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Bond Failure and Its Prevention in Composite Restoration – A Review

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Abstract

Aim
To do a review on bond failure in composites and its prevention

Objective
To determine the reason for bond failure in composite restoration and to assess the methods by which bond failure can be prevented

Background
The quest for inventing a restorative material mimicking the natural teeth in both function and aesthetic aspect has been the foremost concern of a dentist today which has led to wide spread evolution of composite restorative materials. The advantage of composite resins is its versatile usage because of its tooth like appearance as well as its property of bonding to the tooth structures. But it also holds some disadvantages among which the most important is bond failure

Reason
So this review is to explore in detail the reasons for the occurrence of bond failure in composite restorations and the ways by which we can prevent them to ensure a long term success of composite restorations

Key Words: composite restoration; bond failure; prevention

INTRODUCTION

The quest for an artificial restorative material mimicking natural tooth both in function and aesthetics in the oral environment still remains a foremost concern to the dentist which has led to the use of various restorative materials in dentistry. The concept of bonding to tooth structure has led to major modifications in cavity preparation, with a general trend towards the increased preservation of healthy, natural tooth structure. Despite the significant improvements of adhesive systems, the bonded interface remains the weakest area of tooth-coloured restorations. Adhesive techniques still accompany a higher placement complexity and technique sensitivity. Even though achieving a good bond may be a challenge due to various factors, understanding the mechanism of bonding and the characteristics of the bonding interface between resin composites and tooth substrates is important for the development of a promising bonding system.

Clinical relevance statement:
Composite restoration is the most commonly used restorative material used in clinics due to its high aesthetics, but bond failure in composites is one of the major obstacle in its use , so identifying the causes of bond failure and ways to prevent it is important to use composites widely

FACTORS INFLUENCING ADHESION OF COMPOSITE TO TOOTH STRUCTURE

I. Clinical factors affecting adhesion
II. Factors affecting adhesion to mineralized tissue

I. Clinical Factors Affecting Adhesion [1] :

Extra oral –
- Moisture contamination from hand piece or air water syringe.
- Oil contamination of hand pieces or air water syringe.
- Presence of bases or liners on prepared teeth

Intra oral-
- Salivary and or blood contamination
- Surface roughness of tooth surface.
- Mechanical undercuts in tooth preparation.
- Fluoride content of teeth
- Presence of plaque, debris, calculus, extrinsic strains or debris.
- Tooth dehydration

Moisture Contamination from hand pieces or air-water syringes: The source of leakage can be caused by several situations (Gordon J et al, 1992) [1]. Among them are
- Lack of drying devices on air lines leading from the compressor, allowing wet air to be carried to the syringe or hand piece.
- Condensation of water in air lines after the compressed air has been dried, but before the hand piece or syringe location.
- Leakage of water through gaskets in plumbing at the dental chair unit.

Blowing air from the hand piece or air syringe on to a dry surface as a test procedure will demonstrate easily if water contamination is present.

Oil contamination of hand pieces or /Air water syringes: The oil comes from air compressors, most of which are not maintained well in dental offices (Roberts HW et al, 2005). Any of the current dentin bonding agents combined with oil contamination provides an unpredictable clinical result and potential clinical failure. Removing all oil from dental air lines should be an immediate objective. Air filters are placed on the air lines after the air compressor and before the air syringe or hand piece.

Constituents of temporary cements: If temporary cements such as Zinc oxide eugenol have been in place on the tooth for several days, the liquid portion of the cement would be completely absorbed by the zinc oxide and are rendered relatively inert. No differences were noted in bonds of dentin bonding agents or resin cements to dentin or enamel surfaces that have had eugenol or noneugenol cements on them for two weeks when compared to virgin tooth surfaces. Fresh liquid eugenol placed on dentin or enamel just before bonding could be a negative factor in adhesion.

Salivary and Blood Contamination: Although dentin is a wet substance, the constituents of saliva and blood create an environment that can destroy dentin bonding. Use of rubber dam or other dry field aids are necessary to avoid salivary or blood contamination during placement of tooth adhesion materials.

Effect of saliva contamination on bond strength

In relation to saliva contamination, it was hypothesized that the presence of salivary glycoprotein decreases dentinal permeability up to 65%, leading one to suppose that adhesion would be impaired in the presence of saliva. However, controversial results have been reported. While some studies using etch-and-rinse adhesives reported that saliva contamination reduces bond strength (Pashley et al and Fritz et al, Munaga et al (2014)), other authors observed that the presence of saliva did not influence the adhesion process. Further investigation of this aspect, focusing on long term effect of saliva contamination on bond strength is required

Surface Roughness of Tooth structure: The difference in surface roughness created by tungsten carbide burs and diamond abrasives influence the adhesion of composites to tooth surface. Diamonds cut irregularities in tooth structure that are related directly to the size of diamond particles used on the diamond abrasive instrument. These range from less than 10μm to about 100μm. Mechanical retention of composites may be increased slightly by the microscopic roughness produced on dentin or enamel by rotary cutting instruments.

Mechanical Undercuts in Tooth preparation: Mechanical undercuts hold restorative materials from bodily dislodgment from the preparation, as well as resist some microscopic movement of the restorative material caused by thermal or polymerization influences.

Fluoride content of Teeth: Increased fluoride content of enamel has been shown to resist acid etching (Gordon J et al, 1992) [1]. This reduction in enamel acid- etch effectiveness is not significant clinically if the etching time is increased to allow more time for the acid to degenerate the enamel surface and produce more roughness. Fluoride presence in dentin appears to influence bonding dentin adhesion agents negatively.

Presence of Plaque, Calculus, Extrinsic stains or debris: After etching, the plaque covered surface remains shiny. Penetration of plaque by the less-aggressive acids used in dentin bonding agents is not possible, and clinical adhesive failure will result. Any enamel or dentin surface that requires bonding must be clean before the bonding procedure begins.

Tooth dehydration: Dentin is a wet tissue. Bond strength could be related to wetness of dentin. It may be that over drying could lead to collapse of the collagen mesh which impedes the formation of hybrid layer. Drying only until the obvious shine of moisture is gone is a good clinical guide.

II. Factors Affecting Adhesion To Mineralized Tissues [2]

Physico chemical Properties of Enamel and the Effect of Acid Etching: Enamel consists of 96% inorganic material (Hydroxyapatite), only a small amount of organic matter and 4% H_2O. In the oral environment, the organic pellicle covers the enamel surface reducing the surface energy of enamel to 28 dynes / cm, which creates complex surface for bonding. Cutting the enamel surface during cavity preparation removes the organic pellicle but does not increase the surface energy. Etching increases the surface energy to 72 dynes/cm. A more homogeneous structure with higher inorganic content and higher surface energy makes enamel a more predictable structure for bonding.

Physico Chemical Properties of dentin: Dentin is composed of 65-90% of inorganic material and 30-35% of organic material. Highly variable structure with higher organic content makes dentin less predictable to bonding compared to enamel. Dentinal fluid in the tubules is under a slight but constant outward pressure from the pulp intra pulpal fluid pressure is 25-30 nm Hg (or) 30-40 cm H_2O.

Transformed dentin structure due to physiologic and pathological process: Dentin is a dynamic substrate which undergoes continuous changes in composition and microstructure. Heavy sclerotic dentin has areas of complete hyper mineralisation without tubule exposure even when etched with acid. All the changes bring the adhesive treatment less receptive than the normal dentine.

Dentin permeability: Two types of dentinal permeability must be considered. The diffusion of substances through tubules filled with dentinal fluid to reach the pulp intratubular dentinal permeability. The second important type of dentinal permeability is the diffusion of monomer into demineralized intertubular dentin, the dentin between the tubules. This is referred to as intertubular dentinal permeability. [3] Both intratubular and intertubular dentinal permeability is important in dentin bonding.

The dentin smear layer: The smear layer formed on instrumented tooth surfaces can reduce dentinal permeability by 86% and tends to weaken the bond strength between the restorative material and the cavity wall. Thus, etching of the cavity is recommended to remove smear layer. One factor that might interfere with the demineralization potential of a self-etch adhesive is the instrument used to create the smear layer. Dentin surfaces ground with diamond burs tended to present more compact smear layers. Smear layer denseness, more so than thickness, may compromise bonding efficacy of adhesives, especially of self-etch systems [4].

Internal and External dentinal wetness: Internal dentinal wetness depends upon several factors such as diameter of tubule, length, viscosity of fluid, pressure gradient etc. External dentinal wetness has a negative effect on bond strength. As the level of humidity in air rises, the bond strength decreases**.**

Failures in dentin bonding :

Despite significant improvements of adhesive systems, bonded interface remains the weakest area of tooth coloured restorations. If dentin / adhesive interface is exposed to oral cavity- marginal discoloration, poor marginal adaptation and subsequent loss of retention of restoration are frequent clinical findings. Even though several studies revealed excellent immediate and short term bonding effectiveness of dental adhesives, durability and stability of resin bonded interface on dentin created by some bonding systems remain questionable.

Morphological and histological considerations

This causes inadequate bonding at material tooth surface interface which includes cavity configuration (C factor) and dentinal tubules orientation, capillary movement of dentinal tubule fluid, physical characteristics of restorative material (filler loading, volumetric expansion, modulus of elasticity and polymerization contraction), inadequate margin adaptation of restorative material during insertion, inappropriate barrier protection (dental rubber dam), tooth location, occlusal stresses / tooth flexure and patient age consideration.

C – Factor

C-Factor is the ratio of bonded (flow-inactive) to unbonded or free (flow active) surface. An increase in number of bonded surface results in higher C-Factor and greater contraction stress on adhesive bond, which leads to potential for bond disruption from polymerization effects. Unrelieved stress in composite may cause internal bond disruption as well as marginal gaps around restorations that increase microleakage [5]. Immediate bond strength of approximately 17 mpa may be necessary to resist contraction stresses that develop in composite during polymerisation to prevent marginal debonding.

Sclerotic dentin:

Sclerotic dentin is formed either as a reactive process or aging and is seen in the occlusal and non-carious cervical lesions, the latter being more common. The dentinal tubules are partially or completely obliterated with rod like sclerotic casts via peritubular apposition and minerals in the saliva. These sclerotic plugs are protected by a layer of shiny hypermineralized layer which is acid resistant and acts as a diffusion barrier during adhesive procedures. This layer contains denatured collagen with large calcium and phosphate crystals.

To improve the micromechanical adhesion to sclerotic dentin, two strategies can be followed. First strategy is by doubling the etching time or by using stronger acids. However resin tag formation does not occur in this approach. Other method is by removal of hypermineralized layer using a rotary instrument to obtain intertubular retention. However this may be detrimental when the lesion is close to the pulp. Another disadvantage of this approach is, the smear layer formed during this procedure which contains acid resistant hypermineralized dentin chips and whitlockite crystals derived from sclerotic casts that creates additional diffusion barrier when total-etch or self-etch technique is used.

Moist versus dry dentin surfaces:

Vital dentin is inherently wet. The wet bonding tech prevents spatial alterations that occur upon drying demineralized dentin. Such alterations may prevent the monomer from penetration. The use of adhesive system on moist dentin is made possible by incorporation of organic solvents acetone or ethanol in the primer or adhesive, because solvent ca displace water from the dentin surface and moist collagen network, it promotes the infiltration of resin monomer through the nanospaces of dense collagen web.

Polymerization shrinkage

Polymerization shrinkage is a major problem with composite resins. The polymerization reaction of light cured composites induces polymerization contraction stress on tooth structures when a composite resin is bonded to cavity walls. This creates contraction stress, which has the potential to initiate the failure of the composite – tooth interface if the forces of polymerization contraction exceed dentin bond strength. If this occurs, adverse consequences such as postoperative sensitivity, microleakage, secondary caries, and microcracking of the restorative material can result.

MICROLEAKAGE

Micoleakage is the diffusion of a substance into a fluid filled gap or a defect between filling materials and tooth structure (Crim et al in 1989). Microleakage is related to several factors, such as dimensional changes of materials due to polymerisation shrinkage, thermal contraction, absorption of water, mechanical stress and dimensional changes in tooth structure. [6] The polymerisation shrinkage of a composite resin can create contraction forces that may disrupt the bond to the cavity walls, leading to marginal failure and subsequent microleakage. Modern composite resins undergo volumetric contractions ranging between 2.6% to 4.8 %. Even when modern dentine bonding agents exhibit bond strengths to dentine higher than 20 MPa20, exceeding the contraction stress generated by polymerisation stress (13-17 MPa), the total contraction forces may be higher than the adhesive strength, leading to open margins.

The shape of the cavity can also challenge the adaptation of the restorative material to the margins. Indeed, the C-factor of cavities is closely related to the occurrence of microleakage, especially when restored with a composite resin and dental adhesive.

Another contributing factor may be the coefficient of thermal expansion. The coefficient of thermal expansion of composite resin (25 to 60 ppm°C-1) is several times larger than that of enamel (11.4 ppm°C-1) and dentin (8 ppm°C-

1). This physical property is also reported to be responsible for microleakage in resin-based restorations.

One of the weakest aspects of Class II composite resin restorations is microleakage at the gingival margin of proximal boxes. This is related to the absence of enamel at gingival margins, resulting in a less stable cementum-dentine substrate for bonding. In addition, the orientation of the dentinal tubules can negatively affect the quality of hybridization and thus favour leakage in resin-based restorations placed in deep interproximal boxes.

V shaped gap formation due to properties of composite is seen in class V cavities, declining the retention by 20% in five years leading to tooth sensitivity, marginal staining and marginal chipping that leads to partial or complete restoration replacement [7].

Nanoleakage within the Hybrid Layer : Presence of sub micron spaces within the hybrid layer in the absence of gap formation between resin composite and the hybrid layer (**Sano et al 1994**) [8]. Nanoleakage leads to hydrolytic degradation of collagen fibres which compromises the long term integrity of resin dentin interface and decreases the bond strength overtime

Aging of hybrid layer

Clinical longevity of the hybrid layer seems to involve both physical and chemical factors. Physical factors such as occlusal chewing force, repetitive expansion and contraction stresses due to temperature changes within oral cavity are supposed to affect the interface stability. Acidic chemical agents in dentinal fluid, saliva, food and beverages and bacterial products further challenge the tooth / biomaterial interface resulting in various pattern of degradation of collagen fibers and resin components [9].

Degradation of resin

Hydrolysis is a chemical process that breaks covalent bonds between the polymers by addition of water to ester bonds, resulting in loss of the resin mass: this is considered as one of the main reason for resin degradation within the hybrid layer, contributing to the reduction in bond strengths created by dentin adhesives over time. Water sorption caused a significant decrease in the modulus of elasticity of the resins that is thought to contribute to reductions in bond strength, independent of resin hydrolysis. [10]

The application of one step self etching adhesive system could lead to bond failures as a result of excess water present in its composition which results in incomplete polymerization of adhesive system, therefore water sorption by hydrophilic resin monomers both in hybrid layer and in tags contribute to low tensile bond strengths.

The etch-and-rinse or the self-etch strategy, by combining hydrophilic and ionic resin monomers into the bonding such as in simplified adhesives (i.e. two-step etch-and-rinse and one-step self-etch systems) the bonded interface lacks a nonsolvated hydrophobic resin coating. This leads to the creation of hybrid layers that behave as semi-permeable membranes permitting water movements throughout the bonded interface even after the adhesive is polymerized. This water passage was revealed by studying the permeability of bonded interfaces and by using a tracer detectable by electron microscopy such as ammoniacal silver nitrate. This tracer stains pathways water-filled diffusion throughout the bonded interface that are often manifested as creating the so-called **"water trees"**[11], i.e. characteristic water channels at the surface of the hybrid layer that extends into the adhesive layer, supporting the hypothesis of complete permeation of simplified adhesive bonded interfaces to water. Water movements begin as a diffusion-type mechanism then becomes more rapid as transport pathways form relatively large water-filled channels. Similar water movements within the adhesive layer can be driven by osmotic pressure gradients due to high concentrations of dissolved inorganic ions and hydrophilic resin monomers resulting in the formation of water blisters over the adhesive layer.

Degradation of exposed collagen fibrils

The combined degradation of resin and collagen may increase the water content of the bonded interface, leading to a further detrimental effect on the longevity of the bond; water has in fact been claimed as one of the major cause for collagen degradation. Within the hybrid layer, two degradation patterns can be observed: loss of resin from interfibrillar spaces and disorganization of the collagen fibrils. Such degradation may result from the hydrolysis of resin and/or collagen, thereby weakening the physical properties of resin–dentin bond. [10]

Matrix Metalloprotienases:

Matrix Metalloproteinase (MMPs) are a family of zinc dependent structural and functional related endopeptidases that are capable of degrading extracellular matrix proteins [12]. These enzymes have deleterious effect that breaks down collagen and other extra cellular proteins. Exposed collagen fibrils at the bottom of the hybrid layer due to imperfect resin impregnation might be affected by MMPs inducing hydrolytic degradation which might result in reduced bond strength. Most MMPs are synthesized and released from odontoblast in the form of pro enzymes, requiring activation to degrade extracellular matrix components. Unfortunately they can be activated by acidic properties of adhesive system. Etch and rinse adhesives (Mazzone et al, 2006) and Self etch adhesives (Nishitani et al, 2006) have been confirmed to have the ability to reactivate gelatinase and collagenase in demineralised dentin. Lehmann et al, 2009 showed the increased activation of MMPs after using self etch adhesives.

Chlorhexidine, which has been used as a disinfectant in cavity preparation and oral irrigation, has been shown to have anti MMP properties [12]. Pashley et al found that 0.2% chlorhexidine inhibited collagen degradation. Moon et al measured the shear bond strength of an etch and rinse dentin bonding system with and without the use of 2 % chlorhexidine in the bonding procedure. They found a 24% increase in shear bond strength when 2% cholrhexidine was used.

If a total etch bonding system is employed, then chlorhexidine should be incorporated into the bonding process. A different approach to collagen degradation issue with self etching adhesive is to use a product that provides a protective barrier. With the addition of pyridinium bromide, a 2-µm thick acid base resistant zone (ABRZ) develops below the hybrid layer. If a self etching system is to be used then the material selection in producing an ABRZ should be considered.

Long term degradation of resin – dentin bond

The bond degradation may be seen as a result of adhesive displacement by water within the interface, which leads to hydrolysis. This hydrolysis occurs in the collagen fibrils or resin within the bonded interface. Acidic conditioners are used to demineralize the layer that is smeared and the underlying intact dentin to create an exposed collagen network, providing space for resin impregnation. The poorly resin infiltrated zone is considered the weakest region, because it leaves naked collagen fibrils that are highly susceptible to hydrolysis over the long term. Bond degeneration can occur due to degradation of collagen fibrils occurs in the hybrid layer as a result of the activation of host-derived matrix metalloproteinase (MMP) within the dentin matrix. Water tree propagation might be a symptom of degradation of bonding resin after aging of the resin adhesives [11].

However, other causes of hydrolysis, such as the resin, collagen fibrils or unknown factors, also may affect the relationship between water tree expression and bond strength after aging. The degradation of bonds can occur without water trees, but it is likely that degradation may be accelerated in the presence of additional water perfusion.

Conclusion

Improved dental adhesive technology has extensively influenced modern concepts in restorative dentistry. The acid-etch technique for enamel bonding lead to the development of revolutionary restorative, preventive and esthetic treatment methods. Unlike bonding to enamel, bonding to dentin presents a much greater challenge due to its various complexities. While the bonding agents have made remarkable progress, each new generation has been characterized by new problems not previously exhibited by their predecessors. Improvements in dentin bonding materials and techniques are likely to continue. However, even as the materials themselves become better and easier to use, proper attention to technique and good understanding of bonding process remain essential for clinical success. '

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