Dentin bonding in perspective

James C. Setcos, DDS,BDSc,MSc

Indiana University, Indianapolis, Indiana, USA.


Abstract: Forming a bond to dentin has been a great challenge. Dentin is a vital tissue composed of organic material and water in addition to the inorganic content. Operative procedures on dentin produce a loosely-bound surface of unorganized material known as the "smear layer". For optimum bonding to occur, this layer needs to be removed or altered. A dentin bonding agent should be biocompatible and should form an instantaneous bond, strong enough to resist the forces of polymerization shrinkage, finishing procedures and thermal expansion and contraction. The bond should be stable and impervious over time. The clinical procedures should be convenient, with minimal "technique sensitivity" and should attain a consistently superior bond. Excitement surrounds the latest generation of dentin bonding agents which now show in vitro bond strengths approaching those of etched enamel. One system utilizes hydrophilic and hydrophobic monomers. Hydroxyethyl methacrylate (HEMA) and maleic acid are used to solubilize the dentin surface before coating it with resin bonding agent. Another system uses a treatment sequence starting with aluminum oxalate as a mordant, followed by a surface active compound such as N-phenylglycine and glycidyl methacrylate in acetone, and then by an acetone solution of PMDM (the adduct of pyromellitic acid dianhydride and 2-hydroxyethyl methacrylate). For some years, a third system has been available in Europe. This system cleanses dentin with ethylene diamine tetraacetic acid (EDTA), then primes it with an aqueous mixture of HEMA and glutaraldehyde (Gluma).

Key words: Composite resins; dental materials; dentin bonding; restorative dentistry.

Reprint requests: Dr. James C. Setcos, Department of Dental Materials, Indiana University School of Dentistry, 1121 W. Michigan St., Indianapolis, IN 46202, USA.

INTRODUCTION

There has been a long and continuous search to achieve a strong, permanent bond to all hard tissues of teeth. Adhesion to enamel has now become a common practice since Buonocore et al. showed that acid-etching of enamel with phosphoric acid solution improved the retention of resin materials. The resin penetrated and polymerized in small surface micropores in the outer 10-40 μm on the etched enamel surface. This resulted in the formation of retentive resin tags. Forming a bond to dentin has been a much greater challenge. Dentin is a vital tissue composed of approximately 50% (by volume) organic material and water, in addition to the inorganic content. Operative procedures on dentin produce a relatively loosely-bound surface of unorganized material known as the "smear layer". For optimum bonding to occur, this layer needs to be removed or altered.

Indications for dentin bonding

The major indications for bonding to dentin include cervical erosion and toothbrush abrasion lesions or where carious destruction results in cavosurface margins in dentin /cementum. Such areas as deep proximal boxes or any areas at the periphery of a restoration would benefit from a tight and impervious bond between the dentin and restorative material. Marginal leakage which can lead to marginal discoloration, pulpal irritation, and secondary caries may be prevented when such a seal is established.

With increasing utilization of esthetic techniques such as porcelain veneers, more cases of margins in dentin are likely to occur. Techniques such as heavy tooth reduction to esthetically "realign" teeth may involve complete reduction of enamel from the tooth in some areas. Furthermore, as the population continues to age, we can also expect more restorative situations involving margins on root surfaces. Reliable dentin bonding is particularly important for all these areas at the periphery of a restoration where little or no enamel is present. The integrity of the entire restoration can be compromised by an area of weak bonding around the margin.

First generation dentin bonding agents

In 1956, Buonocore et al. studied the first generation of "cavity primers" which contained agents such as
glycerophosphoric acid. They used a methacrylate-based dentin adhesive that was capable of bonding to the inorganic phase of dentin, but it yielded rather low bond strengths which were clinically unacceptable. The chemical basis for this resin-dentin adhesive was the interaction of a phosphate group which was attached to the methacrylate, with calcium ions on the dentin surface. With storage in water, the bond strength diminished, possibly due to hydrolysis of the phosphate-calcium bond.

In 1962, Masuhara et al. developed an adhesive system which was designed to facilitate chemical adhesion to collagen. The system used Tri-n-butyl borane (TBB) as a co-catalyst. It was used commercially in Palakav. A few years later, Bowen used surface active N-phenyl glycine glycidyl methacrylate to improve wettability and consequently adhesion properties. This was the basis of Cosmic Bond.

Requirements for effective dentin bonding

In 1961, a national workshop co-chaired by Phillips & Ryge was held at the Indiana University School of Dentistry to encourage research that would develop truly adhesive restorative materials for dentistry. This conference brought together scientists in several disciplines to work towards this common goal.

A consensus of requirements for an adhesive dental material, as covered then, are still eminently valid. It was recognized that strong cross-boundary forces (chemical and physical) depended on good wetting and intimate contact between the surfaces to be bonded. Also, forces which are acting during the application stage need to remain active for a long time. Low contraction forces within the material will contribute to this. The objective is to seek a strong, permanent adhesive bond between the tooth and restorative material and a completely impervious marginal seal especially for cervical C1 V lesions located in dentin. An agent which provides chemical covalent bonding with the tooth would be preferable to one affording ionic or hydrogen bonding.

An effective dentin bonding agent needs to be biocompatible, should resist microleakage and forces placed on the restoration, such as occlusal forces. It should also resist polymerization contraction which can produce microscopic gaps at the tooth-restoration interface. Ideally, there should be a strong and immediate bond to dentin which resists thermal contraction and expansion. This bond should not diminish with time. Hydrolysis probably played a significant role in the failure of the earlier materials.

Second generation dentin bonding agents

The second generation of dentin bonding agents have been referred to as dentin-enamel bonding agents because there was also an increased bond strength to etched enamel. They still had the phosphate-calcium bond as an underlying goal. However, the Bis-GMA molecule was substituted as the methacrylate and an unfilled resin was added to the adhesive. So, many of these agents were halophosphorous esters of Bis-GMA (e.g. Scotchbond, Bondlite, Prisma Universal Bond), while others were based on polyurethane (e.g. Dentin Adhesit). In general, they were much improved over the first generation but still did not achieve a long lasting bond, possibly due to hydrolysis of the phosphate-calcium bond. Using these materials, clinical studies have shown a wide range of retention rates for restorations with no mechanical retention. The results were not promising.

Third generation dentin bonding agents

Excitement surrounds the current third generation of dentin bonding agents which show in vitro bond strength values approaching those to etched enamel. In 1982, Bowen et al. reported a technique of treating dentin with a series of reagents to improve bond strengths. This is known as oxalate dentin bonding. After the dentin bonding agent is applied, the composite should be placed in layers to reduce marginal gaps that may form because of polymerization contraction. Also, on the enamel the acid-etch technique can be additionally used with a phosphate bonding agent or unfilled resin.

The original Bowen system was based on the acidified ferric oxalate. For better color stability and reduced margin discoloration, aluminum oxalate has been substituted in the commercially available system (Tenure). Using scanning electron microscopy (SEM), Gwinnett examined prepared dentin treated with Tenure dentin cleanser. The smear layer was removed and the dentin tubules were widened to a depth of about 10 μm. Recently the commercial product (Tenure) incorporated the acidified aluminum oxalate with the N-phenyl glycine, reducing the number of application steps. The surface is then treated with two adhesion-promoting resins that chemically bond the composite to the dentin.

Another system (Gluma) has been available for some years in Europe. In 1985, Asmussen & Munksgaard reported on the new approach to dentin bonding. In view of dentin's high proportion of organic material and water, and since complete drying of vital dentin is both impossible and undesirable in clinical practice, an adhesive which works in an aqueous environment was considered to be an advantage. This has been the basis of the long and elusive search for the "barnacle" cement.

The strategy of Asmussen & Munksgaard is to bond to the collagen, the organic component of dentin. After the enamel is etched, the next step is to remove the smear layer with a dentin cleanser. Then a primer, an aqueous solution of glutaraldehyde and HEMA, is applied for approximately 30 seconds before the dentin is dried by an air blast and coated with a layer of low viscosity resin. In addition to a mechanical interlocking...
effect in the open ends of the dentin tubules, a chemical bond is apparently established. The system (Gluma®) bonds with a strength almost as high as that to etched enamel.

The third product in this latest generation is Scotchbond 2. It utilizes hydrophilic monomers like HEMA and maleic acid to remove or alter the smear layer. A bonding resin of hydrophilic and hydrophobic monomers like HEMA and Bis-GMA is then added before the composite resin.

**Future developments**

In the final analysis, the failure mode in the clinical situation is the telling point. We need to analyze clinical cases to determine if the site of failure is predominantly adhesive or cohesive. Hydrolysis is an important consideration as well as factors related to presence or absence of the smear layer. Obviously, these answers are not easily obtained.

The future holds the prospect of adhesive systems which will revolutionize our current procedures on cavity preparation and even caries removal. This comes at a time when an aging population is increasingly retaining their natural teeth with an increase in the need to restore root lesions.

Further developments on non-shrinking direct materials or compensating liners could further reduce stresses inherent in present restorations. Restorative materials with coefficients of thermal expansion similar to tooth tissues would reduce the stress on bonding agents. Adhesive materials would encourage procedures such as the minimally invasive tunnel preparations suggested more than 50 years ago, coupled with injection of a bonding restorative material. In the absence of non-shrinking materials, Bowen & Setz have proposed the use of glass inserts to minimize the amount of resin subject to shrinkage.

A primary goal would be to achieve bonding forces with the substrate equal to the cohesive strength of the substrate itself, namely that of the dentin and enamel. On a practical note, establishing valid and reproducible laboratory tests to determine such forces and to correlate the results with clinical experiences is a key in the search for the dental adhesives. Establishing a suitable standard dentin substrate (or substitute) which yields consistent laboratory results would be a great step forward.

Finally, we must seek a better understanding of the mechanisms of dentin bonding, whether bonding is mechanical or chemical, and how the bond strength values from the laboratory relate to the clinical acceptability as well as the relationship to microleakage. If there is microleakage, the advantage of high bond strengths may be negated by other clinical problems such as sensitivity, marginal discoloration and secondary caries.

**CONCLUSION**

The goal remains an impervious, stable and strong bond with a biocompatible material which can be handled in an easy, consistent manner. Permanent adhesive procedures could reduce treatment time and be more comfortable for the patient.

Future developments need to focus on dental adhesive systems coupled with non-shrinking materials or compensating liners which will revolutionize our current dental procedures.

**REFERENCES**