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REVIEW ARTICLE

Its All About Bonding

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ABSTRACT

To satisfy the growing esthetic demands of today's dental patients, improvements in materials and procedures have been made to make it possible to reproduce the natural appearance of natural teeth with direct and indirect esthetic restorations. Esthetic techniques involve a bonding step to ensure durability and reliability. Thus, the ideal bonding system should be biocompatible, bond indifferently to enamel and dentin, have sufficient strength to resist failure as a result of masticatory forces, have mechanical properties close to those of tooth structures, be resistant to degradation in the oral environment and easy to use for the clinician.

The mechanical properties of the bonding mechanism achieved with hybrid layer and resin tag formation can be greater than the forces of polymerization contraction. Apparently, the future has a sound background in the past.

Keywords: Esthetic, Composites, Biocompatible.

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INTRODUCTION

Dental bonding/adhesion is a dental procedure in which a dentist applies a tooth-colored resin material (a durable plastic material) and cures it with visible, blue light. This ultimately 'bonds' the material to the tooth and improves the overall appearance of teeth. The concepts of large preparations and extension and prevention, proposed by Black in 1917, have gradually been replaced by smaller preparations and more conservative techniques. One major problem in restorative dentistry is the lack of proper union between the restorative material and the tooth surface. The process of inventions over a period of time have led to the development of technique and modalities which help in adhesion and thereby reducing the tooth restoration gaps. Tooth bonding techniques have various clinical applications, including operative dentistry and preventive dentistry as well as cosmetic and pediatric dentistry, prosthodontics and orthodontics.[1]

Adhesive dentistry began in 1955 with a paper by Dr Michael Buonocore on the benefits of acid-etching.[2] With changing technologies, dental adhesives have evolved from no-etch to total-etch (4th- and 5th-generation) to self-etch (6th, 7th and 8th generation) systems. The evolution of products improved not only physical properties but also convenience. Currently, only two new 'universal adhesives' have been commercialized.[3]

Advantages of Adhesive Techniques

Bonded restorations have a number of advantages over traditional, nonadhesive methods as follows:

- Traditionally, retention and stabilization of restorations often required the removal of sound tooth structure. This is not necessary in many cases, when adhesive techniques are used.
- Adhesion also reduces microleakage at the restoration—tooth interface. So by preventing the micro leakage of oral fluids and bacteria along the cavity wall—reduces the clinical problems, such as postoperative sensitivity, marginal staining and recurrent caries—all of which may jeopardize the clinical longevity of restorative efforts.
- Adhesive restorations better transmit and distribute functional stresses across the bonding interface to the tooth and have the potential to reinforce weakened tooth structure.
- Adhesive techniques allow deteriorating restorations to be repaired and debonded restorations to be replaced with minimal or no additional loss of tooth material.
- Last but not the least, these adhesive techniques have expanded the range of possibilities for esthetic restorative dentistry.[4]

An adhesive bond between two any two structures can be created by one or more of the following mechanisms:

- Micromechanical adhesion
- Physical adhesion
- Chemical adhesion
- Molecular entanglement. More usually, a combination of some or all of these is active in creating a adhesive bond.[5]

Micromechanical adhesion results from the presence of surface irregularities, such as pits and fissure, that give

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rise to microscopic undercuts. A prerequisite for this form of adhesion is that the adhesive can readily adapt to the surface of the substrate. For example, resin-enamel bond, resin-ceramic bond for veneers and inlays and the resin metal bond for resin bonded fixed partial dentures.[6]

Physical adhesion results when two surfaces come in close proximity to one another and secondary forces of attraction can be generated through dipole-dipole interactions. The magnitude of the interaction energy is dependent on the mutual alignment of the dipoles. This is considerably less than the bond energy of the primary bond. If an adsorbed molecule dissociates on contact with a surface and the constituent atoms rearrange themselves in such a way as to form covalent or ionic bonds, a strong adhesive bond can result. This form of adhesion is known as chemisorption. Covalent bonding occurs for an isocyanate adhesive, which can bond to soft tissues via surface hydroxyl and amino group. An ionic bond is believed to form between the carboxyl groups of the glass polyalkenoate cements and calcium ions in the enamel and dentin.[7]

The adhesive strength/bond strength is the measure of the load bearing capability of the adhesive. Adhesion refers to the forces or energies between atoms/molecules at an interface that hold two phases together. In dental literature, adhesion is often subjected to tensile/shear forces in debonding tests and the mode of failure is quantified. If the bond fails at the interface between two substrates, the modes of failures is referred to as adhesive. It is referred to as cohesive if failure occurs in one of the substrates, but not at the interface. But, the mode of failure is often mixed.[8]

The phenomenon of adhesion depends on certain factors, the main factors are as follows:

- Surface energy
- Wetting
- Contact angle

When two substances are brought into intimate contact with each other, the molecules of one substance adhere or are attracted to molecules of another. This force is called adhesion when unlike molecules are attracted, and cohesion when molecules of the same kind are attracted. The material film added to produce the adhesion is known as adhesive, and the material to which it is applied is called the adherend. For adhesion to exist, the surfaces must be attracted to one another at their interface. Concerned to dental structures, enamel which contains primarily hydroxyapatite—has high surface free energy. It is difficult to force two solid surfaces to adhere. Regardless of how smooth these surfaces may appear, they are likely to be extremely rough when viewed on an atomic/microscopic scale. Consequently when they are placed in apposition, only the peaks come in contact. Because, these areas usually constitute only a small percentage of total surface area, no perceptible adhesion takes place. One method of overcoming this difficulty is to use a fluid that flows into these irregularities to provide contact over a greatest part of the surface of the solid. To produce adhesion in this manner, the liquid must flow easily over the entire surface and adhere to solid. This characteristic is known as wetting. The extent to which an adhesive wets the surface of an adherend may be determined by measuring the contact angle between the adhesive and the adherend. If the molecules of the adhesive are attracted to the molecules of the adherend as much as or more than they are to themselves, the liquid adhesive will spread completely over the surface of the solid, and no angle will be formed. Thus, smaller the contact angle between the adhesive and an adherend, the better the ability of the adhesive to fill in irregularities on the surface of the adhered. Complete wetting occurs at a contact angle of 0° and no wetting occurs at an angel of 180°.[9]

Enamel contains hydroxyapatite, which has high surface free energy whereas dentin is composed of two distinct substrates hydroxyl apatite and collagen, which has low surface energy. In the oral environment, the tooth surface is contaminated by an organic saliva pellicle and low critical surface tension of approximately 28 dynes/cm. Likewise, instrumentation of the tooth substrate during cavity preparation produces a smear layer with a low surface free energy. Therefore, the tooth surface should be thoroughly cleaned and pretreated prior to bonding procedures to increase its surface free energy and hence to render it more receptive to bonding.

Adhesion to Enamel

Adhesion to enamel is achieved through acid etching of highly mineralized substrate which substantially enlarges its surface area for bonding. This enamel bonding technique, known as acid-etch technique was introduced by Buonocore in 1955. Enamel etching transforms the smooth enamel surface into an irregular surface with a high surface free energy of about 72 dynes/cm, more than twice that of etched enamel. Enamel bonding agents are commonly based on bisGMA/UDMA with diluents such as TEDGDMA and HEMA. Acid etching removes about 10 µm of enamel surface and creates a microporous layer from 5 to 50 µm deep. Enamel bonding depends on resin tags becoming interlocked with surface irregularities created by etching. Phosphoric acid in a concentration from 30 to 40% is the most commonly used etchant. There forms a precipitate of dicalcium phosphate dehydrate that cannot be easily removed. Etching time also has been reduced from traditional 60 to 15 seconds and it has been shown that it has shown similar surface roughness and etching pattern as that of 60 seconds. Primary teeth require longer etching time since the enamel is more aprismatic than that of permanent. As H_3PO_4 is said to be more aggressive, other alternatives have been suggested, like (1) EDTA, (2) pyruvic acid and (3) sulphuric acid ethylene diamine tetra-acetic acid.[10]

Bonding to Dentin

The classic concepts of operative dentistry have been challenged in the last two decades by the introduction of new adhesive techniques first for enamel and then for dentin. Nevertheless, adhesion to dentin still remains difficult.

Challenges in Dentin Adhesion

Bonding to enamel is a relatively simple process with no major technical requirements or difficulties. Bonding to dentin, on the other hand, presents a much greater challenge. Enamel is highly mineralized tissue, composed of more than 90% (by volume) hydroxyapatite. Dentin contains substantial proportion of water and organic material primarily type I collagen. Dentin tubules enclose cellular extension from the odontoblasts and, therefore, are in direct communication with the pulp. The number of tubules decreases from about 4,5000/mm^3 close to the pulp, to about 20,000/mm^3 near the DEJ. The tubules occupy an area of only 1% of the total surface near the DEJ, whereas they compromise 22% of the surface close to the pulp. Adhesion can be affected by the remaining dentin thickness after tooth preparation. Bond strengths are generally less in deep dentin that in superficial dentin. But, some dentin adhesives like 4-META monomer, do not seem to be affected by dentin depth. Whenever tooth structure is prepared with a bur/other instrument residual organic and inorganic components form a 'smear layer' of debris on the surface. Smear layer fills the orifices of dentinal tubules (forming smear plugs) and decreases dentinal permeability by up to 86%. Composition of smear layer is basically HA and altered natural collagen. Removal of smear layer and smear plugs with acidic solutions may result in an increase of the fluid flow onto the exposed dentin surface. This fluid may interfere with adhesion, because hydrophobic resins do not adhere to hydrophilic substrate if the resin tags are formed in the dentinal tubules.[11]

Dental Adhesive System

The dental adhesive system consists of a conditioner (etchant), primer and bonding agent (adhesive) (Fig. 1). Criteria for an ideal dental adhesive system (Philips and Rage) are as follows:

- Should provide a high bond strength to dentin that should be present immediately after placement and that should be permanent.
- Should show good biocompatibility to dental tissue including pulp.
- Minimize microleakage at the margins of restorations.
- Prevent recurrent caries and marginal staining.
- Be easy to use and minimally technique sensitive.
- Possess good shelf life.
- Be compatible with a wide range of resins.
- System should not be toxic or sensitizing to the operators and patients.
- Should seal the tooth surface from oral fluids.[12]

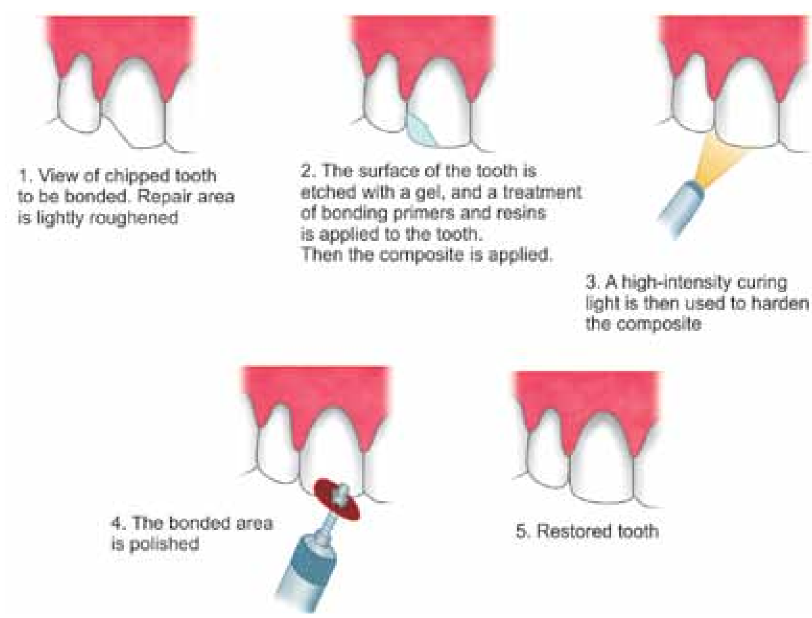

Fig. 1: Five-part illustration showing the technique of bonding

The Generational Development of Adhesive Systems

The first generation adhesives in the late 1970s were really nothing of the sort. While their bond strength to enamel was high (generally, all the generations of adhesives bond well to the microcrystalline structure of enamel; it is their bond strength to the semiorganic dentin that is the major problem facing dentists), their adhesion to dentin was pitifully low, typically no higher than 2 MPa. Bonding was achieved through chelation of the bonding agent to the calcium component of the dentin.[13] It was common to see debonding at the dentinal interface within several months. Postoperative sensitivity was common when these bonding agents were used for posterior occlusal restorations.[14]

In the early 1980s, a distinct second generation of adhesives was developed. These products attempted to use the smear layer as a bonding substrate. This layer is bonded to the underlying dentin at a negligible level of 2 to 3 MPa. The weak bonding strengths of this 'generation' (2-8 MPa to dentin) meant that mechanical retention form in cavity preparations was still required. Restorations with margins in dentin saw extensive microleakage, and posterior occlusal restorations were likely to exhibit significant postoperative sensitivity.[15]

In the late 1980s, two component adhesive systems were introduced. The marked improvement that these bonding agents represented warranted their classification as third-generation adhesives. Significant increases in bonding strength to dentin (8-15 MPa) diminished the need for retention form in the cavity preparation. Erosion, abrasion, and abfraction lesions were treatable with minimal tooth preparation, hence the beginning of ultraconservative dentistry. A noticeable decrease in postoperative sensitivity with posterior occlusal restorations was very welcome. Third-generation adhesives were the first 'generation' that bonded not only to tooth structure, but to dental metals and ceramics as well. The downside to these bonding agents was their longevity.[16]

In the early 1990s, fourth-generation bonding agents transformed dentistry. The high bond strength to dentin (17-25 MPa) and decreased postoperative sensitivity in posterior occlusal restorations encouraged many dentists to begin the switch from amalgam to direct posterior composite fillings.[17]

This generation is characterized by the process of hybridization at the interface of the dentin and the composite. Hybridization is the replacement of the hydroxyapatite and water in the surface dentin with resin. This resin, in combination with the remaining collagen fibers, constitutes the hybrid layer. Hybridization involves both the dentinal tubules and the intratubular dentin, dramatically improving bond strength to dentin. Total etching and moist dentin bonding, concepts developed by Fusayama and Nakabayashi in Japan in the 1980s, introduced to North America by Bertollotti, and popularized by Kanca, are innovative hallmarks of the fourth-generation adhesives. The materials in this group are distinguished by their components; there are two or more ingredients that must be mixed, preferably in precise ratios. This is easy enough to accomplish in the research laboratory, but rather more complicated chairside. The number of mixing steps involved and the requirement for exact component measurements tend to confuse the process and reduce the bonding strengths to dentin. This led to the development and the great popularity of the fifth-generation dental adhesives. These materials adhere well to enamel, dentin, ceramics, and metal, but most importantly, are characterized by a single component, single bottle. There is no mixing, and thus less possibility for error. Bond strengths to dentin are in the 20 to 25+ MPa range, suitable for all dental procedures (except in conjunction with self-curing resin cements and self-curing composites). Fifth-generation bonding agents, easy to use and predictable, are the most popular adhesives today. There is little technique sensitivity in a material that is applied directly to the prepared tooth surface. Postoperative sensitivity has been reduced appreciably.[18]

Dentists and researchers have sought to eliminate the etching step, or to include it chemically in one of the other steps. The sixth-generation adhesives require no etching, at least at the dentinal surface. While this generation is not universally accepted, there are a number of dental adhesives that are designed specifically to eliminate the etching step. These products have a dentin-conditioning liquid in one of their components; the acid treatment of the dentin is self-limiting, and the etch by-products are incorporated into the dentinal-restorative interface permanently. There have been some questions raised by researchers as to the quality of the bond after aging in the mouth. Interestingly, the bond to the dentin (18-23 MPa) remains strong after time, while it is the bond to the unetched, unprepared enamel that is suspect. Additionally, the multiple components and multiple steps in the various sixth-generation techniques can cause confusion and lead to error. There have also been some concerns about the efficacy and predictability of various innovative mixing procedures. A new, simplified adhesive system has been introduced that is the first representative of the seventh generation of adhesive materials. Just as the fifth-generation bonding agents made the leap from previous multicomponent systems to a rational and easy-to-use single bottle, the seventh generation simplifies the multitude of sixth-generation materials

Fig. 2: Classification of contemporary adhesive into three-step total etch, two-step total-etch, two-step self-etch and the single-step self-etch systems. The two-step total-etch and the single-step self-etch adhesives may be considered as simplified adhesives in which hydrophilic resins are employed without an additional coating of comparatively more hydrophobic resins

into a single component, single-bottle system. Both the sixth and seventh generation adhesives are available for self etching, self-priming adhesion for dentists who are seeking improved procedures with minimal technique sensitivity and little or no postoperative sensitivity.[19] The eighth generation bonding agents are dual cured, self etching, nanoreinforced agents and produce bond strength of more than 30 MPa to dentin and enamel with no postoperative sensitivity (Table 1 and Fig. 2).[20]

Applications in Prosthodontics

There are several benefits in using adhesive technique in removable prosthodontics as well as fixed prosthodontics. Bonding between metal components and the denture base resin has an important role in the longevity of removable prostheses. The combination of metal conditioners and alumina air-abrasion is effective in fabricating and repairing removable dentures. Acidic monomers (4-META and MDP) are appropriate for base metal alloys, including Co-Cr alloy and titanium alloy, while thione monomers (MTU-6 and VBATDT) are suitable for noble metal alloys such as gold alloy and silver palladium-copper-gold (Ag-Pd-Cu-Au) alloy. As an alternative to conventional restorations, resin-bonded restorations can provide precisely parallel guide planes with well-made rest seats.[21]

Applications in Restorative Dentistry

Bonding materials are essential for modern restorative dentistry (i.e. composite restorations and composite cements). Methacrylic resin-based adhesives, i.e. bonding materials are crucial for an adhesion between composite resin-based materials (CRM) and tooth substances, i.e. enamel and dentin.[22]

Applications in Endodontics

A limited amount of research evidence has been published about bonding in the root canal system. Adhesive obturating materials are in the early stages of development. Continued research and development is likely to result in improvements and in new, more effective materials.[23]

Disadvantages of Bonding

The acrylic materials used in bonding do not last as long as typical crown. Bonds will eventually chip or become discolored. The bonded plastic coating can break off on biting something hard or accidentally falling and bumping a tooth. Bonds last an average of 5 years, and are also more susceptible to stains than compared to natural teeth. Smoking cigarettes, drinking tea or coffee may cause some discoloration.

CONCLUSION

To satisfy the growing esthetic demands of today's dental patients, improvements in materials and procedures have been made to make it possible to reproduce the natural appearance of natural teeth with direct and/or indirect esthetic restorations. Esthetic techniques involve

Table 1: Classification of bonding agents

Type of bonding agents	*Generation*	*Components*	*Examples*
Total etch, multiple bottle, light cured	4th	Phosphoric acid, primer with catalyst, adhesive with catalyst	Adper Scotchbond multipurpose plus (3M ESPE), all bond 3 (Bisco), Bond-It (Pentron Clinical), Luxa bond total etch (DMG America), Opti bond FL (Kerr Corp)
Total etch, multiple bottle, dual cured	4th	Phosphoric acid, primer with catalyst, adhesive with catalyst	Adper Scotchbond multipurpose plus (3M ESPE), all bond 3 (Bisco), Bond-It (Pentron Clinical), Luxa bond total etch (DMG America)
Total etch, single bottle, light cured	5th	Phosphoric acid, primer adhesive	Adper single bond plus (3M ESPE), all bond plus (Bisco), Opti bond plus (Kerr Corp)
Total etch, single bottle, dual cured	5th	Phosphoric acid, primer adhesive with catalyst	Bond-1 (Pentron Clinical), Excite DSC (Ivoclar vivadent), Prime and bond NT (Dentsply)
Self etch, light cured	6th type 1	Acidic primer, adhesive	Adper Scotchbond SE self-etch (3M ESPE), Clearfill SE bond (Kuraray, America), Clearfill SE protect (Kuraray, America), FL bond II (Shofu Dental)
Self etch, dual cured	6th type 2	Acidic primer, adhesive, catalyst	Adhe SE (Ivoclar Vivadent), Clearfill Liner bond 2V (Kuraray America), Contax (DMG America), Nanobond (Pentron Clinical)
Self etch, light cured	6th type 2	Acidic primer, adhesive	Adper prompt L pop self-etch adhesive (3M ESPE), Brush and bond (Parkell), all bond SE (Bisco)
Self etch (no mix), light cured	7th	Acidic primer, adhesive	Adhe SE One F (Ivoclar Vivadent), Bond force (Tokuyama Dental), Clearfill SE Bond (Kuraray, America), G Bond (GC America), Xeno IV (Dentsply)
Self etch, dual cured	7th	Acidic primer, adhesive catalyst	Clearfill DC bond (Kuraray, America), Xeno IV DC (Dentsply), Futura bond DC (VOCO America)

a bonding step to ensure durability and reliability. Although important improvements in bonding have been made in the last 30 years, note that the requirements of an ideal bonding system are quite similar to those indicated by Buonocore. Apparently, the future has a sound background in the past.[24]

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