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ADHESIVE SYSTEM OF DIRECT RESTORATIONS

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Certification of supervisor

I certify that this project entitled " *Adhesive system of direct restoration*" was prepared by fifth year student *Kawther Yahya Hyder* under my supervision at the college of dentistry University of Baghdad in partial fulfilment of graduation requirement for Bachelor Degree in Dentistry .

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Dedication

This graduation project is dedicated with gratitude first and foremost to my almighty God who has been with me from the beginning to this point, no word can describe how much I love you. To my parents who always motivate and support me to achieve continuous in my way, you mean the world for me. To my grandfather and grandmother, I will never forget your kindness, support and love that you had been displayed for me. And to my friends who mean a lot for me. Special thanks for you all, I will always appreciate all you have done.

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Introduction

The development and regular use of adhesive materials has begun to revolutionize many aspects of restorative and preventive dentistry. Attitudes towards cavity preparation are altering since, with adhesive materials, it is no longer necessary to prepare the cavity to provide mechanical retention through such features as dovetails, grooves, undercuts, sharp internal angles in order to retain the filling (**Vaidyanathan TK and Vaidyanathan J, et al 2009**). These techniques are, therefore, responsible for the conservation of large quantities of sound tooth substance, which would otherwise be victim to the dental bur. Micro leakage a major dental problem, which is probably responsible for many cases of secondary caries, may be reduced or eliminated. These adhesive are therefore critical for the success of aesthetic materials restorative in modern dentistry. (**Stomatol A, 2017**)

Definition of adhesive bonding and composition:

Dental adhesives: are solutions of resin monomers that make the resin dental substrate interaction achievable (**Perdigão J, 2007**). Adhesive systems are composed of monomers with both hydrophilic groups and hydrophobic groups. The former enhance wettability to the dental hard tissues, while the latter allow the interaction and co-polymerization with the restorative material (**Van Landuyt KL, Snauwaert J and De munck J et al, 2007**). The chemical composition of adhesives also includes curing initiators, inhibitors or stabilizers, solvents and, in some cases, inorganic fillers (**Van Landuyt KL, Snauwaert J and De munck J et al, 2007**). However, it is necessary to consider the anatomy of tooth. In particular, composition and structure of two main tissues, enamel and dentine, need to be examined in order to understand how they influence adhesive bonds.

The mineralized part of the tooth is a complex structure made of different hard tissues, which have a quite distinct ultra-morphology and composition. Enamel is composed of a hard solid crystalline structure-hydroxyapatite (HAp) with strong intermolecular forces, high-energy surface, besides water and organic material. Dentin is a biological composite of HAp that envelops collagen. Dentin is intrinsically humid, and less hard than enamel, with low intermolecular forces and low-energy surfaces. The dentin is different from enamel, as it has smear layer, organic contents and presence of fluid inside the dentinal tubules. In addition, the density of dentinal tubules varies with dentinal depth and, as well as the water content of dentin, is lowest in superficial dentin and highest in deep dentin. In superficial dentin, which contains fewer tubules, the permeation of resin into intertubular dentin will be responsible for most of the bond strength. In deep dentin, dentinal tubules are more in number: the intratubular permeability of resins will be responsible for higher bond strength (**Susin AH, Vasconcellos WH and Saad JR, et al 2007**). Dentin is also a substrate that undergoes change with age in an asymmetrical physiological aging process, leading to an increase of dentin thickness and decrease in dentin permeability (**Perdigão J, 2010**). Furthermore, sclerotic and carious dentin suffers structural changes that result in a higher mineralization and a consequently reduced permeability (**Perdigão J, 2010**). Unlike dentin, enamel can be dried easily: so bonding process to enamel is different from that of dentin. (**Stomatol A, Sofan E and Sofan A et.al 2007**)

The history of dental adhesive:

The history of dental adhesives started as early as 1949, when Dr. Hagger, a Swiss chemist who worked for DeTrey/Amalgamated Dental Company, applied the patent for the first dental adhesive: only dentin was initial substrate for bonding not the . Hagger patented a “Cavity Seal” material to be used in combination with the chemically curing resin “Sevriton”, in 1951. This product

contained an adhesive called glycerolphosphoric acid dimethacrylate, which was polymerized using a sulfinic acid initiator, later known as “Sevriton Cavity Seal”. This adhesive rely on acidic monomers capable of etching and interacting on a molecular level with tooth surfaces in order to form physical/chemical bonds between the restoration and the tooth. Hagger’s concept was soon adopted by other investigators and different generations of dental adhesives evolved thereafter, despite the fact it was the first time that bonding to tooth structure became commercially available through the formation of an interface very similar to what is called today the hybrid layer (**Söderholm KJ, 2007**). In 1952, it was postulated by Mclean and Kramer, that this material, “Sevriton Cavity Seal”, chemically bonded to tooth structure (**Mclean JW, and Kramer IRH, et al 1952**). This was the first report of changes in dentin promoted by an acidic monomer and may be considered to be the precursor of the hybrid layer concept (**Mclean JW, and Kramer IRH, et al 1952**). That concept is obvious in the development of newer generation of dentin adhesive. In 1954, Buonocore conducted successfully his first experiments on adhesion to enamel trough acid etching and he focused on altering the enamel surface to obtain a bond with filling material. Besides his groundbreaking research, in 1955 he described using 85% phosphoric acid to alter the enamel surface that could provide a surface suitable for bonding with risen and also to improve the retention of acrylic resin to pit-and-fissures (**Buonocore M, 1955**). The mechanism of acid-etch enhanced adhesion was not published until 1968 (**Buonocore M, Marsui A and Gwinnett AJ, et al 1968**), when Buonocore, Matsui and Gwinnett discussed the effect of phosphoric acid conditioning, which produced “prism-like” tags of resin materials that penetrated enamel surfaces. These resin tags were not seen in unconditioned enamel. The effect of phosphoric acid on enamel resulting in increased adhesion was now part of the dental literature, but it would be many years later that this principle would be widely accepted. This was the pioneering research of Minimally Invasive Dentistry (**Sezinando A, 2014**). Enamel

conditioning with phosphoric acid results in the formation of microporosities where resin penetrates to form “prism-like” resin tags. This yields an enamel bonding predominantly micromechanical (**Swift E, Jr and Perdigão J, et al 1995**). While the same concept applied to dentin in 1958 remained problematic, due to the use of strictly hydrophobic resins. As well, the high polymerization shrinkage of acrylic filling materials gave Buonocore’s invention only little impact on Restorative Dentistry at this time.

Whereas original simple bonding agents evolved to multi-step systems, recent development focuses on simplification of the application procedure in order to abate technique sensitivity and reduce manipulation time. (**Stomatol A, Sofan E and Sofan A et.al 2007**)

Composition of bonding agents:

The adhesive system consist of the following: (**Anusavice KJ, Shen C and Ralph Rawls H, 2019**).

- a. Etchant-37% phosphoric acid
- b. Primers-HEMA (2-hydroxyethyl methacrylate) is a widely used primer monomer because of its high hydrophilicity and solvent like nature.
- c. Solvents-The most commonly used solvents are water, ethanol, and acetone. Solvent has a specific contribution to improve bond adhesion
- d. Adhesives- Adhesive resins mostly composed of mainly of hydrophobic dimethacrylate such as bis-GMA, TEGDMA, and urethane dimethacrylate (UDMA)
- e. Initiators- Polymerization can be initiated through a photo initiator system consisting of the photos nsitizer (e.g. camphoroquinone) and an activator (e.g.,

tertiary amine) for a self-cure resin system with an initiator such as benzoyl peroxide

f. Fillers-silica particles

g. Other ingredients like glutaraldehyde act as desensitizer, paraben used as antimicrobials, fluoride to prevent secondary caries, and chlorhexidine to prevent collagen degradation.(Navyasri K, Krishna Alla R and Vineeth G et.al 2019)

Mechanism of action of adhesive system of direct restoration:

The primary mechanism of adhesion to enamel and dentin is attributed to micromechanical interlocking between the adhesive resin and apatite crystallites in enamel or the exposed collagen fibril net work in the dentin, the micromechanical interlocking was classified as "hybridization" to highlight the formation of distinctive layer (hybrid layer) comprising of adhesive resin and natural tooth with proprieties (**Söderholm K, 1991**)

The hybrid layer in dentin may be considered a form of tissue engineering according to pashely et al.(**Rueggeberg FA, 1991**)

However ,the inter fibrillar porosities within collagen network of 10_ 30 nm serving as a sort of scaffold for adhesive resin infiltration are far smaller than 5_20 um porosities in most bio_ engineering scaffolds (**Söderholm K, 1991**).

Secondary mechanism of adhesion comprise chemical and physical interaction between adhesive monomers and tooth tissue , chemical bonding was confirmed between certain functional monomers 10_MDP, 4_MET , and phenyl _ P and ca+2 in hydroxy apatite .it was also shown that hydrolytic stability of

formed ionic salts determine the stability of chemical bond , Four different mechanisms of adhesion have been described as follow :

1. Mechanical adhesion—interlocking of the adhesive with irregularities in the surface of the substrate, or adherent.
2. Adsorption adhesion_ chemical bonding between the adhesive and the adherent; the forces involved may be primary (ionic and covalent) or secondary (hydrogen bonds, dipole interaction or van der Waals) valence forces.
3. Diffusion adhesion—interlocking between mobile molecules such as the adhesion of two polymers through diffusion of polymer chain ends across an interface.
4. Electrostatic adhesion—an electrical double layer at the interface of a metal with a polymer that is part of the total bonding mechanism.

In dentistry, bonding of resin-based materials to tooth structure is a result of four possible mechanisms, as follows:

Mechanical—penetration of resin and formation of resin tags within the tooth surface.

Adsorption—chemical bonding to the inorganic component (hydroxyapatite) or organic components (mainly type I collagen) of tooth structure.

Diffusions—precipitation of substances on the tooth surfaces to which resin monomers can bond mechanically or chemically.

A combination of the previous three mechanisms

For good adhesion, close contact must exist between the adhesive and the substrate (enamel or dentin). The surface tension of the adhesive must be lower than the surface energy of the substrate . Failures of adhesive joints occur in

three locations, which are: 1) cohesive failure in the substrate ; (2) cohesive failure within the adhesive and (3) adhesive failure, or failure at the interface of substrate and adhesive

A major problem in bonding resins to tooth structure is that all methacrylate-based dental resins shrink during free-radical addition polymerization. Dental adhesives must provide a strong initial bond to resist the stresses of resin shrinkage (**Perdigão J, 2019**)

Enamel adhesive:

Various concentrations of phosphoric acid have been used to etch enamel. Most current phosphoric acid gels have concentrations of 30% to 40%, with 37% being the most common, although some studies using lower concentrations have reported similar adhesive values (**Gwinnet AJ, and Kanca JA, et al 1992**). An etching time of 60 seconds originally was recommended for permanent enamel using 30% to 40% phosphoric acid Although one study concluded that shorter etch times resulted in lower bond strengths, other studies using scanning electron microscopy (SEM) fig (1-1). showed that a 15-second etch resulted in a surface roughness similar to that provided by a 60-second etch (**Barkmeier WW, Shafer SE and Gwinnett AJ, et al 1986**).

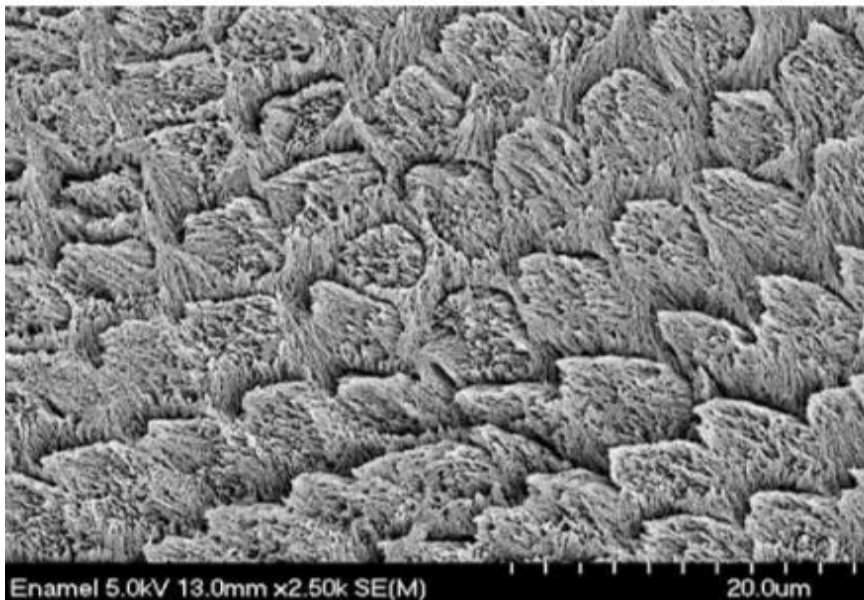


Fig (1-1): scanning electron micrograph of enamel etched with 35% phosphoric acid for 15 seconds.(**Andre V and Lee W, et al 2019**)

Other in vitro studies have shown similar bond strengths and leakage for etching times of 15 and 60 seconds(**Barkmeier WW, Erickson RL and Kimmes NS et al 2009**).

As measured in the laboratory, shear bond strengths of composite to phosphoric acid-etched enamel usually exceed 20 megapascals (MPa) and can range up to 53 MPa, depending on the test method used(**Barkmeier WW, Erickson RL and Latta MA, et al 2009**) .Such bond strengths provide adequate retention for a broad variety of procedures and prevent leakage around enamel margins of restorations(**Shafer SE, Barkmeier WW and Kelsey WP, et al 1987**)

Acid etching transforms the smooth enamel into an irregular surface and increases its surface-free energy. When a fluid resin-based material is applied to the irregular etched surface, the resin penetrates into the surface, aided by capillary action Monomers in the material polymerize, and the material becomes interlocked with the enamel surface (**Buonocore MG, Matsui A and Gwinnett AJ, et al 1968**). he formation of resin micro tags within the enamel surface is the fundamental mechanism of resin-enamel adhesion (**Barkmeier WW, Shafer SE and Gwinnett AJ, et al 1986**). Fig (1-2)



Fig (1-2): A and B Transmission electron micrographs of enamel adhesive interface after application of adper single bond .(**Andre V and Lee W, et al 2019**)

Bonding to enamel is a relatively simple process, without major technical requirements or difficulties . Bonding to dentin presents a much greater challenge. Several factors account for this differences between enamel and dentin bonding. Enamel is a highly mineralized tissue composed of more than 90% (by volume) hydroxyapatite whereas dentin contains a substantial proportion of water and organic material, primarily type I collagen.(**Veis A, 1993**) Dentin also contains a dense network of tubules that connect the pulp with the dentin enamel junction (DEJ) . A cuff of hyper mineralized dentin called per tubular dentin lines the tubules. the less mineralized intertubular dentin contains collagen fibrils with the characteristic collagen banding. Intertubular dentin is penetrated by submicron channels, which allow the passage of tubular liquid and fibrils between neighboring tubules, forming intertubular anastomoses.

Dentin adhesion

Adhesive materials can interact with dentin in different ways mechanically, chemically, or both (**Yoshihara K, Yoshida Y and Hayakawa S et al, 2011**). The importance of micromechanical bonding, similar to what occurs in the enamel bonding, has become accepted. (**Van Meerbeek B, Ionosphere S and Bream M et al, 1992**)Dentin adhesion relies primarily on the

penetration of adhesive monomers into the network of collagen fibrils left exposed by acid etching .(Tay FR, Gwinnett AJ and Wei SH et al, 1997). However, for adhesive materials that do not require etching, such as glass ionomer cements and some phosphate-based self-etch adhesives, chemical bonding between polycarboxylic or phosphate monomers and hydroxyapatite has been shown to be an important part of the bonding mechanism.(Yoshihara K, Yoshida Y and Hayakawa S, et al 2011)Contemporary strategies for bonding to dentin .

Dentin is an intrinsically hydrated tissue, penetrated by a maze of fluid-filled tubules. Movement of fluid from the pulp to the DEJ is a result of a slight but constant pulpal pressure. (Brännström M, Linden LA and Johnson G, et al 1968)Pulpal pressure has a magnitude of 25 to 30 mm Hg or 34 to cm H₂O.(Terkla LG, Brown AC and Hainisch AP, et al 1987) Dentinal tubules enclose cellular extensions from the odontoblasts and are in direct communication with the pulp Inside the tubule lumen, other fibrous organic structures such as the lamina limitans are present, which substantially decreases the functional radius of the tubule. The relative area occupied by dentin tubules decreases with increasing distance from the pulp . The number of tubules decreases from about 45,000/mm² close to the pulp to about 20,000/mm² near the DEJ.7 the tubules, occupy an area of only 1% of the total surface near the DEJ whereas they occupy 22% of the surface close to the pulp.74 the average tubule diameter ranges from 0.63 μm at the periphery to 2.37 μm near the pulp .(Marchetti C, Piacentini C and Menghini P, et al 1995)

Adhesion can be affected by the remaining dentin thickness after tooth preparation. Bond strengths are generally less in deep dentin than in superficial dentin.(Sattabanasuk V, Shimada Y and Tagami J, et al 2004)

Some dentin adhesives including one-step self-etch adhesives, do not seem to be affected by dentin depth.(**Adebayo OA, Burrow MF and Tyas MJ, et al 2008**)When the concentration of cross-linked carboxyterminal telopeptide of type I collagen was evaluated using an immunoassay to detect the degree of collagen degradation significantly increased degradation was measured for a two-step etch-and-rinse adhesive compared to a one-step self-etch adhesive.(**Zhang L, Wang DY and Fan J, et al 2014**). In the same study, collagen in deep dentin underwent significantly more degradation than collagen in superficial dentin after thermal fatigue.(**Zhang L, Wang DY and Fan J, et al 2014**) Degradation of collagen by dentin proteinases is known to negatively affect the bonded interface. (**Perdigão J 2019**)

The classification of adhesive system

The classifications of the adhesive systems have been numerous: By generations, by number of clinical steps and by modes of action (**Ekambaram M, Yiu CKJ and Matinlinna JP, et al 2014**).

The classification according to generation:

The classification by generations determined by the dental industry, refers to the order in which the adhesive systems were developed according to their complexity. Each generation has sought to reduce the number of containers involved in the process, also simplifying the number of steps (**Perdigão J, Lambrechts P and Van Meerbeek B, et al 1996**).

Table (1-1): classification of adhesive bonding according to generation.

Generation	Number of steps	Surface pre-treatment	Components	Shear bond strength (MPa)
1 st	2	Enamel etch	2	2
2 nd	2	Enamel etch	2	5
3 nd	3	Dentine conditioning	2-3	12-15
4 th	3	Total etch	3	25
5 th	2	Total etch	2	25
6 th	1	Self-etch adhesive	2	20
7 th	1	Self-etch adhesive	1	25
8 th	1	Self-etch adhesive	1	Over 30

First Generation

The first generation bonding systems were published by Buonocore in 1956, who demonstrated that use of glycerophosphoric acid dimethacrylate (NPG-GMA) containing resin would bond to acid etched dentin (**Buonocore M, Wileman W and Brudevold F, et al 1956**). These bonding agents were designed for ionic bonding to hydroxyapatite or for covalent bonding (hydrogen bonding) to collagen. However, immersion in water would greatly reduce this bond. After nine years, Bowen used a coupling agent to overcome this problem (**Bowen RL, 1965**). He addressed this issue using that acted as NPG-GMA a primer or adhesion promoter between enamel/dentin and resin materials by chelating with surface calcium, where one end would bond to dentin, and other would polymerize with composite resin (**Bowen RL, 1965**). Overall, this generation leads to very poor clinical results as well as low bond strength in the 1-3 MPa range (**Kugel G, and Ferrari M, 2000**).

Second generation

The second generation of dentin bonding agents were introduced in the late 1970s, and sought to improve the coupling agents that were utilized in the first generation of adhesives. The 2nd generation of dentin adhesives primarily used polymerizable phosphates added to bis-GMA resins to promote bonding to the calcium in mineralized tooth structure (**Kugel G and Ferrari M, et al 2000**). Bonding mechanism involves formation of ionic bond between calcium and chlorophosphate groups. This ionic bond would rapidly degrade in water submersion (again analogous to saliva) and even the water within the dentin itself, and cause debonding and/or Microleakage (**Kugel G and Ferrari M, et al 2000**). The smear layer was still not removed, and this contributed to the relatively weak and unreliable bond strengths of this second generation (**Kugel G and Ferrari M, et al 2000**). The smear layer is really a smooth layer of inorganic debris that remains on the prepared dentin surface as a result of tooth preparation with rotary instruments (the drill). This generation of bonding agents is no longer used, due mainly to failed attempts to bond with a loosely bond smear layer. Bond strength: 4–6 Mpa (**Broome JC, Duke ES and Norling BK, et al 1985**).

Third generation

In the late 1970s and early 1980s, third generation dentin bonding agents were presented. The third generation bonding systems introduced a very important change: the acid etching of the dentin in an effort to modify or partially remove the smear layer (**Kugel G and Ferrari M, et al 2000**). This opened the dentin tubules and allowed a primer to be placed after the acid was completely rinsed away. While this method achieved a greater bond, it was considered controversial in dentistry as the feeling existed that dentin ought not to be etched. After the primer was added, an unfilled resin was placed on both

dentin and enamel. The weak link with this generation was the unfilled resins that simply did not penetrate the smear layer effectively according to Tao et al. in 1988 (**Tao L, Pashley DH and Boyd L, et al 1988**).

Fourth generation

In 1980s and 1990s, fourth generation dentin bonding agents were introduced. The fourth generation materials was the first to achieved complete removal of smear layer (**Kugel G, Ferrari M, et al 2000**) and still considered as the golden standard in dentin bonding. In this generation, the three primary components (etchant, primer and bonding) are typically packaged in separate containers and applied sequentially. The concept of total-etch technique and moist dentinal hallmarks of the 4th generation systems (**Kugel G, and Ferrari M, et al 2000**), where dentin and enamel are etched at the same time with phosphoric acid (H_3PO_3) for a period of 15–20 s (**Tay FR, Gwinnett AJ and Wei SHY, et al 1994**). However, the surface must be left moist “wet bonding”, in order to avoid collagen collapse. The application of a hydrophilic primer solution can infiltrate the exposed collagen network forming the hybrid layer (**Alex G, 2008**). The hybrid layer is formed by the resin infiltrated surface layer on dentin and enamel. The goal of ideal hybridization is to give high bond strengths and a dentin seal (**Nakabayashi N, Kojima K and Masuhara E,1982**). Bond strengths for these adhesives were in the low- to mid-20 MPa range and significantly reduced margin leakage compared to earlier systems (**Buonocore M, 1955**). This system was very technique sensitive and required an exacting technique of controlled etching with acid on enamel and dentin, followed by two or more components on both enamel and dentin. These systems are very effective when used correctly, have good long-term clinical track record, and are the most versatile of all the adhesive categories, because they can be used for virtually any bonding protocol (direct, indirect, self-cure, dual-cure or light-cure). These systems are still the standards by which the newer

systems are judged. However, these systems can be very confusing and time consuming with so many bottles and application steps. Because of the complexity of multiple bottles and steps, dentists began requesting a simplified adhesive system. (**Stomatol A, 2017**)

Fifth generation

In the 1990s and in the ongoing decade, the fifth generation bonding systems sought to simplify the process of fourth generation adhesion by reducing the clinical steps which results in reduced working time. These are distinguished by being “one step” or “one bottle” system. In addition, an improved way was needed to prevent collagen collapse of demineralized dentin and to minimize if not totally eliminate, postoperative sensitivity (**De Munck J, Van Landuyt K, and Peumans M, et al 2005**). So the most common method of simplification is “one bottle system” combined the primer and adhesive into one solution to be applied on enamel and dentin simultaneously with 35 to 37% phosphoric acid for 15–20 s. This single bottle, etch-and-rinse adhesive type shows the same mechanical interlocking with etched dentin occurs by means of resin tags, adhesive lateral branches and hybrid layer formation and shows high bond strength values to dentin with marginal seal in enamel (**Alex G, 2008**). These kinds of adhesives systems may be more susceptible to water degradation over time than the fourth generation. This is because the polymerized primer of the “one bottle system” tends to be hydrophilic in nature. However, when using the fourth generation, the hydrophilic primer is covered by a more hydrophobic resin, making it less susceptible to water sorption. Not all 5th generation adhesives are compatible with dual and self-cured or core materials. The lower PH of the Oxygen-inhibited layer, or the monomers in some simplified products, are too acidic and thereby de-activate the tertiary amine in chemical-cured composites. As well as the same in regards to the number of applications

(unfilled need more applications), so it is critical to follow the manufacturer's directions.(**Stomatol A, 2017**).

Sixth generation

The sixth generation bonding systems introduced in the latter part of the 1990s and the early 2000s also known as the “self-etching primers”, were a dramatic leap forward in technology. The sixth generation bonding systems sought to eliminate the etching step, or to include it chemically in one of the other steps: (self-etching primer + adhesive) acidic primer applied to tooth first, followed by adhesive or (self-etching adhesive) two bottles or unit dose containing acidic primer and adhesive; a drop of each liquid is mixed and applied to the tooth. It is recommended that the components are mixed together immediately before use. The mixture of hydrophilic and hydrophobic resin components is then applied to the tooth substrate (**Pashly EL, Agee K and Pashly DH, et al 2002**). Evidently, these bonding systems are characterized by the possibility of achieving a proper bond to enamel and dentin using only one solution (**Kugel G, Ferrari M, et al 2000**). The biggest advantage of the sixth generation is that their efficacy appears to be less dependent on the hydration state of the dentin than the total-etch systems (**Alex G, 2008**). Unfortunately, the first evaluations of these new systems showed a sufficient bond to conditioned dentin while the bond with enamel was less effective. This may be due to the fact that the sixth generation systems are composed of an acidic solution that cannot be kept in place, must be refreshed continuously and have a pH that is not enough to properly etch enamel (**Fabianelli A, Vichi A and Kugel G, et al 2000**). In order to overcome this problem, it is recommended to etch enamel first with the traditional phosphoric acid prior to using it. However, those utilizing this technique should take care to confine the phosphoric acid solely to the enamel. Additional etching of the dentin with phosphoric acid could create an “over-etch” situation where the demineralization zone is too

deep for subsequently placed primers to completely penetrate (**Alex G, 2008**). While data indicates that 6th generation adhesives will adhere well to dentin (41 MPa at 24 hours), the bond to enamel is at least 25% weak to enamel than both the 4th and 5th generation adhesives in pooled data studies. Several respected clinicians have utilized 6th generation adhesives for bonding to dentin after selectively etching the enamel.

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Seventh generation

The seventh generation bonding systems was introduced in late 1999 and early 2005. The seventh generation or one-bottle self-etching system represents the latest simplification of adhesive systems. With these systems, all the ingredients required for bonding are placed in and delivered from a single bottle (Alex G, 2008). This greatly simplifies the bonding protocol as the claim was that could be achieved consistent bond strengths while completely eliminating the errors that could normally be introduced by the dentist or dental assistant who had to mix the separate components with other more complicated systems. However, incorporating and placing all of the chemistry required for a viable adhesive system into a single bottle, and having it remain stable over a reasonable period of time, poses a significant challenge (Alex G, 2008). These inherently acidic systems tend to have a significant amount of water in their formulations and may be prone to hydrolysis and chemical breakdown (Nishiyama N, Tay FR and Fujita K, et al 2006). Furthermore, once placed and polymerized, they are generally more hydrophilic than two-step self-etching systems; this condition makes them more prone to water sorption, limits the depth of resin infiltration into the tooth and creates some voids (Tay FR, Pashly DH, et al 2003). The advantage of this generation was not any mixing required and the bond strengths were consistent. However, the seventh generation

adhesives have proven to have the lowest initial and long term bond strengths of any adhesive on the market today that may be considered as disadvantage. Seventh generation adhesives involve the application of etch, primer, and adhesive which have already been mixed, followed by light curing the tooth. Seventh generation adhesives are “all-in-one” (Yaseen SM and Subba Reddy VV, et al 2009) if there has ever been such a thing. The clinical and scientific data on these adhesives proves that they are hydrophilic and degrade more rapidly. In addition, the chemistry must be acidic, as etch is involved in this liquid, and this has been shown to adversely react with the composite initiator systems. (Stomatol A, 2017)

Eighth generation

In 2010, voco America introduced voco futurabond DC as 8th generation bonding agent, which contains Nano sized fillers (Pashley DH and Tay FR, et al 2001). In the new agents, the addition of nano-fillers with an average particle size of 12 nm increases the penetration of resin monomers and the hybrid layer thickness, which in turn improves the mechanical properties of the bonding systems (Kasraei SH, Atai M and Khamverdi Z, et al 2009). Nano-bonding agents are solutions of nano-fillers, which produce better enamel and dentin bond strength, stress absorption, and longer shelf life (Joseph P, Yadav C and Satheesh K, et al 2013). It has been observed that filled bonding agents produced higher in vitro bond strength. These new agent from self-etch generations have an acidic hydrophilic monomers and can be easily used on the etched enamel after contamination with saliva or moisture (Karami Nogourani M, Javadi Nejad Sh and Homayunzadeh M, et al 2010). Based on the manufacturer, nano-particles acting as crosslinks, will reduced the dimensional changes (Kasraei SH, Atai M and Khamverdi Z, et al 2009). The type of nano-fillers and the method that these particles are incorporated affect the adhesive viscosity and penetration ability of the resin monomers into collagen

fibers spaces (**Kasraei SH, Atai M and Khamverdi Z, et al 2009**). Nano-fillers, with dimensions larger than 15–20 nm or a content of more than 1.0 percent by weight, both can increase the viscosity of the adhesives, and may cause accumulation of the fillers over the top of the moistures surface. These clusters can act as flaws which may induce cracks and cause a decrease in the bond strength (**Kasraei SH, Atai M and Khamverdi Z, et al 2009**).(**Stomatol A, 2017**).

Classifications according to clinical step are:

Three-Step Etch-and-Rinse Adhesive

Although the smear layer acts as a “diffusion barrier” that reduces the permeability of dentin, it may be considered an obstacle that must be removed or chemically modified to permit resin bonding to the underlying dentin (**Suyama Y, Lührs AK and De Munck J, et al 2013**)Based on that consideration, a new generation of dentin adhesives was introduced for use on acid-etched dentin.(**Eliades G, 1994**) Removal of the smear layer via acid etching led to improvements in the in vitro bond strengths of resins to dentin.(**Kanca J, 1992**)Because the clinical technique involves simultaneous application of an acid to enamel and dentin, this method was originally known as the “total-etch” technique. Now more commonly called etch-and-rinse technique, it was the most popular strategy for dentin bonding during the 1990s and remains somewhat popular today the 1990s and remains somewhat popular today

Application of acid to dentin results in partial or total removal of the smear layer and demineralization of the underlying dentin.(**Perdigão J, Lambrechts P and Van Meerbeek B, et al 1996**) Acids demineralize intertubular and peritubular dentin, open the dentin tubules, and expose a dense filigrees of collagen fibrils, increasing the microporosity of the intertubular dentin fig (2_1).

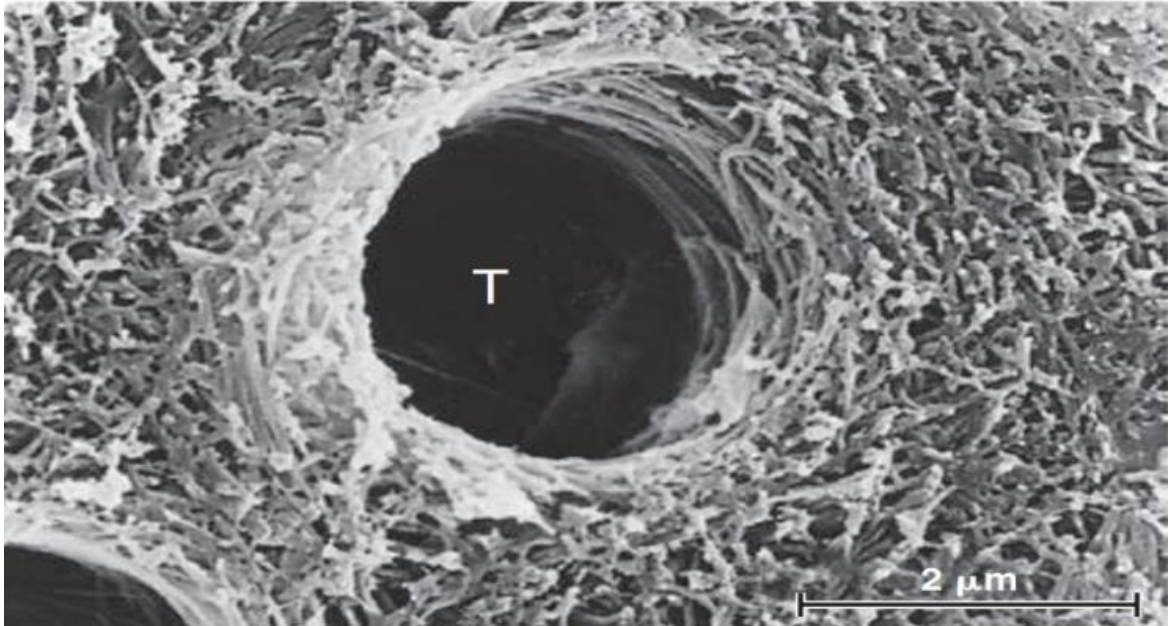


Fig (2-1):Scanning electron micrograph of dentin that was kept moist after rinsing off the etchant.(**Andre V and Lee W, et al 2019**)

Dentin is demineralized by up to approximately 7.5 μm depending on the type of acid, application time, and concentration (**Perdigão J, Lambrechts P and Van Meerbeek B, et al 1996**). (**Perdigão J, 2019**)

Two-Step Self-Etch Adhesives

Introduced in Japan, two-step self-etch adhesives (SEAs) contain an acidic monomer that functions as a self-etching primer and a hydrophobic non-solvated bonding resin. The acidic primers include a phosphonated and/or carboxylated resin molecule that performs two functions simultaneously etching and priming of dentin and enamel. In contrast to conventional etchants, the acidic primers are not rinsed off. The bonding mechanism of SEAs is based on the simultaneous etching and priming of enamel and dentin, forming a continuum in the substrate and incorporating smear plugs into the resin tags (Fig. 2-2).(Akimoto N, Takamizu M and Momoi Y, et al 2009)In addition to simplifying the bonding technique, the elimination of rinsing and drying steps

reduces the possibility of over wetting or over drying dentin, either of which can affect adhesion adversely.(**Kanca J, 1992**)Also, water is always a component of the acidic primer because it is needed for the monomers to ionize and trigger demineralization of hard dental tissues; this makes SEAs less susceptible to variations in the degree of substrate moisture but more susceptible to chemical instability due to hydrolytic degradation.(**Fukuoka A, Koshiro K and Inoue S, et al 2011**). (**Perdigão J, 2019**)

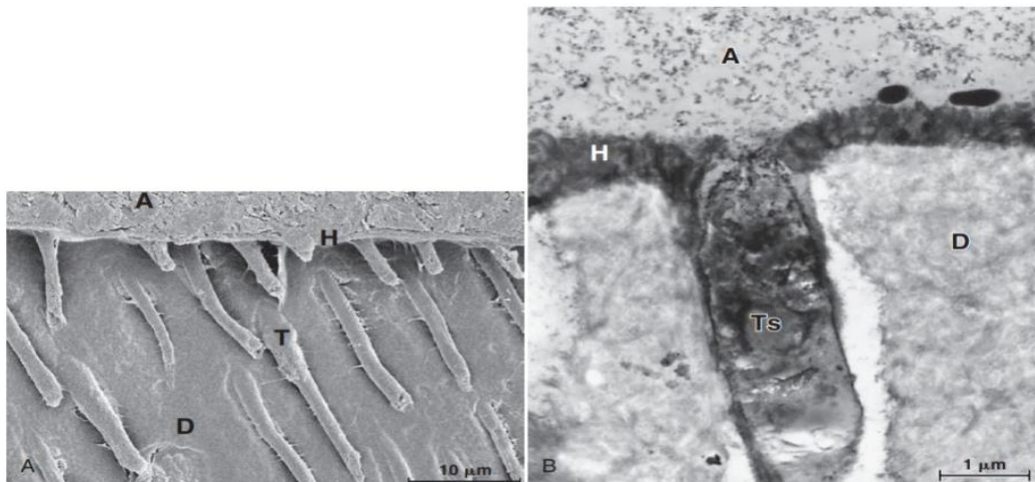


Fig: (2-2):Scanning electron micrograph of a resin dentin interface (**Andre V and Lee W, et al 2019**)

Two-Step Etch-and-Rinse Adhesives

Much of the research and development (R&D) has focused on the simplification of the bonding procedure. A number of dental materials manufacturers market a simplified, two-step etch-and-rinse adhesive system. Some authors refer to these as fifth-generation adhesives. A separate etching step still is required. In vitro dentin bond strengths obtained with two-step etch-and-rinse adhesives have improved so much that they approach the level of enamel bonding. However, three-step etch-and-rinse adhesives result in better

laboratory and clinical performance than two-step etch and-rinse adhesives.(Peumans M, De Munck J and Van Landuyt KL, et al 2012) . (Perdigão J 2019)

One-Step Self-Etch Adhesives

Continuing the trend toward simplification, no-rinse self-etch , materials that incorporate the fundamental steps of etching, priming and bonding into one solution have become increasingly popular.

In contrast to conventional adhesive systems that contain an intermediate light-cured, low-viscosity bonding resin to join the composite restorative material to the primed dentin–enamel substrate, these one-step SEAs contain uncured ionic monomers that contact the composite restorative material directly. their acidic unreacted monomers are responsible in part for the incompatibility between these simplified adhesives and self-cured composites Additionally, one-step SEAs tend to behave as semipermeable membranes, facilitating hydrolytic degradation of the resin–dentin interface.(Tay FR, Pashley DH and Suh BI, et al 2002) Because these adhesives must be acidic enough to be able to demineralize enamel and penetrate dentin smear layers, the hydrophilicity of their resin monomers, usually organophosphates and carboxylates, also is high. Some of these resin monomers are too hydrophilic, which makes them liable to water degradation.(Tay FR and Pashley DH, et al 2003). (Perdigão J, 2019)

Table 2: classification of adhesive system according to clinical step

Type	Brand Names (Manufacturer)	COMPONENTS		
		1	2	3
Three-step etch-and-rinse	Adper Scotchbond Multi-Purpose (3M Oral Care) All-Bond 2 (Bisco, Inc.) All-Bond 3 (Bisco, Inc.) OptiBond FL (Kerr Corporation) Solobond Plus (Voco) Syntac (Ivoclar Vivadent)	Phosphoric acid	Hydrophilic primer	Bonding resin
Two-step etch-and-rinse	Admira Bond (Voco) Adper Single Bond Plus (3M Oral Care) Excite F (Ivoclar Vivadent) One-Step Plus (Bisco, Inc.) OptiBond SOLO Plus (Kerr Corporation) Prime & Bond NT (DENTSPLY Sirona) Prime & Bond XP (DENTSPLY Sirona)	Phosphoric acid	Combined (hydrophilic primer + bonding resin)	
Two-step self-etch	AdheSE (Ivoclar Vivadent) All-Bond SE (Bisco) Clearfil SE Bond (Kuraray Noritake Dental Inc) Clearfil SE Protect (Kuraray Noritake Dental Inc) OptiBond XTR (Kerr Corporation)		Self-etching primer	Bonding resin
One-step self-etch	Clearfil S ³ Bond Plus (Kuraray Noritake Dental Inc) Futurabond M (Voco) iBond (Heraeus Kulzer) OptiBond All-in-One (Kerr Corporation) Xeno IV (DENTSPLY Sirona) Xeno V ⁺ (DENTSPLY Sirona)		All-in-one Self-etch hydrophilic primer/bonding resin	
Two-step etch-and-rinse or	Adhese Universal (Ivoclar Vivadent) All-Bond Universal (Bisco, Inc.) Clearfil Universal Bond (Kuraray Noritake Dental Inc) Futurabond U (Voco) One Coat 7 Universal (Coltene)	Phosphoric acid	Hydrophilic bonding resin	
One-step self-etch	Prime & Bond Elect (DENTSPLY Sirona) Scotchbond Universal Adhesive (3M Oral Care) Prime & Bond Active (DENTSPLY Sirona)		Self-etch hydrophilic primer/bonding resin	

Immediate dentin sealing (IDS)

involves applying an adhesive system to dentin directly after tooth preparation, before impression. This was considered an alternate to delayed dentin sealing (DDS), a technique in which hybridization is performed following the provisional phase and just before the indirect restoration luting procedure. This study aimed to compare the bond strength of restorations to dentin of the IDS and the DDS techniques throughout a systematic review and meta analysis. The following PICOS framework was used: population, indirect restorations;

intervention IDS; control, DDS; outcomes, bond strength; and study design, in vitro studies. (**Hardan L, Devoto W and Bourgi R, et al 2021**) after tooth preparation, before impression. This was considered an alternate to delayed dentin sealing (DDS), a technique in which hybridization is performed following the provisional phase and just before the indirect restoration luting procedure. This study aimed to compare the bond strength of restorations to dentin of the IDS and the DDS techniques throughout a systematic review and meta analysis. The following PICOS framework was used: population, indirect restorations; intervention IDS; control, DDS; outcomes, bond strength; and study design, in vitro studies. The IDS technique compared to the DDS technique were considered. Meta-analyses were carried out by using a software program (Review Manager v5.4.1; The Cochrane Collaboration). Comparisons were made by considering the adhesive used for bonding (two-step etch-and-rinse, three step etch and-rinse, one-step self-etch, two-step self-etch, and universal adhesives). A total of 3717 papers were retrieved in all databases. After full-text assessment, 22 potentially eligible studies were examined for qualitative analysis, leaving a total of 21 articles for the meta-analysis. For the immediate bond strength, regardless of the adhesive strategy used, the IDS technique improved the bond strength of restorations to the dentin ($p < 0.001$). Taking into account the subgroup analysis, it seems that the use of the IDS technique with a two-step etch-and-rinse or a one-step self-etch adhesive system does not represent any advantage over the DDS technique ($p = 0.07$, $p = 0.15$). On the other hand, for the aged bond strength, regardless of the adhesive strategy used, the IDS technique improved the bond strength of restorations to the dentin ($p = 0.001$). The subgroups analysis shows that this improvement is observed only when a three-step etch-and-rinse adhesive system ($p < 0.001$) or when a combination of an adhesive system plus a layer of flowable resin ($p = 0.01$) is used. The in vitro evidence suggests that the use of the IDS technique improves

the bond strength of dentin to resin-based restoration. (**Hardan L, Devoto W and Bourgi R, 2021**) .

Factor related to failure of resin bounding

Mechanism of hybrid layer degradations:

Degradation of the hybrid layer remains an important issue in clinical dentistry as it drastically reduce the life time of tooth colored resin composite restoration. There is a persuasive necessity to understand the underlying mechanism behind the degradation of the resin_dentin interface are (1) enzyme _mediated dentin collagen degradation (e.g. matrix metalloproteinase)(MMPs) are cysteine cathepsins (CTPs)(intrinsic or proteolytic degradation of the organic matrix) and (2) extrinsic hydrolysis of polymeric matrix . This later also includes hydrolysis of the silane_coupling molecule which may cause debonding of the fillers from the polymer matrix. These degradation processes may occur simultaneously and reduce the durability of resin_dentin bonds as well as the prognosis of tooth. (**Miletic V and Sauro S, 2017**)

Matrix Metalloproteinase inhibitors

MMPs are endogenous Zn^{2+} - and Ca^{2+} dependent enzymes, capable of degrading almost all extracellular matrix (ECM) components Mechanisms of MMPs inhibition is cationic-anionic reaction, cationic agents like chlorhexidine (CHX) may electrostatically bind to negatively-charged catalytic sites of MMPs, blocking the active site Chelating or coordinate covalence bond with zinc or calcium present in the catalytic domain also leads to loss of catalytic activities of MMPs Chlorhexidine CHX inhibition of proteases may be related to its cation chelating property, and calcium ions released by adhesive primers may be responsible for the loss of inhibition by CHX over time. Adhesives with MMPs

has the potential to decrease the degradation of the collagen brils within the hybrid layer via inhibiting the host derived collagenolytic activity.

When primer and bonding resin are applied to etched dentin, they penetrate the intertubular dentin, forming a resin–dentin interdiffusion zone that is the hybrid layer. They even penetrate and polymerize in the open dentinal tubules, and form resin tags. For most of the etch-and-rinse adhesives, the ultramorphologic characterization of the transition between the hybrid layer and the unaffected dentin suggests that a sudden shift from hybrid tissue to unmineralized tissue occurs without any un filled space or pathway that can cause leakage. The demarcation line seems to be made of hydroxyapatite crystals embedded in the resin from the hybrid layer. For self-etch systems, the transition is more subtle, with a top layer of resin-impregnated smear residues and a deeper layer, close to the unaffected dentin, rich in hydroxyapatite crystals.

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