Biomaterials Journal
http://www.biomatj.com
Online ISSN: 2812-5045

Type of the Paper (Review Article)

Factors affecting the durability of adhesive junction :a review

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Citation: *Lojain Taraman . **Factors affecting the durability of adhesive junction :a review** . Biomat. J., 2 (5),3 – 12 (2023)*

https://doi.org/10.5281/znodo.5829408

Received: 20 May 2023
Accepted: 30 May 2023
Published: 31 May 2023

Abstract:. Recently, the durability and serviceability of dental restoration is a concern not only to the dentist but also to the patient. Although there are huge improvements and modifications in the adhesive system, several factors still control the success and stability of the adhesive junction**.**

Keywords: *adhesive junction, durability, degrdation and aging, enhancement.*

Introduction

The conservative approach of restoring tooth structure in both function and esthetic is the prime objective in the dental field. This approach mainly depends on using adhesive to bond tooth-colored restoration to the tooth structure either directly or indirectly. Although there are huge improvements and modifications in the adhesive system, several factors still control the success and stability of the adhesive junction. (1)

Clinical longevity is a critical aspect because the adhesive interface deteriorates over time. Marginal leakage is the primary factor in filling failure. it may cause marginal discoloration, secondary caries, and a loss of retention. The majority of the existing dental adhesives show excellent short- and immediate-term bonding effectiveness, but the longevity and stability of resin-bonded surfaces are still questionable. (2)

The fundamental factors affecting the durability of the adhesive junction are the tooth substrate, the dentin hydrophilicity, the adhesive material characteristic, and their physicochemical properties. Some factors related to the clinical procedure include tooth preparation, handling and application of restoration, and curing mode. While patient-related factors such as preventive and oral hygiene measurements after

treatment. (3,4)

The basic technique for bonding to enamel and dentine is mainly based on an exchange process. In which minerals taken out of dental hard tissues are substituted by resin monomers. This resin monomer with polymerization will

interlock the produced pores micromechanically. The adhesive interface is liable to degradation and is considered an area of weak bonding that affects the adhesive junction's durability and restoration. [3]

Factors affecting the durability of adhesive junction

1. **Bonding tooth substrate (Enamel and Dentin)**

The tooth consists of two main structures. Enamel is responsible for stiffness, hardness, and brittleness characters. While dentin forms the main bulk of the tooth and protects the pulp. Also, it makes the tooth flexible and softer and can withstand stresses from chewing without fracture. During tooth structure replacement, it is difficult to achieve stable bonding due to the difference between enamel and

dentin. [3]

Physicochemical properties of enamel and the acid etching effect:

Enamel mainly consists of a high mineral content of 90 vol% mineral, 4 % protein, and 6 % water. Insufficient roughness to the enamel surface may result in poor adhesion to enamel. That is why acid etching is a critical step that depends on using a suitable etchant (phosphoric acid). With several modifications, nowadays the etchant concentration ranges from 32 to 37 %, and the time of application range from 15-30 second. [3]

Acid etching is used to remove organic pellicles in enamel. Also, it removes the smear layer which is composed of debris and bacteria from cutting the enamel surface during caries removal. The etch will remove enamel rods leaving micropores, resin infiltrates to form micromechanical interlocking by forming a resin tag which will provide a stable resin enamel bonding interface. [3]

Physicochemical Properties of dentin:

Adhesion to the dentin surface is challenging and more complex because of the dentin composition. Dentin is composed of 50% vol mineral and 30% organic matrix and 20% water. The organic part is divided into 90% collagen type I and 10% non-collagenous protein. Dentin consists of dentinal tubules that are not regularly distributed. The dentinal tubules are responsible for the wet characteristic of dentin. The fluids increase by cutting tooth structure. [5]

Additionally, by applying an acid etch the minerals in dentin will solubilize and interchange with water. This led to raising water content to 70%. Therefore, displacing water is mandatory to obtain the adhesion of the resin to dentin this may be done by using the liquid mixture of solvents and adhesive monomers. [6]

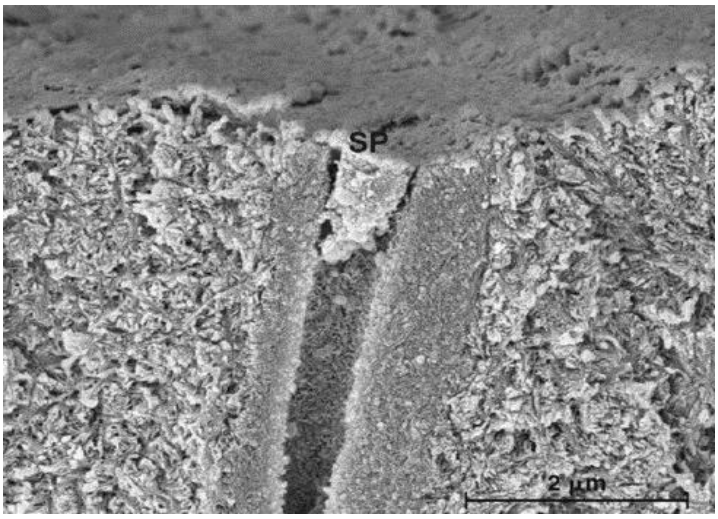
Dentin demineralized and give collagen fibrils that engage with the adhesive resin by using a light cure to polymerize it to form a hybrid layer. Although dentin shows high bond strength at the beginning, it is reduced with

time. this is because of increasing water sorption due to the nature of dentin, the amount of remaining water, and the hydrophilicity of the adhesive. [7]

The dentin smear layer:

The smear layer is formed during cavity preparation and carious removal in the dentin part plugged into the tooth structure. It is difficult to be removed by washing or blowing it with air. There is a point of argument on whether to remove the smear layer or not. As some studies declare that some bonding agents show the ability to be used over it as it contains calcium. While others claimed that the bond strength improved when the smear layer is removed. It can be removed by using suitable acid etching. Also, it can be modified by using adhesive resin with mild acidity to penetrate it and bond to intact dentin. The smear layer may interfere with good bonding. (**Figure.1**)[1,3]

Figure.1 Scanning electron micrograph of a smear plug blocking the entrance of a dentinal tubule.



2. Adhesion mechanism technique

The main concept of the adhesion technique to tooth substrate depends on exchanging the inorganic content with synthetic resin in two phases. The first phase is based on creating micropores in the enamel and dentine surface. This can be done by removing the calcium phosphate by using suitable acid. While the second phase is based on the infiltration of the resin to the created pores to form hybridization. [8]

There are several clinical strategies for adhesion as etch and rinse or self-etch approach. Although the etch-and-rinse is considered the gold standard approach, the self-etch eliminates the technique sensitivity of the other approach. For instance, over-etching and drying. Etch-rinse can be classified according to the technique steps into three steps:

separate etching and rinsing, primer, and adhesive application. While the two steps approach is simpler it involves etching and rinsing as a step and the primer is added to the adhesive and considered as one step. [6,9]

The self-etch approach is accomplished by using a system of acidic monomers (such as phosphoric acid or carboxylic acid esters) that act on tooth structure without rinsing. It can be classified into two steps: the etch and primer in one step and the adhesive resin in the second step. While one step is known as all-in-one as it relays on using a single compound of etch, primer, and adhesive resin as one step. [3,8,9]

Although self-etch provides a user-friendly adhesive system by reducing the number of steps, the quality of mechanical interlocking is lower than the etch and rinse technique. Also, some of the adhesive monomers may combine with the remaining hydroxyapatites. This will result in a weak, non-stable adhesive junction. [3]

3. Hydrolytic degradation of the adhesive

Vital dentin is inherently wet, and complete drying of dentin is difficult to be achieved clinically. Water has been considered an obstacle to attaining an effective adhesion of resins to dentin. Therefore, certain modification of bonding involves a wet bonding technique to inhabit collagen matrix collapse. Many adhesives combine hydrophilic and hydrophobic monomers in the same bottle, dissolved in an organic solvent such as ethanol or acetone. [9]

The hydrophilic monomer such as hydroxy ethyl methacrylate (HEMA). Its hydrophilicity promotes adhesion and enhances bond strength. On the other hand, it may absorb water leading to dilution of the monomer before curing. Also, it is liable to hydrolysis because of the presence of an ester group.[3,8,9]

In addition to hydrophilicity, water, as well as organic solvents (ethanol/acetone) trapped inside the hybrid layer, can degrade their integrity. The remaining solvent and water are difficult to be removed and compromise the bond strength as well as the hybrid layer. The absence of a hydrophobic resin seal and the hydrophilicity of water may trap the adhesive layer forming a “water tree” pattern that is more prominent by silver nitrate tracer and considered as nano-leakage. This problem is evident in the self-etching “all-in-one” approach. (**Figure**.**2**) This will decrease bond durability.[1,3,4,6]

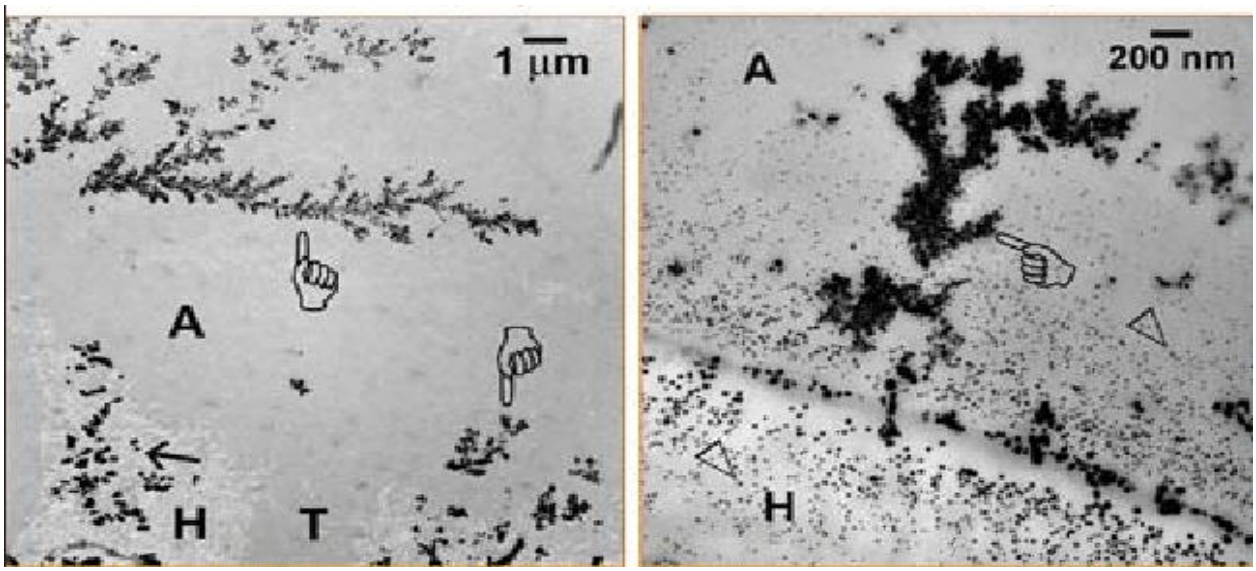


Figure.2 Transmission electron micrograph showing "water tree" pattern detected by using silver nitrate tracer.

4. Degradation of exposed collagen fibrils

The degradation of resin and collagen could be due to increasing the moisture content of the bond interface, which reduces the longevity of the bond.

Water is said to be one of the main causes of the breakdown of collagen. The hybrid layer degradation patterns can be observed as resin loss and disassembly of interfibrillar spaces and collagen fibril. (**Figure.3**) The hydrolysis will cause the deterioration of resin and/or collagen. Hence, reducing the physical properties of the resin-dentin bond.[2,3,9]

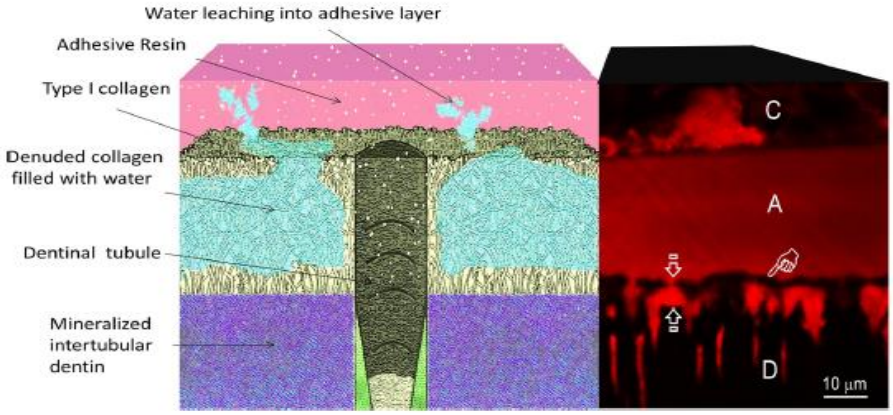


Figure.3 (a) 3D schematic showing the denuded collagen filled with water. (b) confocal laser scanning showing resin-dentin (black region) while water (red region) distributed in the hybrid layer C: composite resin A: adhesive D: dentin. [3]

5. Collagenolytic Enzymes in Dental Tissues

Matrix metalloproteinase (MMP)is an enzyme that plays a role in hybrid layer degradation. MMPs are a family of endopeptidases, a class of zinc and calcium that can degrade the extracellular matrix components. MMP has several species found normally in human dentin such as MMP-2, MMP-8, MMP-9, and MMP-20. Collagen is mainly attacked by MMP-8, while gelatin is attacked by MMP-2 and MMP-9.[2,3,5]

The host-derived proteinases are present in dental caries, erosion, and periodontal pathogen. They show a potent decrease in dentin bonding. Some studies declared that proteolytic enzymes in absence of bacteria can slowly degrade the dentin matrices. MMPs contain a catalytic domain composed of cysteine which is responsible for the activity of proteolytic enzymes. It was found that the activity of both MMPs and cysteine cathepsin is higher and more prominent in acidic environments and carious dentin than intact dentin.[2,3,5,8]

6. Polymerization shrinkage

Polymerization shrinkage is one of the huge problems facing resin restoration. Because of the contraction stresses created by curing the restoration. These stresses may result in microleakage and failure of the adhesive junction. It is more prominent at the interface if the contraction stresses are higher than dentin bond strength. [4]

7. Aging and quality of the hybrid layer

The quality of the hybrid layer is one of the critical factors affecting bond durability. Certain nano spaces may be created and lead to nano-leakage which will reduce the bond strength. Also, this may lead to the degradation of the adhesive junction. [2,4]

The aging of the hybrid zone relies on certain physical and chemical factors. Physical factors related to the force of occlusion with the chewing process. Besides, continuous shrinkage and expansion from temperature fluctuation within the oral environment will interfere with the adhesive interface's durability. Acidic chemical factors that come from food, beverages, and bacterial product in saliva may interfere with the durability of the tooth/ restoration interface. This may give rise to certain deterioration of collagen fiber and resin content. [4]

Clinical factors affecting the durability of the adhesive junction

Some clinical factors may control the longevity and stability of adhesive junction and restoration. This is related to cavity preparation, the quality of the remaining tooth structure, and the complete removal of the carious lesion. It was found that bond strength to intact dentin is higher than to carious affected dentin. Caries propagation may lead to mineral contents reduction and distribution of collagen and non-collagenous protein structures. This will result in a decrease in mechanical properties and adhesive junction durability. [4]

Proper cleaning of tooth structure and removal of plaque and calculus is critical to improving adhesive durability. Also, tooth dehydration from over-drying may affect adhesive durability. As it may result in a collapse of dentinal collagen and prevent the hybrid layer formation. [4]

Intra-oral contamination and improper isolation before the adhesive application can cause a decrease in adhesive junction durability and failure of the restoration. Therefore, before adhesive application, it is critical to avoid salivary or blood contamination. [4,5]

It was found that salivary contamination may decrease bond stability. Although it is a point of debate as some studies claimed that saliva is not affecting the adhesion. But more analyses are needed to declare the effect of salivary contamination on long-term bond strength. Sometimes contamination may be also from oil leakage of the handpiece affecting the adhesive junction's durability. [4]

Some studies claimed that the degree of surface roughness may affect bonding. The irregularities created depend on the type of bur used in cavity preparation as well as the size of the abrasive particles. It will increase mechanical retention and restoration durability. [4]

Methods to enhance the durability of the adhesive junction:

1) **MMPs inactivation and inhibition**

There are several strategies to counteract the effect of MMPs either by inactivation or inhibition. Some studies claimed that cross-linking agents are considered as a method for MMPs inactivation either by using glutaraldehyde, carbodiimide HCL, or riboflavin. The use of glutaraldehyde is limited because of its toxic effect. [5,10]

MMPs inhibitor may be used as chlorohexidine gluconate 2% which is an antiseptic and antimicrobial agent used widely in dentistry. It is recommended to be applied after the acid etching step and before the primer and adhesive application. Other MMP inhibitors may be used such as benzalkonium chloride (BAC) used as a cavity desensitizer. [5,10]

Furthermore, tetracycline is used as an antimicrobial agent. This may improve the durability of dentin bonding. MDPB is 12-Methacryloyloxydodecylpyridinium bromide may be added to inhibit MMPs. It preserves the hybrid layer and prevents the loss of bond strength to improve bonding durability. [5]

2) Removal of carious affected dentin

It is important to remove all the carious lesions on the dentin. To provide a proper marginal seal to the intact tooth structure. This will result in preventing caries progression and the formation of secondary caries. [4,5,10]

3) Chemical bonding

There are some approaches to adding functional monomer to the adhesive resin such as 10-methacryloyloxidecyldihydrogen phosphate (10-MDP). This functional monomer plays a role in increasing the chemical bonding to hydroxyapatite present in tooth structure. Some functional monomers may be added to mild self-etch adhesive systems such as N, N- Di ethanol p-toluidine (phenyl-P). This tends to enhance adhesion durability. [5,10]

4) Biomimetic remineralization

One of the latest approaches is to mimic hard tissue mineralization. This can take place by exchanging water matrix with appetite crystals in the hybrid layer. It is a process to increase mechanical properties by replacing water with minerals. Some polyanions such as polyacrylic and poly aspartic acid are used to merge with collagen and regulate physiological mineralization. This gives calcium a chance to bind and promote appetite nucleation. [5]

Some in vitro studies declared that the biomimetic remineralization strategy shows a great effect on enhancing bond strength and durability with time. Although several investigations, research, and developments for clinical application are needed. To prevent the loss of the hybrid layer integrity. [5]

5) Strategies to decrease the hydrolytic degradation of the adhesive

It is advised to use ethanol to remove the residual water, because of its high vapor pressure. Ethanol shows an effect in increasing the resin infiltration and prevention of monomer phase separation. Although it shows enhancement, especially in wet bonding, it is a sensitive technique. It requires complete evaporation as it may affect the polymerization process. [3]

Long-term adhesion to the tooth structure

It is advisable to use the selective etching technique by applying the etch on the enamel. Also, a certain conditioner is used on the smear layer and intact dentin to form exposed collagen. Hence allow space for resin infiltration. It is preferred to use MMP inhibitor or inactivator to extend the durability of the restoration and prevent hydrolytic degradation. Crosslinking agents such as DMSO may be used to make the exposed collagen matrix stiffer, and prevent its degradation. [3,5]

Conclusion

There are several factors controlling the durability of the adhesive restoration. Tooth substrate is one of the important factors as bonding to dentin require certain modification in the clinical procedure. Research and improvement in resin monomer infiltration are required. Regardless of the huge enhancement in the resin adhesive material, it is still essential to understand the process of bonding properly. [3,5]

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