesive resin cement.
4. Insert the dual-cure resin cement into the intaglio, seat restoration. For zirconia, it is crucial to apply constant pressure during cementation to improve the bond strengths.[51]
5. Tack-cure for 1-2 seconds; remove cement excess; light cure around the margins as indicated by the respective manufacturer.

Contamination of the Substrate During the Bonding Procedure

1. Contamination of dentin/enamel

Contamination with blood or saliva may occur, especially when absolute isolation is not used. Saliva contamination is less critical than blood contamination.[52]

Several decontamination methods have been proposed to restore dentin bond strengths after saliva contamination. For classical ER adhesives, if surface contamination with saliva occurs after etching, it is recommended to dry the saliva, followed by the application of the adhesive, which results in bond strengths similar to those of the uncontaminated surfaces.[53] If saliva contamination occurs after the application but before light curing the adhesive, it is recommended to wash, air dry, and reapply the adhesive, followed by light curing. If saliva contamination occurs after light curing the adhesive, then re-application of the adhesive after washing and drying is not necessary.[54]

Similar findings have been reported for recent universal adhesives, especially when used in ER mode. Dentin bond strengths of two universal adhesives, Adhese® Universal and Scotchbond™ Universal, decrease with saliva contamination after the application of the adhesive, but water rinsing, drying, and reapplication of the adhesive improve bond strengths to control levels.[55] For the SE mode, a study tested Clearfil™ Universal Bond. Saliva contamination occurred after preparation or after curing the adhesive. The two decontamination methods were either rinsing and air drying, or rinsing, air drying, and reapplying the universal adhesive. The study reported that the bond strengths deteriorated over time up to 1 year, regardless of the decontamination method.[56] This study also tested the 2-step self-etch adhesive Clearfil™ SE Bond. For this adhesive, saliva contamination was most critical when the contamination occurred after the primer application. Rinsing with water, air-drying, and reapplying the primer regained the bond strength to control levels that were maintained over time.[56]

Contamination with blood reduces bond strengths significantly for all adhesives. When blood is rinsed, followed by air drying and adhesive application, bond strengths increase, but not to the original control level.[57] If contamination occurs after light curing the adhesive, decontamination methods do not prevent the decrease in bond strengths. Alternatively, rinsing and drying the contaminant followed by adhesive re-application may be effective depending on the adhesive type.[58]

When using glass ionomer-based composites (GICs), contamination with saliva does not seem to affect the bond strengths of a conventional GIC (GC Fuji IX GP®) and a resin-modified GIC (GC Fuji II LC®). In addition, the microleakage around enamel margins of these GIC restorations contaminated with saliva does not increase after thermocycling.[59]

Preparations are often contaminated with hemostatic agents. The most popular hemostatic agents are aluminum chloride and ferric sulfate. These agents prevent the penetration of the adhesive into the dentin surface.[60] Hemostatic agents remain on the tooth surface and result in decreased bond strengths, especially with adhesives used in SE mode.[60] Rinsing the contaminated surface with chlorhexidine or 17% EDTA or extending the adhesive application time increased the dentin bond strengths of Scotchbond™ Universal.[60]

ViscoStat™ Clear (25% aluminum chloride) decreases the bond strengths of Prime & Bond Active® and Scotchbond™ Universal when applied in SE mode.[61] In another study, Clearfil™ Universal Bond Quick, OptiBond™ Universal, and Scotchbond™ Universal were used in either ER or SE mode.[61] Contaminating dentin with 25% aluminum chloride adversely affected the bond strengths of the three universal adhesives in SE mode.[61] However, the bond strengths did not decrease after contamination when the universal adhesives were used in ER mode.[62] The use of ferric sulfate (ViscoStat™) does not negatively affect the bond strengths.[61]

2. Contamination of the lithium disilicate intaglio

Several methods have been advocated to remove the contamination residue from the intaglio of lithium disilicate restorations. When the intaglio is contaminated with saliva prior to etching with HF or prior to the application of the silane, three methods were effective for enhancing the bond strengths: 1) surface treatment with 5% HF* followed by a 10-MDP/silane solution; 2) 37% phosphoric acid followed by a 10-MDP silane solution; or 3) the single-component ceramic primer Monobond Etch & Prime.[63]

Air-water spray, 35% phosphoric acid, 70% alcohol, and Ivoclean® have been deemed effective cleaning methods for removing saliva from lithium disilicate ceramic that has been previously etched and silanized.[63] For blood contamination, air/water spray alone was identical to the use of 35% phosphoric acid or Ivoclean®.[64]

The use of a silicone disclosing medium to check the restoration fit after etching the intaglio with HF* may also leave some residual

contamination. Re-etching with 5% HF* to remove the contamination resulted in bond strengths comparable to those of uncontaminated surfaces.[65] Ivoclean® was also effective, but resulted in slightly lower bond strengths than those of 5% HF.[65]

** Hydrofluoric acid is toxic and corrosive; it is damaging to soft tissues*

3. Contamination of the zirconia intaglio

The most effective method to remove the saliva contamination residue from the zirconia intaglio is sandblasting.[66,67] However, many dental providers do not have an intraoral sandblaster for chairside use. For this reason, the use of cleaning pastes and cleaning solutions has been advocated in many CE courses. The literature is ambiguous regarding the best method other than sandblasting. Several studies have tested water spray, phosphoric acid etching, 0.5% sodium hypochlorite (NaOCl), isopropyl alcohol, and cleaning pastes, including Ivoclean®. No difference in bond strengths to zirconia was reported between water spray, Ivoclean®, 0.5% NaOCl and noncontaminated zirconia.[68] Another study concluded that 0.5% NaOCl resulted in higher bond strengths than water spray and phosphoric acid etching.[69] A systematic review found that the bond strengths obtained with sandblasting or cleaning with NaOCl were comparable to those for uncontaminated zirconia.[67] The advantage of using NaOCl is that the solution is available in many dental offices for endodontic procedures. Although 0.5% NaOCl is very effective in removing saliva residues from the intaglio, extensive water-rinsing is necessary after its application.

When using a 10-MDP/silane primer, rinsing off the saliva with water increases bond strength. If saliva contamination occurs after applying the 10-MDP/silane primer, reapplication of 10-MDP/silane solution will preserve bond strengths.[70,71]

The Use of Dentin Disinfectants

The use of chlorhexidine as part of the bonding sequence has been advocated to prevent the degradation of the hybrid layer and help improve the longevity of adhesive restorations.[27,72]

Dentin collagen fibrils contain inactive proteolytic enzymes called matrix metalloproteinases (MMPs) that digest the collagen fibers if they are incompletely enveloped with resin monomers from the adhesive.[27] These enzymes, which can be inhibited by chlorhexidine and other MMP inhibitors, have been identified in both odontoblasts and mineralized or demineralized dentin and have been associated with the degradation of resin-dentin bonds in laboratory studies.[27,73,74] However, more recent research using the same methodology did not confirm the role of MMP inhibitors in the degradation of the bonding reported in previous studies.[75]

Despite numerous in vitro and in situ studies demonstrating the benefits of applying chlorhexidine as an adjunct to dentin bonding,[34] clinical studies with follow-up of over 2 years fail to show any benefit from using chlorhexidine as an MMP inhibitor.[76-78] We do not recommend using any disinfectants as MMP inhibitors prior to inserting adhesive restorations.[78]

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.

Current universal adhesives allow dentists to select an adhesion strategy tailored to their clinical preferences or a certain clinical application. Manufacturers recommend using them with etch-and-rinse (ER), self-etch (SE), or selective enamel etching strategies. However, clinical studies in NCCL have demonstrated that etching enamel with phosphoric acid improves the longevity of the restorations.

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 residual water present in all universal adhesives.

Lithium disilicate and zirconia are the most popular ceramic materials for indirect restorations. Using a reliable and proven luting protocol is paramount for the survival of these restorations. We recommend the use of a silane/10-MDP solution, which has a dual role:

- Silane coupling agent for glass-based ceramics including lithium disilicate
- Primer for zirconia restorations to establish chemical bonding between the 10-MDP molecule and the zirconia intaglio. If the clinician uses a 10-MDP-based resin cement, this primer is not required.

Contamination of the adhesion substrates is a challenging obstacle in clinical dentistry. Contamination with blood worsens the prognosis for the durability of the adhesive procedure more than contamination with saliva. For dentin and enamel, the use of universal adhesives with the ER technique is less prone to deterioration of the bonding than the SE technique in case of contamination with saliva.

Dentin disinfectants and desensitizing solutions have been very popular as a step of the dental adhesion procedure. However, strong clinical evidence has demonstrated that these solutions do not improve the outcomes of direct composite restorations.[19,78] An adequate bonding technique is much more relevant than the use of disinfectants and desensitizing solutions.

Attachment 1

Some Available Products Used in Adhesive Dentistry

Product	Company
All-Bond Universal®	BISCO
G-CEM One™	GC America
G-Multi Primer™	GC America
GC Fuji II LC®	GC America
GC Fuji IX GP®	GC America
Prime & Bond Active®	Dentsply Sirona
Adhese® Universal	Ivoclar Vivadent
Ivoclean®	Ivoclar Vivadent
Monobond Etch & Prime	Ivoclar Vivadent
Monobond Plus®	Ivoclar Vivadent
OptiBond™ Universal	Kerr Corporation
iBond® Total-Etch	Kulzer GmbH
Clearfil™ Ceramic Primer Plus	Kuraray America
Clearfil™ SA Luting	Kuraray America
Clearfil™ SE Bond	Kuraray America
Clearfil™ SE Protect	Kuraray America
Clearfil™ Universal Bond Quick	Kuraray America
Panavia™ SA Cement	Kuraray America
RelyX™ Unicem	Solventum
Scotchbond™ Universal	Solventum
Scotchbond™ Universal Plus	Solventum
Peak™ Universal Bond	Ultradent Products
VicoStat™	Ultradent Products
VicoStat™ Clear	Ultradent Products

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1. **Etching with phosphoric acid...**
   a. Dissolves the smear layer
   b. Creates microporosities on enamel for micromechanical retention
   c. Result in durable bonding to enamel
   d. All of the above

2. **One of the following characteristics is an advantage universal adhesives:**
   a. Potential for chemical bonding to calcium in hydroxyapatite when used in SE mode
   b. Etching dentin with phosphoric acid improves their clinical outcomes
   c. Indicated for few restorative procedures
   d. Only indicated for the ER strategy

3. **Bonding to enamel is more reliable than bonding to dentin because:**
   a. Enamel tubules have odontoblasts
   b. Dentin is organic and humid
   c. Dentin contains hydroxyapatite
   d. Enamel is very porous

4. **The results of clinical research with universal adhesives at 5 years show:**
   a. Excellent clinical behavior in non-carious cervical lesions 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 enamel performance of some self-etch universal adhesives.**
   a. Etch dentin
   b. Apply chlorhexidine
   c. Scrub the adhesive vigorously
   d. None of the above

6. **If surface contamination with saliva occurs with universal adhesives after the application of the adhesive**
   a. If used as ER adhesives, there is no need to reapply the adhesive
   b. If used as SE adhesives, the bond strengths decrease regardless of the contamination method
   c. If used with selective enamel etching, the adhesive must be applied after 3 minutes
   d. None of the above

7. **What improves adhesion to lithium disilicate surfaces?**
   a. A universal adhesive with silane in its composition
   b. A 3-step ER adhesive
   c. A silane solution with 10-MDP
   d. Application of chlorhexidine on the tooth preparation

8. **Regarding the use of chlorhexidine as an MMP inhibitor to prevent the degradation of the bonding, clinical studies have reported that**
   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. **Universal adhesives can be used for crown buildups with dual-cure composite materials. Why do most universal adhesives require a dual-cure activator?**
   a. Universal adhesives are acidic
   b. Universal adhesives contain a silane
   c. LED curing lights are incompatible with universal adhesives
   d. Dual-cure composite buildup materials change color without adding the dual-cure activator to the adhesive

10. **Which procedure(s) increase bond strengths to zirconia?**
    a. Sandblasting the intaglio surface
    b. Using a 10-MDP-containing primer or a 10-MDP-containing resin cement
    c. Applying constant pressure during cementation
    d. All of the above

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AGD Mastership: ☐ Yes ☐ No

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Evaluation - Dental Adhesives 7th Edition

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	1 = POOR 1	2	3	4	5 = Excellent 5	
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2. How would you rate the quality of the content?	☐	☐	☐	☐	☐	
3. Please rate the effectiveness of the author.	☐	☐	☐	☐	☐	
4. Please rate the written materials and visual aids used.	☐	☐	☐	☐	☐	
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10. How likely are you to recommend MetLife's CE program to a friend or colleague? *(please circle one number below:)*

10 **9** **8** **7** **6** **5** **4** **3** **2** **1** **0**

extremely likely — neutral — not likely at all

What is the primary reason for your 0-10 recommendation rating above?

11. Please identify future topics that you would like to see:

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