Continuing Education 1

Is Total-Etch Dead? Evidence Suggests Otherwise

Gary Alex, DMD

LEARNING OBJECTIVES

- discuss the current state of total-etch adhesive systems and their place in dentistry today
- explain the process of developing a successful adhesive interface
- explain why newer, simplified adhesive systems might compromise long-term clinical effectiveness

ABSTRACT

Both the total-etch and self-etching systems of today have the potential to provide durable adhesive interface, and despite the proclamations of some, total-etch is alive and well. Indeed, evidence indicates that a viable and growing market remains for total-etch adhesive systems. This paper will discuss the origins, evolution, and idiosyncrasies of the total-etch technique as well as its place in dentistry today. New innovations, the use of antimicrobials to inhibit matrix metalloproteinases (MMPs), and sensitivity issues will also be discussed.

[redacted]

Dental clinicians today must be extremely knowledgeable and proficient in adhesive dentistry. In fact, the placement and predictability of many current restorative procedures is wholly predicated on the ability of dentists to bond or "stick" various materials to the tooth tissues. Dentin adhesive systems have progressed from the largely ineffective systems of the 1970s and early 1980s to the relatively successful total-etch and self-etching systems of today. Although self-etching systems have increased in popularity over the past few years, the total-etch systems of some 30 years ago still set the standard in terms of versatility and long-term predictability.[1] Indeed, total-etch systems still offer certain advantages over their self-etching cousins. This article examines the state of total-etch adhesive systems and their place in dentistry today.

THE SMEAR LAYER

In the past 30 years, a major evolution has occurred in the development and efficacy of dentin adhesive systems and their chemistries. The few available adhesive systems of the 1970s and early 1980s were relatively hydrophobic in nature and unable to adequately penetrate the dentin smear layer. The smear layer is the residue that is left on the surface of the dentin after rotary instrumentation with diamond and carbide burs (Figure 1). It is a thin amorphous layer largely composed of degraded collagen, bacteria, and various inorganic dentin and enamel debris.[2,3]

Early dentin adhesive systems were extremely limited and generally ineffective, in part because they bonded directly to the smear layer and were thus limited by its low intrinsic cohesive strength.[4] In this sense, the smear layer can be viewed as a surface contaminant inhibiting the direct interaction of adhesive agents and the dentin beneath it. At some point it was recognized that the smear layer needed to be removed or modified and bypassed in some fashion, so that adhesive primers and resins could interact directly with the dentin. In the case of total-etch adhesive systems, the smear layer is essentially dissolved with phosphoric acid (H_3PO_4) and subsequently washed away during the rinsing step, exposing the underlying dentin (Figure 2 and Figure 3).

With self-etching systems, various acidic primers are used to modify, disrupt, and/or solubilize the smear layer and, although the remnants are not washed away as with total-etch systems, still permit direct adhesive interaction with the dentin substrate. It is interesting to note that the general concept of smear layer removal and/or modification was elucidated well before the routine use of dentin bonding agents and the placement of composite restorations. In the 1970s, Brännström, demonstrating extraordinary insight, advocated using a mild ethylenediaminetetraacetic solution to remove the dentin smear layer before the placement of amalgam restorations. He further recognized the importance of sealing the dentin after the smear layer was removed (which is exactly what is done today) and used a combination of shellac and polystyrene polymers as a seal and protective liner after smear layer removal.[5]

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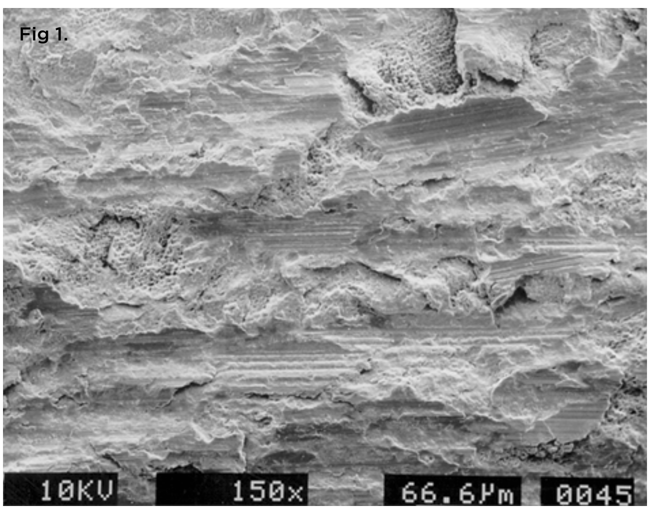
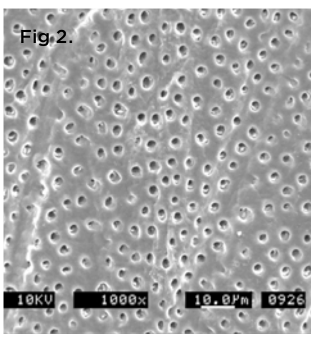
DEMINERALIZATION

The acids and/or acidic primers and conditioners used with either total- or self-etching bonding systems do not just remove and/or disrupt the smear layer, but create a thin zone of demineralization that is either subsequently





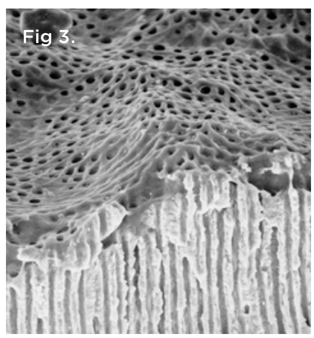


Fig 1. Typical "peanut butter spread on toast" appearance of dentin smear layer. (SEM courtesy of Jenny Wang.) **Fig 2.** Treatment of dentin with phosphoric acid (37% for 15 seconds) removes the smear layer, causes a superficial demineralization of the intertubular dentin, and exposes and opens dentin tubules. (SEM courtesy of Jenny Wang.) **Fig 3.** Cross-section view of Fig 2.

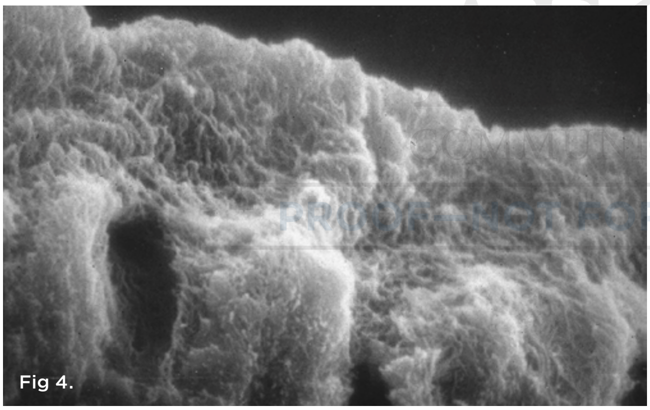
(total-etch) or concurrently (self-etch) infiltrated with various bifunctional primers and resins (Figure 4). In the case of dentin, acid exposure removes or modifies the smear layer, raises surface energy, opens and exposes dentin tubules to varying degrees, and results in dissolution of the inorganic 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 (Figure 5). It is this friable "collagen network" that must be infiltrated by subsequently placed primers and resins to ensure good bonding.[6] The degree and depth of demineralization, as well as the degree of tubule exposure and opening, is contingent on the type of acid used, its concentration, and the application time. It is this demineralized zone that must be infiltrated as completely and thoroughly as possible to ensure predictable bonding.

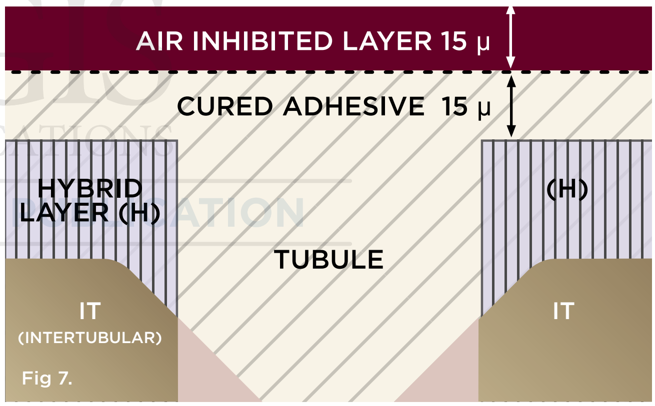
THE HYBRID LAYER

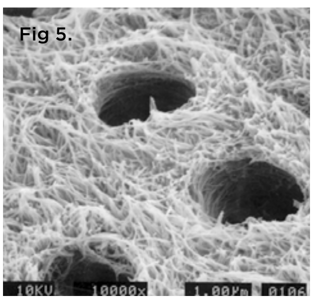
One of the goals in developing a successful adhesive interface is infiltration and penetration into acid-demineralized dentin with various primers and/or resins that can be subsequently polymerized by light and/or chemical curing mechanisms. It is this thin layer of resin-infiltrated dentin, first described in a classic 1982 article by Nakabayashi and colleagues,[7] that is called the hybrid layer. This layer is neither dentin nor resin but a mixture, or hybrid, of the two.

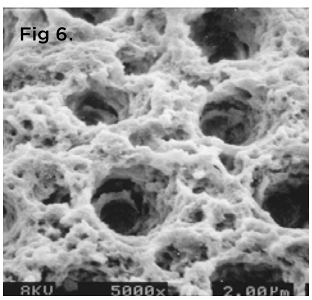
It is often erroneously assumed that the thicker the hybrid layer, the better. In fact, the hybrid layer, which in the case of total-etch is largely resin-encapsulated collagen, is of little quantitative benefit in terms of bond strength regardless of thickness.[8,9] Good hybrid layer formation is simply indicative of thorough resin infiltration through the demineralized zone and engagement of basically intact dentin that has not (or has minimally) been affected by acidic pretreatment and is still mineralized to some degree. In this sense, the goal of effective hybridization is complete and thorough penetration through the demineralized zone, whatever its thickness, and engagement of the underlying and still mineralized dentin (Figure 6).

In addition to penetrating acid-demineralized dentin, primers and resins typically penetrate open dentin tubules, forming resin tags of varying length and quality depending on the particular









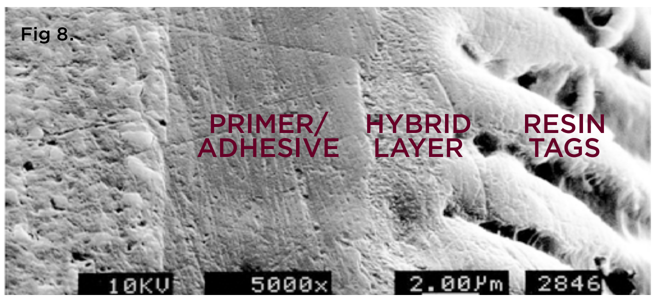


Fig 4. Cross-section of a superficial zone of dentin demineralization after acidic treatment with phosphoric acid; note the exposed collagen fibers. (SEM courtesy of Dr. John Gwinnett.) **Fig 5.** Superior view of exposed collagen fibers after demineralization with phosphoric acid; dentin has been left moist. Primers and resins should completely penetrate collagen fibers. (SEM courtesy of Dr. Franklin Tay.) **Fig 6.** Exposed collagen fibers have been removed with collagenase enzymes, exposing still mineralized dentin. (SEM courtesy of Dr. John Gwinnett.) **Fig 7.** Illustration depicting resin infiltration of collagen forming the hybrid layer. (Illustration courtesy of Dr. Byoung Suh.) **Fig 8.** Hybrid layer forms the foundation of the adhesive interface and is the first link in a series of links that form a bonded assembly between the tooth tissues and restorative material. (SEM courtesy of Dr. John Gwinnett.)

adhesive system. Although micromechanical resin infiltration and entanglement appears to be the primary attachment mechanism to dentin, strong evidence suggests that certain monomers (such as 10-MDP) chemically interact with dentin as well.[10,11] The hybrid layer and associated resin tags form a thin polymerized micromechanically and, in some cases, chemically attached resinous surface layer that acts as the foundation for subsequently placed chemically compatible restorative materials and resin-based cements (Figure 7 and Figure 8).

ORIGINS AND EVOLUTION OF TOTAL-ETCH

In 1955, Buonocore introduced a revolutionary technique for bonding acrylic resins to enamel surfaces.[12] He found that by treating enamel surfaces with phosphoric acid, the subsequently placed restorative resins adhered more durably to the tooth structure. The elucidation of this interaction by Gwinnett and Buonocore[13] was the first step in the modern adhesive story. Subsequent research, clinical observation, and anecdotal evidence have established the long-term reliability of the bond to phosphoric acid-etched enamel surfaces.

While phosphoric acid treatment of enamel was eventually accepted, its use as a dentin conditioner (total-etch) would prove to be far more challenging and controversial. The concept of total-etch, in which both enamel and dentin surfaces are conditioned with phosphoric acid that is subsequently rinsed off, was not an American innovation. It started earlier in Japan with Dr. Takao Fusayama who developed, taught, and published total-etch concepts and protocols in the late 1970s.[14,15] His protégée, Dr. Ray Bertolotti, subsequently introduced these concepts to rather skeptical American dentists in the mid-1980s. The total-etch "torch" was then passed on to Dr. John Kanca who, in 1988, gave an impassioned, and what would prove to be momentous, lecture on a controversial total-etch protocol he developed that combined products from different manufacturers.[16,17] Many in the dental profession were critical of both Kanca and Bertolotti and their "radical" ideas regarding total-etch. As it turned out, Kanca's total-etch protocol would prove to work better than anything else available at the time.

Byoung Suh, PhD, chemist and founder of Bisco, Inc., then developed and marketed one of the first complete adhesive systems specifically designed to be used in a total-etch capacity. This groundbreaking product was a three-step total-etch system (4th generation) (ALL-BOND®, subsequently called ALL-BOND 2®, Bisco, Inc., www.bisco.com), and it quickly dominated the adhesive marketplace. This success in turn led to the development of two competitive three-step total-etch systems, Scotchbond™ Multi-Purpose (later called Scotchbond™ Multi-Purpose Plus) (3M ESPE, www.3MESPE.com) and Optibond® (subsequently called Optibond® FL) (Kerr Corporation, www.kerrdental.com). All three systems, which are still available today, proved to be highly successful and helped pave the way for the "cosmetic revolution in dentistry" by enabling dentists for the first time to bond restorative materials predictably to both dentin and enamel substrates.

The basic protocol when using three-step total-etch systems is the sequential placement of the three primary components (ie, etchant, primer, and bonding resin). These components are typically packaged in separate containers and applied sequentially. Typically, phosphoric acid is placed on enamel and dentin and rinsed off, a hydrophilic primer is then placed, followed by placement of a separate relatively hydrophobic bonding resin. In the author's opinion, while recognizing that other generations of adhesive systems have been clinically successful, the 4th generation three-step total-etch systems developed some 30 years ago are still among the most chemically sound, versatile, and clinically proven adhesive systems available.

Long-term clinical studies confirm the potential effectiveness of 4th generation total-etch systems.[18] Interestingly, Van Landuyt and colleagues recently researched the initial and 6-month water storage bond-strength values of five of the latest 6th and 7th generation self-etching adhesive systems and one of the older 4th generation three-step total-etch systems.[19] The researchers found that all of the latest self-etching systems tested showed significantly decreased bond strength values to dentin after water storage. The three-step total-etch samples not only had the highest initial bond strength values, but these values were stable over the 6-month water storage timeframe. Indeed, the authors of the study concluded that "the decrease in bond strength to dentin may become problematic, especially with one-step adhesives (7th generation), whose immediate bond strengths were already low."[19]

It is important for dentists to understand that although simplified systems are indeed easier and more convenient to use, there may be a trade-off in long-term clinical effectiveness with some systems. Interestingly, at least one manufacturer has gone full circle and, despite selling both a 5th and 6th generation system, recently introduced a new 4th generation system that is basically a modification of a successful total-etch system of some 30 years ago.[20] This system is specifically designed to be more hydrophobic than its predecessor to discourage water sorption and hydrolysis, which can contribute to the degradation of the adhesive interface over time. Also interesting to note is the manufacturer of a 7th generation one-step self-etching system that was introduced just a few years ago with much fanfare and promotion found the need to recently develop and market a total-etch version of that same product. Additionally, a promising new adhesive introduced in 2011 by another leading manufacturer

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is being marketed as a self-etch, selective-etch (only the enamel is etched with phosphoric acid), or total-etch system, depending on the clinician's preference. Several other total-etch systems have been introduced over the past few years. All this indicates there is still a viable and growing market for total-etch systems.

ATTEMPTS AT SIMPLIFICATION

Despite the profound success of 4th generation three-step total-etch systems, some users found them to be complex and time-consuming. One study showed that 25% of dentists using a relatively simple three-step system were using it incorrectly.[21] Although this study may say more about the dentists than the adhesive system, attempts at simplification eventually led to the development of two-step total-etch systems (5th generation). As a group, these are among the most popular systems currently used in dentistry. They have generally proven to be effective, simpler, and faster than their multiple-component predecessors. On the down side, many systems in this category, albeit with some notable exceptions depending on the pH of the primer/adhesive, are not as predictable as three-step total-etch systems when it comes to bonding to self- and dual-cure composites.[22] In addition, the two-step total-etch systems may be more susceptible to water sorption over time than three-step total-etch systems.[23] This is because the polymerized primer of the two-step systems tends to be somewhat 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.[24]

In principle, the "ideal" adhesive system would be one that is hydrophilic when first placed to interact with dentin, which has an inherently high water content, but then become completely hydrophobic once polymerized to discourage water sorption and hydrolysis. Unfortunately, no such chemistry currently exists. One could argue the next best choice would be a graduation from hydrophilic to hydrophobic while moving from the tooth tissues to the interface with the restorative material. This is basically the strategy used by the 4th and many 6th generation adhesive systems, which involve the placement of hydrophilic primers that are then overlaid with more hydrophobic resins.

TOTAL-ETCH IDIOSYNCRASIES

The Achilles' heel of both 4th and 5th generation total-etch systems is that most laboratory studies show their efficacy to be somewhat contingent on the hydration state of the dentin. This appears to be more of an issue with acetone-based systems than with alcohol- or water-based systems but is generally applicable to all total-etch adhesives.[25] An understanding of the concept of "wet bonding"[26,27] is required to optimize the performance of total-etch systems. "Moist bonding" would actually be a more

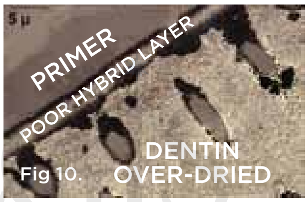

Fig 9. Appropriate degree of surface moisture after acid-etching and rinsing, prior to primer placement when using a total-etch system. Note no puddles of water, yet dentin is visibly moist. **Fig 10.** Purposely over-dried dentin after etching step; hybrid zone formed after primer placement and polymerization is of inferior quality. (SEM courtesy of Dr. Franklin Tay.) **Fig 11.** Same bonding system as shown in Fig 10. Here the dentin surface was left moist after acid-etching and before primer placement and polymerization; hybrid layer is well-formed and has penetrated demineralized zone. (SEM courtesy of Dr. Franklin Tay.) **Fig 12.** Excess water blotted out with a cotton pellet to avoid over-drying.

appropriate clinical description of how the dentin surface should look before placing total-etch primers (Figure 9). As previously mentioned, dentin exposed to phosphoric acid results in dissolution of the inorganic hydroxyapatite matrix. As the matrix dissolves, collagen fibrils become exposed because they are no longer supported and surrounded by their inorganic hydroxyapatite scaffolding.[28,29] Air-drying of acid-etched dentin causes the collapse of these exposed collagen fibers resulting in an amorphous, gelatinous appearing, matted-down mass of collagen that has the potential to interfere with subsequent primer/resin infiltration (Figure 10). In dentin that is left moist after phosphoric acid conditioning, the collagen fibers generally do not collapse, and this "open" collagen network appears to be more permeable to subsequently placed primers and resins (Figure 11).

"Indeed, one of the most interesting and potentially important areas in adhesive research today concerns the use of antimicrobial solutions that inhibit matrix metalloproteinases (MMPs)."

Clinically, one way to achieve the appropriate degree of moisture is to simply not dry at all after rinsing off the phosphoric acid but to simply blot the preparation dry with a cotton pellet (Figure 12) or, in the case of porcelain veneer preparations, simply blot with the end of a cotton roll. Another alternative is to re-wet the dentin after the phosphoric acid has been washed off and the tooth dried. This essentially rehydrates and re-expands collagen that may have collapsed during the air-drying step. Kanca and Alex showed that rehydration of dentin, at least with one popular 5th generation total-etch system and the three rewetting solutions tested, was a time-dependant phenomenon. They found a direct correlation between the length of time the rewetting solutions were in contact with dentin that had been air-dried and shear bond strength values (longer contact times improved bond strength).[30] They speculated that this was probably because the re-expansion of collapsed collagen when rehydrated is not instantaneous but requires a certain degree of time.

MMP INHIBITION: THE NEXT ADHESIVE PARADIGM?

Although some clinicians might consider the rehydration of dentin when using total-etch protocols to be an extra step and waste of time, it could be of significant clinical benefit when using either total- or self-etch systems. Indeed, one of the most interesting and potentially important areas in adhesive research today concerns the use of antimicrobial solutions that inhibit matrix metalloproteinases (MMPs).[31-36] MMPs are zinc-dependent proteolytic enzymes that are capable of degrading the organic matrix of dentin after demineralization with acids. Essentially, MMPs can be thought of as "collagen eaters" and may play a significant role in the degradation of the hybrid layer produced by both total- and self-etch systems.

Breakdown of the hybrid layer may be one of the primary reasons for the ultimate failure of many bonded restorations over time, and it makes sense to attenuate this degradation if possible. Studies show that the application of chlorhexidine or benzalkonium chloride solutions before or in conjunction with the placement of both total- and self-etch adhesives has the potential to inhibit MMP activity, resulting in a more durable adhesive interface.[31,33,35,36] One particularly significant in vivo study examined occlusal composite restorations placed in premolars with a 5th generation total-etch system.[32] Eight teeth in the experimental group were re-wet with a 2% chlorhexidine solution for 30 seconds after etching, washing, and briefly air-drying. Eight teeth in the control group were treated similarly, except chlorhexidine was not applied. The teeth were extracted for orthodontic purposes after 12 months in situ. The authors found that experimental samples in which the dentin was re-wet with the 2% chlorhexidine solution after etching had virtually no degradation of the hybrid layer, while the control samples all demonstrated significant hybrid layer breakdown. One potential fault in this study is that, according to the protocol described, the control samples were "briefly air-dried" after acid-etching while the experimental group was blot-dried after chlorhexidine rewetting "leaving the dentin surface visibly moist." In the author's opinion, it would have made sense to have also blot-dried the control samples (rather than briefly air-dry) so that the initial hydration state of the dentin would have been the same in both groups. In this way, the chlorhexidine would have been isolated as the only variable.

In any case, based on this and other studies,[37,38] the author's current technique when using a rewetting protocol for total-etch systems is the placement of a 2% chlorhexidine solution after the etching step. The solution is allowed to dwell for 30 seconds and then blot-dried, then the primer/adhesive is placed and polymerized. Even clinicians using self-etching systems may benefit by the use of MMP inhibitors that are directly incorporated into the chemistry of the primers[39] or from cleaning and disinfecting the tooth tissues with MMP inhibitors before the use of self-etch adhesives. More research is needed regarding the use of MMP inhibitors in conjunction with self-etching adhesive systems so that specific and scientifically generated protocols can be recommended.

Caution is urged whenever a new chemistry such as chlorhexidine is introduced into the bonding protocol, because the potential exists to adversely affect the bonding characteristics of the subsequently placed dentin primers and adhesives. Clinicians should not just assume that any antimicrobial/rewetting solution can be used with impunity with any adhesive system. In the case of chlorhexidine, there are numerous studies that specifically examined the effect that chlorhexidine, placed at different times in the bonding protocol, had on the bond strength to dentin for both total- and self-etch adhesive systems. Virtually all of the recent studies the author came across found that chlorhexidine did not negatively influence the bond-strength values of the adhesive systems tested.[31,33,40-44] In the case of self-etching resin cements, one study did find a 2% chlorhexidine solution applied to dentin before the placement of the two self-etch resin luting cements tested did have a detrimental effect on bond strength, while the total-etch resin cement system also tested was not adversely affected.[33]

Interestingly, some manufacturers are now incorporating antimicrobials directly into the chemistry of their adhesives. It is possible that some of these antimicrobials will also be shown to inhibit MMPs. During the 1990s, a phosphoric acid gel conditioner was developed that incorporated benzalkonium chloride (BAC) directly into its formulation (UNI-ETCH®, Bisco, Inc.). Studies showed that even after rinsing this etching gel off the tooth tissues, residual BAC remained bound to the collagen and continued to have an antimicrobial effect.[45] Although the BAC in this product was specifically added for its antimicrobial characteristics (personal communication with Byoung Suh, PhD, 2010), a serendipitous benefit turned out to be the potential for this same product to inhibit MMP activity.[34] It is likely that in the future antimicrobials and MMP inhibitors will be incorporated, either directly or indirectly, into adhesive, conditioner, and restorative formulations and protocols. More research is needed regarding MMPs, both to ascertain their true clinical significance and to develop specific, practical, and scientifically driven protocols for both total- and self-etch systems.

Another area of current and potentially very important research involves the use of hydrophobic ethanol/resin solutions that are being used to replace water from the internal compartments of collagen fibrils through an "ethanol wet-bonding" technique. This approach has the potential to significantly improve the longevity of resin–dentin bonds created by total-etch adhesives.[46-48]

RMGI LINERS: STILL A GOOD CHOICE

One way to eliminate the ambiguity some practitioners have with the wet-bonding protocol when employing a total-etch system is to use a technique that eliminates or minimizes the significance of wet-bonding. This can be accomplished by using a resin-modified glass-ionomer (RMGI) liner that covers exposed dentin. Basically, the RMGI liner is placed on as much of the exposed dentin as possible in a thin layer before the etching step (Figure 13 through Figure 16). If most or all of the dentin is covered by the RMGI liner before etching, wet-bonding becomes a non-issue. This is because no demineralization of the dentin will have taken place and, hence, there is no exposed collagen to collapse on air-drying.

After the liner is placed the tooth can be etched, rinsed, briefly dried, and primers and adhesives placed as in the usual bonding protocol. The author recommends ringing the enamel of the preparation for 15 seconds with phosphoric acid and then running the acid into the rest of the preparation, including covering the RMGI liner, for approximately another 10 seconds (Figure 17 through Figure 21). The surface of the RMGI liner is not adversely affected by exposure to phosphoric acid in clinically relevant concentrations and etching times (personal communication with Sumita Mitra, PhD, corporate scientist [retired], 3M ESPE, 2003). RMGI liners have many positive attributes and it is the author's opinion that they offer one of the most effective ways of curtailing microleakage, which is still a significant problem regardless of the adhesive system used. A plethora of research supports the effectiveness of RMGI liners in minimizing microleakage.[49-59] In addition, RMGI liners have the intrinsic ability to both micromechanically and chemically interact with dentin.[60] They are simple to mix and place, release high-sustained levels of fluoride,[61] and have significant antimicrobial properties[62,63] and evidence of very low solubility.[64,65] They also exhibit a favorable modulus of elasticity and coefficient of thermal expansion and contraction similar to that of dentin.[66] It would be interesting to determine if RMGI liners also have the ability to inhibit MMP activity.

Clinicians who are dealing with postoperative sensitivity issues would particularly benefit from the proper use of RMGI liners, as they can virtually eliminate this problem. A detailed rationale and

Fig 13. Deep cavity preparation is a good indication for the use of an RMGI liner. **Fig 14.** Placed in a thin layer, RMGI liner covers most of the exposed dentin, including the walls of the preparation. **Fig 15.** RMGI liner is light-polymerized for 20 seconds. **Fig 16.** View of polymerized RMGI liner.

methodology describing the technique for use of RMGI liners under direct composite restorations is presented in the literature.[6,67]

QUICKER IS NOT NECESSARILY BETTER

With 7th generation one-bottle self-etching systems (which appear to be growing in popularity) all of the ingredients required for bonding are placed in and delivered from a single bottle. While this certainly simplifies the bonding protocol and definitely saves time, this author believes the price for simplification is almost certainly compromise, especially over time. For one thing, incorporating and placing all of the chemistry required for a viable self-etching adhesive system into a single bottle, and having it remain stable for a reasonable period of time, poses a significant challenge. These inherently acidic systems contain a significant amount of water in their formulations, making them prone to hydrolysis and chemical breakdown.[68,69] This problem is exacerbated if these one-bottle formulations are challenged by heat, which can occur while the product is in transit or stored in offices where temperature is not regulated. While refrigeration may help in this regard, the potential for degradation of the chemistry in these systems is significant.

In addition, once placed and polymerized, 7th generation one-bottle primer/adhesives are significantly more hydrophilic than their 4th, 5th, and 6th generation counterparts. This makes them more prone to water sorption over time,[70] which could contribute to hydrolysis and degradation of the adhesive interface[71] as well as a reduction in mechanical properties of any composite restorative subsequently placed.[72] The acidic nature of the polymerized primers of 7th generation adhesives also makes them unsuitable for use with self- and dual-cure materials since acids degrade the tertiary aromatic amines required for chemical polymerization.[73] Over the years, the author has communicated with dozens of well-respected researchers and chemists as well as attended numerous adhesion/material sessions at International Association for Dental Research and American Association for Dental Research meetings, and the clear consensus is that 7th generation adhesive systems, at least at this point, are not as predictable as earlier 4th, 5th, and 6th generation systems. Although there are some recently introduced 7th generation systems that show promise, it is this author's opinion that despite offering ease and simplicity 7th generation adhesive systems for now should be used very selectively, if at all, until improvements are made and independent research clearly demonstrates short- and, more importantly, long-term clinical effectiveness.

TOTAL-ETCH IS DEAD?

There are those who believe total-etch is now obsolete; however, evidence suggests otherwise. Several years ago, a group of academicians, adhesive researchers, and opinion leaders attending an adhesive dentistry symposium sponsored by a major dental manufacturer were asked the following question: "If you were


Fig 17.


Fig 18.


Fig 19.


Fig 20.


Fig 21.

Fig 17 through Fig 21. Phosphoric acid (30% to 40%) is ringed on the enamel first for 15 seconds and then run into the tooth for approximately another 10 seconds. It is then washed out, the tooth is briefly dried, and the restoration is finished using primers and adhesives.

[redacted]

lecturing to a group of 100 dentists and had to recommend an adhesive system for direct composite restorations, what would it be (one answer only)?"[74] Of the 20 responses to this question, 7 recommended 4th generation total-etch systems; 11 recommended 5th generation total-etch systems; 2 recommended 6th generation self-etching systems; and zero recommended 7th generation self-etching systems.

These numbers were remarkably similar to a poll of 63 opinion leaders and researchers responding to the same question at an adhesive symposium held 2 years earlier.[75] In that poll, the breakdown was as follows: 25 recommended 4th generation total-etch systems; 28 recommended 5th generation total-etch systems; 8 recommended 6th generation self-etch systems; and 2 recommended 7th generation self-etch systems. It should be noted that the opinions of those actively involved in adhesive research are not always reflected in what is actually being used by dentists "in the trenches," where clearly more self-etching products are being used than is reflected in these polls.

> "Postoperative sensitivity can occur for any number of reasons, including exposure of dentin during finishing, occlusion being left high, poor technique, or contamination at some point in the bonding protocol."

Perhaps of more current relevance is marketing research from December 2010 from 3M ESPE (personal communication with Beth N. Eskra, marketing supervisor – adhesives portfolio, 3M ESPE, 2010). According to this research, adhesive sales for the company's product line (which includes 4th, 5th, 6th, and 7th generation systems) in the first three quarters of 2010 in the United States were 55% for total-etch systems and 45% for self-etch systems. This same representative stated that this ratio has held true for the past few years and that the overall adhesive share for all dental companies researched by Strategic Data Marketing (SDM) in the first half of 2011was 50.1% for total-etch and 49.9% for self-etch.

The point of this is not to impugn the beliefs of those using self-etching systems, some of which have excellent clinical track records[76] and the author recommends, but to underscore that total-etch is alive and thriving. The reason for this is because total-etch works extremely well for those who are experienced in its use.

Total-etch still has certain advantages over self-etching systems. Phosphoric acid in appropriate concentrations and application times clearly etches enamel very predictably. This is in contrast to most self-etching conditioner/primer solutions, which have generally been shown to be inferior in terms of enamel etching abilities.[77-79] In a 36-month clinical study that compared the clinical performance of a popular self-etching 6th generation system with that of a 5th generation total-etch system, researchers found that while both systems performed acceptably, the self-etching system showed a faster and more progressive enamel marginal degradation.[80] In another 5-year clinical study, researchers found that by first etching the enamel with phosphoric acid before use of the same self-etching adhesive system mentioned in the previous study, they were able to improve enamel marginal integrity.[76] These findings have been corroborated in other clinical studies.[81,82]

In fact, a common clinical technique employed by many using self-etching systems is to first etch the enamel with phosphoric acid to ensure adequate bonding to enamel (selective-etch technique). This helps ensure good enamel bond strength; however, it does require an additional step in the bonding protocol. For those using this technique, the author suggests confining the phosphoric acid to the enamel only. Additional etching of the dentin with phosphoric acid could, in principle, create an "over-etch" situation in which the demineralization zone is too deep for subsequently placed self-etching primers to completely penetrate.[83] Interestingly, the manufacturer of a recently introduced 7th generation one-bottle system that has shown short-term clinical promise claims the product's bond strength to dentin is not adversely affected if the dentin is inadvertently etched by a user employing a selective enamel-etching technique.[84]

In addition to bonding more predictably to enamel, total-etch systems have been shown in several studies to bond to sclerotic dentin more effectively than self-etching systems.[85-87] Clinically, it is often difficult for dentists to differentiate between normal and sclerotic dentin, but if the clinician suspects sclerotic dentin one could argue that total-etch adhesives would be the best choice. In the case of porcelain veneers, where there is ideally a significant amount of enamel to bond to, it makes sense to this author to routinely use total-etch systems, which he has done for many years with a high degree of long-term clinical success. There are other instances in which film thickness concerns or chemical compatibility issues with self- and dual-cure resin cements and composites favor the use of total-etch adhesive systems.

Perhaps the biggest reason for the upsurge in the use of self-etching adhesives is the perceived reduction in postoperative sensitivity some have reported after switching from total-etch systems. The reports of less sensitivity, however, are largely anecdotal in nature. In one of the few controlled clinical studies that examined postoperative sensitivity, researchers placed 30 restorations with a popular 6th generation self-etching system and 36 restorations with a 5th generation total-etch system. They found no difference in sensitivity when patients were evaluated immediately after placement, at 2 weeks, at 8 weeks, and at 6 months after placement.[88] Other clinical studies have reported similar results.[89-91] There are no scientific studies the author is aware of that demonstrate total-etch adhesives cause more sensitivity than self-etching systems.

It is difficult to reconcile the results of the few scientific studies that are available with what many dentists have anecdotally reported. One explanation could be that in the clinical studies, where methodology is tightly controlled, it is possible that operators were more meticulous and understanding of the materials and techniques involved. In this regard, self-etching systems may be less technique-sensitive and, hence, leave less chance for an error that might contribute to postoperative sensitivity.

Sometimes postoperative sensitivity has nothing to do with the particular adhesive system used. Postoperative sensitivity can occur for any number of reasons, including exposure of dentin during finishing, occlusion being left high, poor technique, or contamination at some point in the bonding protocol. Frustratingly, postoperative sensitivity sometimes occurs even when dentists do everything exactly correctly, as teeth do not always respond as expected. No system can absolutely guarantee the complete elimination of postoperative sensitivity every time. The best clinicians can do is be knowledgeable and meticulous, practice good technique, understand the idiosyncrasies and nuances of their particular adhesive system, and do their best.

CONCLUSION

Proper management of the adhesive interface is crucial for the predictable placement of many current dental restorative materials. This requires an understanding of the materials being used, the substrate being bonded, and a correct and precise clinical protocol. The bottom line is that it is incumbent on every dentist to learn about his or her specific adhesive system, its idiosyncrasies, its strengths and weaknesses, and how to maximize its performance.

ABOUT THE AUTHOR

Gary Alex, DMD
Private Practice, Huntington, New York

The author dedicates this article to Garrick and Ashleigh, who continue to inspire and amaze him.

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Is Total-Etch Dead? Evidence Suggests Otherwise

Gary Alex, DMD

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PLEASE COMPLETE ANSWER FORM ON PAGE 38, INCLUDING YOUR NAME AND PAYMENT INFORMATION.

1. **Adhesive systems of the 1970s and early 1980s were relatively what in nature and unable to adequately penetrate the dentin smear layer?**
   A. hydrophilic
   B. hydrophobic
   C. water-soluble
   D. demineralizing

2. **The acids and/or acidic primers and conditioners used with either total- or self-etching bonding systems remove and/or disrupt the smear layer and create a thin:**
   A. area of surface energy.
   B. hydroxyapatite matrix.
   C. zone of demineralization.
   D. zone of remineralization.

3. **One of the goals in developing a successful adhesive interface is penetration into acid-demineralized dentin with various what, which can be subsequently polymerized?**
   A. curing mechanisms
   B. primers and/or resins
   C. phosphoric acids
   D. none of the above

4. **The concept of total-etch, in which both enamel and dentin surfaces are conditioned with phosphoric acid that is subsequently rinsed off, was started in:**
   A. Japan.
   B. Korea.
   C. Sweden.
   D. United States.

5. **Although simplified adhesive systems are easier and more convenient to use, there may be a trade-off in:**
   A. short-term performance.
   B. long-term clinical effectiveness.
   C. esthetics.
   D. the ability to release fluoride.

6. **Attempts at simplification eventually led to the development of two-step total-etch systems (5th generation), which as a group are among the:**
   A. most popular systems currently used in dentistry.
   B. most ineffective systems currently used in dentistry.
   C. least popular systems currently used in dentistry.
   D. least successful systems currently used in dentistry.

7. **Most laboratory studies show the efficacy of both 4th and 5th generation total-etch systems to be somewhat contingent on the hydration state of the:**
   A. hybrid layer.
   B. collagen fibrils.
   C. enamel.
   D. dentin.

8. **An understanding of the concept of what is required to optimize the performance of total-etch systems?**
   A. wet bonding
   B. air-drying
   C. dehydration
   D. hydroxyapatite scaffolding

9. **What are zinc-dependent proteolytic enzymes that are capable of degrading the organic matrix of dentin after demineralization with acids?**
   A. benzalkonium chloride (BAC) solutions
   B. matrix metalloproteinases (MMPs)
   C. polymerizable monomers
   D. resin-modified glass-ionomer (RMGI) liners

10. **RMGI liners have the intrinsic ability to both micromechanically and chemically interact with dentin and:**
    A. are simple to mix and place.
    B. release high-sustained levels of fluoride.
    C. have significant antimicrobial properties.
    D. all of the above

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