Bonding systems for restorative materials — a comprehensive review

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Abstract

The acid-etch technique for bonding composite resins to enamel has revolutionized the practice of pediatric restorative dentistry. Although bonding resins to dentin has proved to be a difficult challenge, ongoing advances have improved the reliability and predictability of dentinal adhesion. The purpose of this paper is to review the subject of dentin bonding: its development, current status, and clinical methods to improve performance (Pediatr Dent 20:2 80–84 1998).

Enamel etching

Buonocore reported in 1955 that acid could be used to alter the surface of enamel to "render it more receptive to adhesion."[1] He had discovered that acrylic resin could be bonded to human enamel after conditioning with 85% phosphoric acid. Buonocore accurately predicted several potential uses for this new technique, including Class III and Class V restorations and pit and fissure sealants.

Most present-day enamel etchants contain 30–40% phosphoric acid and produce shear bond strengths of composite resin to enamel of about 20 MPa.[2, 3] Bond strengths in this range provide routinely successful retention and sealing of resins for a variety of clinical applications.

Development of resin/dentin adhesives

Although development of dentin adhesives began in the early 1950s,[4, 5] progress was very slow until recent years. In the early 1960s, Bowen synthesized a "surface-active comonomer" that could theoretically mediate water-resistant chemical bonds of resins to dentinal calcium.[6] However, commercial products based on this comonomer demonstrated very poor clinical performance.[7]

A "second generation" of dentin bonding agents was developed for clinical use during the early 1980s. With the exception of Scotchbond™ Dual-Cure (3M Dental Products Division, St. Paul, MN) and Bondlite® (Kerr Corporation, Glendora, CA), second-generation bonding agents are no longer available. Most of these materials were halophosphorous esters of unfilled resins such as Bis-GMA (bisphenol A-glycidyl methacrylate) or HEMA (hydroxyethyl methacrylate).[8] They bonded to dentin through improved surface wetting and ionic interaction between the phosphate groups and calcium in the dentinal smear layer.[9] These agents had shear dentin bond strengths of only about 1–10 MPa,[9, 10] which was too weak to counteract the polymerization shrinkage of composite resin. Therefore, composite usually separated from dentin, forming marginal gaps that allowed microleakage.[11]

The clinical performance of phosphonate esters used without enamel etching or mechanical retention was relatively poor, with fairly high percentages of cervical restoration loss over 1- to 3-year evaluation periods.[12, 13]

Third-generation adhesives were introduced in the United States during the late 1980s. These systems either modified or removed the smear layer to allow resin penetration into the underlying dentin.[14, 15] Shear dentin bond strengths of agents such as Scotchbond 2 (3M), Gluma (Heraeus Kulcer Dental Products, South Bend, IN), Tenure (Den-Mat Corporation, Santa Maria, CA), Prisma Universal Bond 3 (Dentsply Caulk, Milford, DE), Syntac (Ivoclar Vivadent, Amherst, NY), and XR-Bond (Kerr) were typically greater than those of the second-generation agents. However, their performance was still unpredictable, even in laboratory studies.[15–19]

Although these dentin adhesives were more effective than their predecessors in reducing microleakage at dentin and cementum margins[18, 19] they certainly did not eliminate marginal leakage.[20, 21] Clinically, these systems provided better retention rates and marginal integrity than earlier adhesives.[22, 23]

Fourth-generation dentin adhesives

The next generation of dentin bonding systems appeared in the early 1990s and is still widely used. Most of these systems are based on the "total-etch" technique, or simultaneous etching of enamel and dentin, typically with phosphoric acid. Improvement in dentin bond strengths by etching was first demonstrated by Fusayama in 1979,[24] but the concept of total-etching only recently gained acceptance in the United States.[25] Etching of dentin traditionally was discouraged because data from early studies seemed to indicate that phos-

phoric acid etching of dentin caused pulpal inflammation.[26, 27] However, very little acid actually penetrates dentin, so it seems unlikely that the acid is directly responsible for most pulpal damage.[28] Much evidence now indicates that lack of an adequate marginal seal is the primary cause of pulpal inflammation associated with permanent restorations. Little or no inflammation may occur if restorations are sealed well enough to prevent bacterial invasion of the pulp.[29, 30]

The bonding mechanism of the fourth-generation adhesive systems is a three-step process: (1) condition, (2) prime, and (3) bond. Conditioning (or etching) removes the smear layer, opens the dentinal tubules, increases dentin permeability, and decalcifies the intertubular and peritubular dentin. Removal of hydroxyapatite crystals leaves a collagen meshwork that can collapse and shrink due to the loss of inorganic support.[31]

After the conditioner is rinsed off, a primer consisting of a solvent with one or more hydrophilic resin monomers is applied. Primer molecules contain two functional groups—a hydrophilic group and a hydrophobic group. The hydrophilic group has an affinity for the dentin surface and the hydrophobic (methacrylate) group has an affinity for resin. The primer wets and penetrates the collagen meshwork, raising it almost to its original level. The primer also increases the surface energy, and hence the wettability, of the dentin surface. Unfilled resin is applied and penetrates into the primed dentin, copolymerizing with the primer to form an intermingled layer of collagen and resin commonly called the "hybrid layer".[31-33] Formation of this hybrid layer of dentin and resin, which was first described by Nakabayashi et al. in 1982,[34] is thought to be the primary bonding mechanism of most current adhesive systems.[35]

Several major dental product manufacturers market fourth-generation bonding systems that etch dentin with phosphoric or other acids. Examples include All-Bond 2 (Bisco, Inc., Schaumburg, IL), Amalgambond (Parkell, Farmingdale, NY), Clearfil Liner Bond (Kuraray/J. Morita USA, Inc., Tustin, CA), EBS (ESPE America, Norristown, PA), OptiBond FL (Kerr), ProBond (Dentsply Caulk), and Scotchbond Multi-Purpose Plus (3M). Many investigators have reported shear bond strengths for these materials that approach or exceed the typical enamel bond strength of 20 MPa.[36-38] In addition, microleakage studies indicate that they provide a better marginal seal than earlier generations of adhesives.[39, 40]

Fifth-generation dentin adhesives

Because the three-step bonding systems are perceived by some as being too complicated and time-consuming, many manufacturers have attempted to simplify systems by combining certain steps. The most common method of simplification is combination of the primer

and bonding-agent steps to make "one-bottle adhesives". Numerous one-bottle adhesives are now available, including Prime & Bond 2.1 (Dentsply Caulk), One-Step (Bisco), OptiBond Solo (Kerr), Single Bond (3M), and Tenure Quik with Fluoride (Den-Mat).

The description of these materials as "single-component", "one-bottle", or "one-step" systems is inaccurate. They require conditioning of enamel and dentin prior to application of the primer/adhesive, and most require two or more applications of the latter.

Considering the fact that these materials are promoted as "simplified" systems, bond strengths reported for the one-bottle adhesives have been disconcertingly variable. Some investigators have reported values similar to those of conventional three-step systems while others have reported lower values.[41-44] Much of the variation in bond strengths may be due to technique factors. The acetone-based systems in particular appear to require a dentin surface that is neither too moist nor too dry.[45] Some refinements in both the formulation and clinical techniques for these materials should be expected. However, Prime & Bond (in one version or another) has been used in Europe for more than 3 years with apparent clinical success.

Bond strengths

In this paper, as in much of the dental materials literature, bonding systems have been compared by their shear bond strengths. However, it must be noted that laboratory bond strengths do not directly predict clinical performance. In a typical test, extracted human or bovine teeth are ground flat, an adhesive system is applied, and a composite resin post is bonded to the surface. A loading force is applied to shear or pull the composite from dentin. Laboratory tests generally ignore the effects of polymerization shrinkage, pulpal pressure, dentinal fluid, and tooth flexure. Bond-strength testing is not totally without value, however—as more and more data are generated by various laboratories, a rough rank ordering of adhesives is possible and provides a reasonable basis for predicting clinical performance.

Much less information is available regarding resin bonding to primary teeth than to permanent teeth, but bond strengths to primary teeth may be somewhat lower.[46] However, one study indicated that adhesives could provide bond strengths to primary dentin that were as high or higher than the bond to primary enamel.[47]

A recent study of fourth-generation dentin adhesives (All-Bond 2, Amalgambond, and Scotchbond Multi-Purpose) reported bond strengths to primary dentin between 9.9 to 17.9 MPa, depending on conditions.[48] These values are less than those usually reported for the same systems on permanent dentin. The authors speculated that the smaller dentin thickness of primary teeth

may partially explain this result. With reduced dentin thickness, adhesives generally have lower bond strengths and there is more likelihood of cohesive dentin failure at lower loads.

Clinical factors in dentin bonding

A number of clinical factors affect the longevity of bonded composite restorations. A list of guidelines to help ensure clinical success and longevity follows:

1. Use proper isolation. Hydrophilic bonding systems may tolerate saliva contamination to a certain degree.[49] However, evidence for such tolerance remains minimal and the mechanism is not well understood, so proper isolation using rubber dams or alternative methods is considered essential to clinical success with current adhesive systems.

2. Bond to enamel. Whenever a restoration is bonded to dentin, the adjacent enamel should be etched. Years of experience have proved that enamel etching is a very reliable method of bonding resins to tooth structure. In addition, when bevels are used, they provide a gradual transition of composite material onto the tooth and thus a better esthetic result.

3. Roughen sclerotic dentin. Bonded restorations are more likely to fail when they are bonded to highly sclerotic dentin.[50] Light roughening with a diamond or carbide bur may provide more micromechanical locking between resin and dentin. While not encountered as frequently in pediatric dentistry as in adult restorative dentistry, sclerotic dentin is encountered beneath some carious lesions.

4. Use mechanical retention. With adhesive restorative materials, supplemental mechanical retention (pins, grooves, slots) is frequently not necessary. However, the operator should use mechanical retention in cases where adhesive bonding may not be sufficient to retain or properly seal a restoration.

5. Leave dentin moist after etching. Virtually all present-day dentin adhesives bond to dentin that is at least slightly moist. Systems that contain acetone primers are particularly well suited for bonding to wet surfaces,[36, 45] although the optimum degree of surface moistness varies with specific products. However, as a general rule, dentin should not be desiccated. If dentin is dried excessively to check the enamel etch, it should be remoistened to improve bond strengths.[51]

The "moist bonding" technique is used because desiccation of etched dentin can cause collapse of the unsupported collagen network, inhibiting adequate wetting and penetration by the primer or primer/adhesive. However, the clinician must be aware that pooled moisture should not be allowed to remain on the tooth, as excess water can dilute the material and reduce its effectiveness. A glistening, hydrated surface is the preferred appearance.

6. Apply and dry primers correctly. Dentin primers and fifth-generation primer/adhesives must be applied in adequate quantity. Some materials require multiple coats, and others probably benefit from application of multiple coats or longer application times. Also, solvents must be driven off completely with compressed air before the bonding agent or composite is applied.[52]

7. Do not over-thin the bonding resin. Application of the resin bonding agent is the simplest step in a three-step bonding sequence. However, if the resin is aggressively air-thinned, oxygen inhibition prevents complete polymerization and results in lower bond strengths. Thinning the bonding agent with a dry brush is better than thinning with compressed air blasts.[53] For direct composite restorations, the bonding agent should be light-cured before the restorative material is placed to optimize the bonding system's performance.[54]

8. Use a flexible restorative system. Flexible restorative materials (e.g., microfill composites) and "stress-breaking liners" (filled bonding resins) may improve the marginal quality of bonded restorations by compensating for stresses generated by polymerization shrinkage and tooth flexure.[55, 56]

9. Fill incrementally. All composites shrink during polymerization. One method of reducing overall polymerization shrinkage is to place and cure composite in increments. Although there is now some controversy about whether this technique provides better marginal adaptation,[57, 58] it still seems advisable, and is necessary when composite thickness exceeds 2 mm (to provide for adequate light curing).[59]

10. Delay finishing. The bond strength of resin to enamel and dentin is greater at 24 h than immediately after placement.[60] Some of this improvement in bond strength actually occurs within the first few minutes, so a brief delay in finishing may help to preserve the integrity of delicate margins.

11. "Rebond" margins. The concept of rebonding is based on the assumption that gaps are likely to occur in at least some marginal areas of any direct composite restoration. The margins are re-etched and sealed with special low-viscosity resins such as Fortify (Bisco) or OptiGuard (Kerr).[61]

12. Follow directions. Reputable manufacturers carefully evaluate their bonding materials and develop specific protocols for proper application. Unfortunately, many clinicians fail to follow directions provided by the manufacturer and either intentionally or unintentionally misuse bonding systems. For example, Scotchbond 2, a popular third-generation bonding system, included a dentin primer and dentin/enamel bonding agent. The bonding agent was used without primer only for restorations bonded to enamel with no dentin involvement. Although some enamel-only bonding is done (sealants, most veneers), nearly all restorations involve dentin, so one would expect similar reorder rates for primer and bonding agent. However, 3M found that the reorder rate for bonding agent was approximately seven times higher than for primer, even when corrected for differences in volume of the bottles (J. Fundingsland, 3M, personal communication, 1997). Because the expected ratio of primer:bonding agent usage would be closer to 1:1, the actual reorder ratio suggests that the system was not being correctly used by many clinicians. Similar stories are known elsewhere in the industry, and reflect a worrisome failure of practitioners to read and follow directions.

Conclusion

Advances in adhesive dental technology have radically changed restorative dentistry. The acid-etch technique for enamel bonding led to the development of revolutionary restorative, preventive, and esthetic treatment methods. More recently, developments in resin/dentin bonding have moved adhesive dentistry an even higher level. Many systems are now available to reliably and durably bond resin to dentin. However, these systems must be used properly to optimize their clinical performance.

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