

Adhesive Considerations in the Placement of Direct Composite Restorations

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ABSTRACT: *The late Dr. John Gwinnett, one of the most brilliant and respected members of the dental research and teaching community, often characterized bonding as a chain, a series of links between the restorative material being placed and the tooth tissues.¹ And as in a chain, the bond of a restorative material to the tooth substrate is only as strong as its weakest link. Dr. Gwinnett inspired a new generation of clinicians and researchers, the author included, to think about adhesion in an entirely new fashion. Insights and innovations by contemporaries, friends, and colleagues of Dr. Gwinnett, including Byoung Suh, John Kanca, Charlie Cox, Franklyn Tay, David Pashley, Sumita Mitra, Wayne Barkmeier, and many others, also advanced our knowledge and understanding of adhesion. This eventually led to the development of many of the various adhesive techniques and materials utilized in dentistry today. This paper will focus on some of the current concepts and techniques developed to manage the adhesive interface during the placement of direct posterior composite restorations.*

Direct composite resins have the potential to offer a reasonably predictable alternative to amalgam and other metal-based restoratives. This assumes they are utilized in the appropriate clinical situation and are properly placed. In fact, the increasing demand for tooth-colored restorations, conservation of tooth structure, and cosmetic dental procedures has encouraged the widespread placement of direct composite restorations.²⁻⁴ The greater level of clinical success with direct composites is most likely related to material developments, improved clinical skills and techniques, and dramatic advances in adhesive technology.⁵ Since the use of directly placed composites is a mainstay in the majority of restorative practices, it is imperative that dentists understand the rationale for specific clinical techniques, as well as material idiosyncrasies, in order to optimize the adhesive interface between the composite restorative and the tooth substrate.

The majority of direct composites utilized in restorative dentistry today consists of a methacrylated resin matrix (ie, usually a blend of several resins) that is mixed with various glass filler particles, pigments, stabilizers, and chemical and/or light activated initiators. The filler particles in composites are typically silanated. Silane serves as a coupling agent between organics (ie, the resin matrix) and inorganics (ie, the glass fillers). Filler particles can be manufactured in various shapes and sizes and from any number of inorganic

glasses (eg, silica, zirconia-silica, barium silicate, lithium, strontium, and ytterbium). As a generalization, larger particle, more heavily filled composites have superior physical properties while smaller particle composites, such as microfills, are not as strong but have a tendency to wear and polish better.⁶ While an in-depth discussion and characterization of composite chemistry and classification is beyond the scope of this particular paper, clinicians should be aware that the specific nature of the composite being utilized has a direct bearing on what is occurring at the adhesive interface. For example, all current composite formulations shrink to some degree during polymerization (ie, generally 1.5% to 5% by volume). The total amount of shrinkage, the rate of shrinkage, and the elastic modulus (ie, stiffness) of the composite are just some of the factors that influence the degree of stress and strain (ie, deformation) induced at the adhesive interface during composite polymerization.

When placing a direct composite, the actual linkage between composite and the tooth tissues is usually mediated through the use of a dentin bonding agent. The development of practical adhesive dentistry can be traced to Michael Buonocore who, in 1955, discovered he could increase the retention of acrylic based restoratives by first treating the teeth with phosphoric acid.⁷ Subsequent research by Buonocore, Gwinnett, and Matsui elucidated the mechanism of adhesion between enamel and resin restoratives via resin tag formation.⁸ Long-term bonding to phosphoric acid-etched enamel surfaces has proven to be highly reliable and predictable; long-term bonding to dentin is not as predictable, regardless of the dentin bonding agent used. Clinicians can generally bond predictably to enamel, but not nearly as predictably to dentin because of the morphologic, histologic, and compositional differences between the two substrates.⁹ For one thing, dentin is a highly variable substrate. Superficial, middle, and deep dentin can vary significantly in their structural and chemical composition. Enamel, on the other hand, is quite consistent throughout and is also considerably more mineralized than dentin. The inorganic content of mature enamel is approximately 96% hydroxyapatite by weight; the remainder consists of water and organic material. Dentin, on the other hand, is approximately 70% hydroxyapatite by weight, 18% organic material (ie, predominantly collagen), and 12% water.^{1,10} These percentages are not consistent and can vary significantly depending on a number of factors, including dentin depth, age of the teeth, and history of tooth trauma and/or pathology. This, coupled with the relatively

high water content of dentin, presents a significant challenge for consistent and reliable long-term bonding. However, this does not mean that stable and strong *initial* bonds to dentin cannot be attained. Laboratory studies have shown that many current adhesive systems are capable of producing bond strengths to dentin that equal or surpass those of acid-etched enamel controls.

The problem is that most of these are short-term studies (ie, often 24 hours) and the focus needs to be on long-term studies. It is of concern that the literature is replete with longer-term studies—both *in vitro* and *in vivo*—that demonstrate a worrisome trend toward eventual degradation of the dentin/adhesive interface.¹¹⁻¹⁸ This could contribute to the observed clinical problem of porcelain veneers sometimes de-bonding over time when preparations are largely in dentin. Rarely is veneer de-bonding a problem when significant amounts of enamel remain.¹⁹ Microleakage, nanoleakage, hydrolysis, dentin permeability, pulpal pressure, shrinkage stress, “water tree” formation, insufficient hybrid layer formation, phase separation, dentin tubule orientation, occlusion, enzymes released by bacteria, and operator error have all been implicated as potential causes of deterioration of the dentin/adhesive interface over time.²⁰⁻²⁵ When placing a direct composite, it makes sense to utilize techniques and materials that, hopefully, will increase their long-term predictability.

KNOW YOUR ADHESIVE SYSTEM

All dentin-bonding systems employ acids of one type or another to facilitate adhesion to the tooth tissues. Acidic treatment of dentin and/or enamel creates a zone of demineralization, which is subsequently (ie, total-etch) or concurrently (ie, self-etch) infiltrated with various bifunctional primers and resins. While many adhesive systems are capable of providing acceptable clinical results if used in a knowledgeable fashion with attention to detail, all have their particular idiosyncrasies.

The fourth generation, or three-step total-etch systems^{a-c} generally have good long-term clinical track records and are perhaps the most versatile of all the adhesive categories because they can be employed for virtually any bonding protocol (ie, direct, indirect, self-cure, dual-cure, light-cure). These systems are still the “gold standard” by which the newer systems are judged. Indeed, none of the newer systems in the marketplace today perform any better, and often perform worse, than the original multiple component total-etch systems of 15 years ago if bond strength to dentin/enamel, microleakage, and long-term durability are used as the evaluation criteria.¹⁶

The fifth generation, or two-step total-etch systems,^{d-i} evolved from the desire to simplify the three-step total-etch system protocol. As a group, these are among the most popular systems presently being utilized in dentistry. They have generally proven to be highly effective, simpler, and faster than their multiple component predecessors. On the down side, many in this category, albeit with some exceptions, are not as predictable as the three-step total-etch systems when it comes to bonding to self- and dual-cure composites.²⁶ In addition, the two-step total-etch systems may be more susceptible to water degradation over time than three-step total-etch systems.²⁷ This is because the polymerized primer of the two-step systems tends to be hydrophilic in nature. When using a three-step system, the hydrophilic primer is covered by a more hydrophobic resin, making it less susceptible to water sorption.²¹

If the clinician elects to utilize a fourth and fifth generation total-etch system in the placement of a direct composite, he or she needs to be aware that the majority of laboratory studies show that these types of systems perform best when placed on moist dentin. This has been termed “wet” bonding,²⁸⁻³⁰ although moist bonding may be a more accurate description of the phenomena. Dentin exposed to phosphoric acid results in dissolution of the inorganic hydroxyapatite matrix. As the matrix dissolves, the collagen fibrils, which are inherent in dentin, become exposed as they are no longer supported and surrounded by their inorganic scaffolding. It is this friable “collagen network” that must be infiltrated by subsequently placed primers and resins to ensure good bonding. Air-drying of acid-etched dentin causes collapse of the collagen network and interferes with subsequent primer/resin infiltration.³¹ In dentin that is left moist (eg, after acid conditioning), the collagen fibrils remain in a relatively “open” state and appear to be more permeable to subsequently placed primers and resins. The author’s recommended technique when utilizing a total-etch protocol on unlined dentin is not to air dry the dentin once the phosphoric acid conditioner is washed off. The excess water is simply blotted out with cotton pellets prior to placing the primer. This results in a visibly moist dentin surface instead of “puddles” of water, which should be avoided.^{32,33} It warrants noting that some total-etch systems, usually those that are acetone-based, appear to be more sensitive to this wet/dry dentin issue than others (eg, alcohol/water based systems). This highlights an inherent ambiguity many have with the concept of wet bonding, namely exactly how wet is wet?

Perhaps the biggest advantage of the sixth generation, or two-component, self-etching systems^{j-n} is that their efficacy appears to be less dependent on the hydration state of the dentin than total-etch systems. Since the dentin is not pre-treated with phosphoric acid—as is the case with total-etch systems—no exposed collagen layer is present to collapse on air-drying prior to placement of the self-etching primers. Clinically this means that “wet” bonding is not a concern and the tooth surface can be briefly air-dried prior to placing a self-etching primer. This is not to say that self-etch systems perform any better than total-etch systems, but they seem to be less technique sensitive in this regard. One could also argue that a possible advantage of a self-etching system is that demineralization of the dentin occurs concurrently with primer infiltration. In principle this helps ensure that the entire zone of demineralization is saturated with primer where it can then be polymerized *in situ*. On the down side, many products in this category do not etch enamel as well as their total-etch cousins³⁴ and many

^a All-Bond 2®, BISCO, Inc., Schaumburg, IL

^b Scotchbond™ Multi-purpose Plus, 3M™ ESPE™, St. Paul, MN

^c OptiBond® FL, Kerr Corporation, Orange, CA

^d One-Step® Plus, BISCO, Inc., Schaumburg, IL

^e Adper™ Single Bond Plus, 3M™ ESPE™, St. Paul, MN

^f OptiBond® Solo, Kerr Corporation, Orange, CA

^g Prime&Bond® NT, DENTSPLY Caulk, Milford, DE

^h Excite®, Ivoclar Vivadent, Amherst, NY

ⁱ One Coat® Bond, Coltène/Whaledent, Cuyahoga Falls, OH

^j Clearfil™ SE Bond, Kuraray America, Inc., New York, NY

^k Simplicity™, Apex Dental Materials, Inc., Deer Park, IL

^l All-Bond SE™ SPE, BISCO, Inc., Schaumburg, IL

^m Adper™ Prompt™ L-Pop™, 3M™ ESPE™, St. Paul, MN

ⁿ One Coat® Self-Etching Bond, Coltène/Whaledent, Cuyahoga Falls, OH

are not compatible with self- and dual-cure composites.²⁶ A common clinical technique reported by many employing one of the popular self-etching systems^j is to first etch the enamel with traditional phosphoric acid prior to using it. This helps ensure good bond strength to enamel but it does require an additional step in the bonding protocol. Those utilizing this technique should take care to confine the phosphoric acid solely to the enamel. Additional etching of the dentin with phosphoric acid could, in principle, create an “over-etch” situation where the demineralization zone is too deep for subsequently placed primers to completely penetrate.

The seventh generation, or one-bottle self-etching systems,^{o-s} represents the latest simplification of adhesive systems. With these systems all the ingredients required for bonding are placed in, and delivered from, a single bottle. This greatly simplifies the bonding protocol. However, the price for simplification may be compromise. Incorporating and placing all of the chemistry required for a viable adhesive system into a single bottle, and having it remain stable over a reasonable period of time, poses a significant challenge. These inherently acidic systems tend to have a significant amount of water in their formulations and may be prone to hydrolysis and chemical breakdown.^{35,36} In addition, once placed and polymerized, they are generally more hydrophilic than two-step self-etching systems, which makes them more prone to water sorption.³⁷ This could contribute to hydrolysis and degradation of the adhesive interface,³⁸ as well as a reduction in mechanical properties of the composite restorative.³⁹ The acidic nature of the polymerized primers in seventh generation adhesives generally makes them unsuitable for use with self-cure composites since their acidic nature degrades the tertiary aromatic amines required for chemical polymerization of self-cure composites.^{37,40,41} It is this author’s opinion that while offering ease and simplicity, seventh generation adhesive systems should be used cautiously until more independent research clearly demonstrates their short- and long-term effectiveness.

In principle, the “ideal” adhesive system would be one that is hydrophilic when first placed in order to interact with dentin, which inherently has a high water content, but then becomes completely hydrophobic once polymerized in order to discourage water sorption and hydrolysis. Unfortunately, no such chemistry currently exists. A new, recently introduced total-etch system^t is among the first to address this issue by utilizing chemistries that are less hydrophilic in nature.

FLOWABLE COMPOSITE LINERS

One common clinical technique thought to improve the performance of direct composite restorations is the use of flowable composites. With this technique a flowable (ie, a lightly filled composite) is placed in a thin layer *after* a dentin bonding agent is placed but prior to placement of a more heavily filled composite restorative. In principle, flowable composites, by virtue of their low viscosity, are able to get into the “nooks and crannies” of the preparation. This helps ensure optimal adaptation to the previously placed dentin bonding agent, as well as to the higher viscosity composite restorative that is subsequently placed. One could also argue that flowable composites, having a relatively low modulus of elasticity, are able to act as stress-reducing liners during polymerization and shrinkage of the subsequently placed composite.⁴² The literature is equivocal regarding the use of flowables under direct composite restorations in terms of reducing microleakage, with some studies strongly

supporting this technique and others showing no benefit.⁴³⁻⁵⁰ Regardless of the research, many dentists have used the technique with generally good success.

RMGI LINERS

Resin modified glass ionomer (RMGI) liners represent an alternative and, in this author’s opinion, possibly better option to flowable composite liners.⁵¹ With this technique a RMGI liner^u is placed on the dentin in a thin layer *prior* to placing a dentin bonding agent and composite restorative. RMGI liners have several potential advantages over flowable composites. RMGI liners have the intrinsic ability to both micromechanically and chemically interact with dentin.⁵² They are simple to mix and place, release high sustained levels of fluoride,⁵³ have significant antimicrobial properties,^{54,55} evidence very low solubility,^{56,57} and exhibit a favorable modulus of elasticity and coefficient of thermal expansion and contraction similar to that of dentin.⁵⁸ One of the most important characteristics of liners in regard to direct composites may be their potential to act as stress-absorbing “buffers” during polymerization shrinkage of the composite restorative. Both flowable composite and RMGI liners have a low modulus of elasticity and the ability to deform and/or flex to a degree when subjected to an external force. This characteristic is thought to attenuate shrinkage stress from the subsequently placed higher modulus composite restorative although, in the case of flowable composites, at least one study showed this to be product specific.⁵⁹ Another study showed that when MOD composite restorations were placed in cavities lined with either a flowable composite^v or a RMGI liner^w that the RMGI group had significantly less cuspal deformation due to polymerization shrinkage.⁶⁰ This could be because the modulus of a RMGI is less than a flowable, therefore more flexible, and/or the fact that RMGI liners undergo hygroscopic expansion once polymerized, which may compensate for some of the polymerization shrinkage.^{61,62} In addition, the success of a flowable composite’s bond to dentin is highly contingent on the operator’s ability to first correctly place a dentin bonding agent. A RMGI liner is placed prior to placing a dentin bonding agent, making it much less technique sensitive in this regard. Many clinicians have anecdotally reported a significant reduction in postoperative sensitivity after switching to RMGI liners.^{62,63} The author considers that the utilization of RMGI liners is also the simplest and most predictable method for managing microleakage/nanoleakage under direct composites. The literature is replete with both in vivo and in vitro studies supporting this belief.⁶⁴⁻⁷⁶ Many of these studies directly compare the use of flowable liners vs. RMGI liners in terms of controlling microleakage. The author has been unable to find any study where flowable composites, in conjunction with a dentin bonding agent, outperform RMGI liners in this regard.

^o I-Bond™, Heraeus Kulzer, Armonk, NY

^p G-Bond™, GC America, Inc., Alsip, IL

^q Xeno® IV, DENSPLY Caulk Milford, DE

^r Clearfil® S3 Bond, Kuraray America, Inc., New York, NY

^s OptiBond® All-In-One, Kerr Corporation, Orange, CA

^t All-Bond 3™, BISCO, Inc., Schaumburg, IL

^u Vitrebond™ Plus, 3M™ ESPE™, St. Paul, MN

^v Revolution®, Kerr Corporation, Orange, CA

^w Vitrebond™, 3M™ ESPE™, St. Paul, MN



FIGURE 1 Preoperative view. The pre-existing restoration failed due to recurrent decay.



FIGURE 2 Fairly extensive decay was removed and the preparation cleaned with a wet pumice mixture on a brush, after which the preparation was washed and briefly air-dried.



FIGURE 3 A thin layer of the RMGI liner was dispensed, mixed, and placed with an applicator, after which it was light-cured for 20 seconds. A sectional matrix, wedge, and ring were also placed.



FIGURE 4 Virtually all of the exposed dentin was covered with a thin layer of the RMGI liner, and a bevel of approximately 45° was placed on the enamel margins.



FIGURES 5 AND 6 Phosphoric acid was placed on all enamel margins for 10 seconds and then flowed into the preparation for another 10 seconds. The acid was thoroughly washed out and the preparation briefly dried. “Wet” bonding was not a significant issue because most of the dentin was already covered with the RMGI liner.



DON'T FORGET THE SMALL DETAILS—WHICH REALLY AREN'T THAT SMALL

- **Check the expiration date!** Dentin bonding agents utilize chemistries that can deteriorate significantly over time. Refrigeration may improve shelf-life, but the dentin bonding agent should be removed from the refrigerator 30 minutes prior to use because some may not perform as well when cold.⁷⁷
- **Make sure to evaporate the solvents.** All adhesive systems employ acetone, ethanol, water, or a combination of these as solvents for their particular monomers. It is very important to evaporate these solvents by air-drying for an adequate period of time prior to polymerization. Inadequate solvent evaporation results in incomplete resin polymerization and can contribute to leakage and breakdown of the adhesive interface.⁷⁸
- **Periodically check the bonding light.** Light tips may become scratched or damaged, bulbs can lose intensity, and filters can crack. All of these can significantly reduce energy output. It is sound policy to regularly test the energy output of bonding lights with a radiometer.
- **If all else fails, read the directions.** Every adhesive system, even those in the same generation, has specific placement idiosyncrasies that must be precisely followed for optimal results. What works well for one system may not be applicable for another system.

The author's personal preference in the placement of direct composites is to utilize a two-step total-etch system^d in conjunction with a RMGI liner^u. The entire issue of wet bonding becomes less of a concern with this technique because a significant portion of

the exposed dentin is covered by the RMGI liner prior to placing the phosphoric acid and resin primer.

The clinical technique is described below:

1. After the preparation is complete, clean the dentin and enamel surfaces with slurry of fine pumice and water using pumice^x on a small brush^y (Figures 1 and 2). The use of an antimicrobial solution is not recommended because in-house corporate studies have shown some of these solutions can have an adverse effect on the adhesion of the RMGI, which will be placed next.⁷⁹ In any case, the RMGI to be placed is antimicrobial.



FIGURE 7 Several coats of a dentin-bonding agent were applied. It is very important to evaporate the solvent carriers prior to polymerization.

^x Preppies™, Ultradent Products, Inc., South Jordan, UT

^y ICB® brush, Ultradent Products, Inc., South Jordan, UT



FIGURE 8 The author utilized a horizontal placement technique for the dentin increments. A2 Body shade composite was utilized for the dentin increments.



FIGURE 9 A lateral placement technique was utilized for enamel increments. The first increment was pulled toward the buccal margin, smoothed, and light polymerized. A1 Enamel shade composite was used for the enamel increments.



FIGURE 10 The next enamel increment was added and pulled laterally toward the lingual margin, smoothed, and light polymerized.

2. Wash thoroughly with an air/water spray; quickly air dry.
3. Mix and place a thin layer of the RMGI liner^u. Note: the author generally covers most of the exposed dentin up to the dentoenamel junction (Figures 3 and 4). Light polymerize for 20 seconds. When placing a RMGI line in this manner, the principle of “wet” bonding using a total-etch system is no longer a major factor because most of the dentin has already been covered by the RMGI.
4. Place phosphoric acid on all enamel margins for 10 seconds; fill the entire preparation with phosphoric acid for another 10 seconds (Figures 5 and 6). Wash thoroughly with air/water spray. Briefly air dry. Blot drying is not required if most of the dentin has been covered by the RMGI.
5. Place several liberal coats of a two-step total-etch system^d (Figure 7) and air-dry for a minimum of 10 seconds. Light cure for 10 seconds.
6. Place a nano-filled composite^z utilizing a horizontal placement technique for the dentin increments and a lateral placement technique for the enamel increments (Figures 9 and 10). Cure each increment for 10 seconds.
7. Finish and polish the completed restoration (Figures 11 and 12).

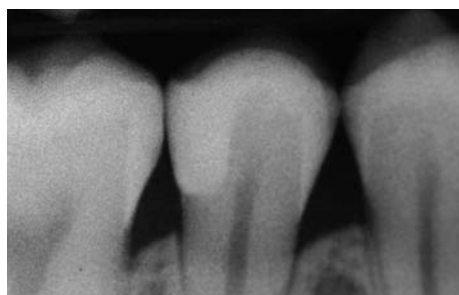


FIGURE 11 Postoperative radiograph demonstrating proper gingival embrasure form and what appears to be a well-integrated and homogenous restoration.



FIGURE 12 Immediate post-placement view of the case. Extra-thin finishing disks are essential for proper interproximal finishing and polishing.

CONCLUSION

Proper management of the adhesive interface is crucial for the predictable placement of direct composites. This requires an understanding of the materials being utilized, the substrate being bonded to, and a correct and precise clinical protocol. It is up to clinicians to objectively examine their own clinical techniques, as well as successes and failures, in order to determine if a change in materials and/or protocol is warranted.

^z Filtek™ Supreme Plus, 3M™ ESPE™, St. Paul, MN

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