LITERATURE REVIEW

Resin Composites

At present, amalgam is still the material of choice in normal dental practice. Although amalgam has been proven to be a superior material because of its properties and cost effectiveness, there is still controversy over its toxicity. Moreover, for patients who are concerned about their esthetics, amalgam is not the material of choice. Instead of amalgam, resin composite is the first material of choice as the demand for esthetic treatment increases.

The resin composites are made of a resin matrix, a dispersed inorganic filler of finely ground glass-like particles and a silane coupling agent that produces a bond between the matrix and the filler (Craig, Powers and Wataha, 2004). Recently, composite materials have been improved in their physical properties. They can be blended and matched to the color of natural teeth. They make the restorations look like natural teeth. In order to achieve a bond to tooth structure, they need bonding agents or dentin adhesives to promote adhesion to the remaining tooth structure.

Adhesion

Adhesion of materials to tooth structure is the most important factor in the retention of all dental restorations. The Glossary of Prosthodontic Terms (1999) defines adhesion as the property of remaining in close proximity, as that resulting from the physical attraction of molecules to a substance or molecular attraction existing between the surfaces of the bodies in contact. Adhesion can be mechanical, physical, chemical or a combination of the above.

The principle of adhesion to tooth structure is based on an exchange process between biomaterial and tooth substance (Van Meerbeek et al., 2001). The exchange process consists of 2 phases; removal of mineral content in tooth structure, resulting in micro-porosities in tooth structure and infiltration of resin within the micro-porosities or hybridization. This process results in micro-mechanical interlocking of resin monomer in the micro-porosities.

Bonding to Tooth Structure

The use of dental adhesives was started by Dr. Buonocore (Buonocore, 1955). He proposed that acids could be used to alter the tooth surface to produce a new surface to which self-curing acrylic restorative material might adhere. Enamel was etched with 85% phosphoric acid and rinsed off with water. After drying, a self-curing acrylic resin mixture was applied and allowed to harden. He found that the group whose surface was treated with acid etching had a duration of adhesion 100 times that of the untreated group.

After successfully etching enamel, Buonocore tried to etch dentin. Unfortunately, it was not successful because of very low bond strengths about 5 MPa (Nakabayashi and Pashley, 1998). The poor bond strength of early dentin bonding agents is due to their poor wetting characteristics and lack of knowledge about dentin structure (Pashley and Carvalho, 1997). Early bonding agents did not penetrate the smear layer well. SEM evaluation revealed that 5 MPa bond strengths were actually measurements of the strength of the cohesive forces holding the smear layer particles together since the failure seemed to occurred within the smear layer (Nakabayashi and Pashley, 1998).

Dentin is considered to be a complex histological structure (Pashley, 1996). Dentin can be regarded as a porous biologic composite of a collagen matrix which is filled with apatite crystal particles (Pashley, 1996; Pashley and Carvalho, 1997). When dentin is etched and air dried, hydroxyapatite crystals, that stabilize and prevent the denaturing of collagen fibers, are removed. The dentin surface becomes poor in mineral and rich with protein. Denatured collagen may interfere with resin infiltration and prevent the formation of a hybrid layer, resulting in low bond strengths. Thus, bonding to dentin is considered to be more difficult and less predictable than enamel bonding (Swift, Perdiagao and Heymann, 1995; Pashley, 1996; Frankenberger et al., 2001; Armstrong et al., 2003). Moreover, there are many variables associated with dentin bonding.

The adhesion to dentin can be affected by many factors such as the structure of the tooth and dentin and materials composition (Heymann and Bayne, 1993; Kiremitci, Yalcin and Gokalp, 2004). For example, Sattabanasuk, Shimada and Tagami, (2004) found that the orientation of dentinal tubules is a factor affecting bond strength.

They found that the bond strength in prepared perpendicular dentin surfaces was higher than that in prepared parallel dentin surfaces. This is because perpendicular dentin surfaces have more intertubular dentin than parallel dentin surfaces in order to form the hybrid layer. Moreover, the presence of moisture from the pulp would interfere with the creation of bond strength (Burrow et al., 1994; Pashley, 1996; Armstrong, Boyer and Keller, 1998). The moisture in dentin is associated to the location of the dentin. The inner third of dentin located near the pulp is dense with dentinal tubules. The increased moisture from deep dentin interferes with the infiltration of resin monomers between the collagen fibers, resulting in a decreased resin impregnated layer necessary to create high bond strengths. However, Burrow et al. (1994) found that tooth age and dentin depth were not significant factors in regards to bond strength when more recent bonding systems were employed.

The bond strength is also based on the chemical composition of bonding adhesive systems used (Heymann and Bayne, 1993; Tjan, Castelnuovo and Liu, 1996; Nikaido et al., 2002; Sung et al., 2002; Lopes et al., 2004; Sattabanasuk et al., 2004).

Dentin Bonding Agents/Dentin Adhesives

Generally, the conventional bonding adhesive consists of three steps, etching, priming and bonding. Various kinds of acids and concentrations such as 10% maleic acids, 2.5% nitric acid, 37% phosphoric acids are used to improve mechanical bonding. However, 30%-40% concentrations of phosphoric acids are mostly used to etch enamel and dentin (Swift et al., 1995; Moll, Park and Haller, 2002). Etching removes the smear layer, opens dentinal tubules, and decalcifies intertubular and peritubular dentin. In conventional adhesives, primer is necessary to re-expand the collagen fibers. Primers act as adhesion promoting agents that help monomer to spread and diffuse into the deeply exposed collagen network by chasing water on the demineralized dentin. Primers contain hydrophilic and hydrophobic groups and are designed to improve the wettability of acid etched dentin. A hydrophilic group such as HEMA (2-hydroxyethyl methacrylate) and PENTA (dipentaerythritol pentaacrylate monophosphate) dissolved in solvent like acetone, ethanol or water. HEMA is an important ingredient for priming in

many current dentin adhesives. HEMA in the primer or conditioner promotes the diffusion of resin monomer into the deeply exposed collagen network, thereby preventing the collapse of the collagen fibers (Ferrari *et al.*, 1996). Bonding agent fundamentally consists of hydrophobic methacrylate-based monomers such as Bis-GMA (bisphenol A glycidyl methacrylate), UDMA (urethane dimethacrylate). Resin monomer infiltrates into the demineralized tooth surface and is polymerized to create the resin tags of the hybrid layer.

The hybrid layer or the hybridized dental hard tissue is the structure formed by demineralization of the dentin surface and subsurface, followed by infiltration of monomer and polymerization. (Nakabayashi and Pashley, 1998) The benefits of the hybrid layer are that it provides high bond strengths between resin and dentin because of its micromechanical interlocking properties and it reduces the micro-leakage between the restoration and the tooth substrate as a result of penetration into dentinal tubules. The hybridization of dentin changes the physical and chemical properties of tooth structure (Nakabayashi and Pashley, 1998). Therefore, new alternative treatment options for the treatment of proximal caries and preventive dentistry have been developed such as conservative tooth preparation or minimal intervention (Joynt *et al.*, 1991) including tunnel restorations and mini-box restorations.

Dentin bonding systems have been directed towards the use of more simplified bonding procedures. Simplified version of dentin adhesives such as one-bottle total-etch adhesives, self-etch adhesives, and the recently introduced all-in-one self-etch adhesives have been proposed in the market. At present, there is no formal classification of adhesive systems, but they can be classified according to their adhesive strategy into three groups, total-etch adhesives, self-etch or self-conditioning adhesives and resin-modified glass-ionomer adhesives (Van Meerbeek *et al.*, 2001).

Current dentin adhesives employ two different means to achieve micro-mechanical retention between resin composite and tooth structure (Tay and Pashley, 2001; Say *et al.*, 2005). The first method removes the smear layer completely and demineralizes tooth structure via acid etching and rinsing, followed by the application of an adhesive resin known as total-etch or etch and rinse adhesive systems. The second

method simultaneously demineralizes dentin and infiltrates it with adhesive monomers. This adhesive system does not totally remove the smear layer. On the other hand, it uses the smear layer as a bonding substrate. It incorporates the smear layer into the hybrid layer. The latter method is known as self-etch adhesive systems

Total-etch Adhesive Systems

The major changes in dentin adhesives were made in Japan in 1977 when the first chemically adhesive resin composite was developed by Kuraray Med Inc. (Ex. Kuraray Co.) and the total-etch technique by Dr. Fusayama was introduced (Fusayama, 1993). This technique simultaneously etched enamel and dentin with the same conditioner (Kanca, 1992).

Total-etch adhesive systems require completely removal of the smear layer and demineralization of tooth substrate via acid etching. Various kinds of acids and concentrations such as 10% maleic acids, 2.5% nitric acid, 37% phosphoric acids are used to provide mechanical bonding. However, 30%-40% concentrations of phosphoric acids are mostly used to etch enamel and dentin. The studies have shown that pH, concentration and application time of etchant can influence the depth of the decalcification (Swift et al., 1995). Etching removes the smear layer, opens dentinal tubules and decalcifies intertubular and peritubular dentin. This is followed by an application of primer and adhesive resin. The priming step of the total-etch technique is a critical procedure, especially when an acetone-based adhesive is use. It has been shown that after acid etching, rinsing, drying and then priming the dentin, a dense layer of collagen fibers covers the prepared surface, making the penetration of bonding resin into the decalcified dentin more difficult (Burrow et al., 1994). Therefore, the wet or moist bonding technique, where the dentin surface is visibly moist, is recommended to improve bond strengths of adhesive systems that use a highly volatile solvent such as acetone (Kanca, 1991,1992; Tay, Qwinnett, Wei, 1996; Al-Ehaideb and Mohammed, 2000; Frankenberger et al., 2001). Kanca (1991) found that bond strengths of total-etch adhesive systems would be dramatically increased when using the wet bonding technique. He explained that it was due to the properties of acetone-water interactions.

The acetone and resin mixture chases and displaces water. If the dentin surface is dried, there is no interaction with water. Thus, the primer molecule will not spread through the dentin surface, resulting in inadequate adaptation between the resin and dentin surface. It has been documented that the use of acid to etch dentin can result in the porous zone beneath the hybrid layer, possibly due to the collapse of collagen network (Cardoso et al., 2004). The incomplete infiltration of resin monomer within the demineralized subsurface and hybrid layer, could be susceptible to degradation and result in low bond strengths (Prati et al., 1998; Perdigao et al., 2000; Tay and Pashley, 2001).

On the other hand, if the demineralized dentin surface is too wet, water will compete with resin to fill in the tubular dentin, which makes it more difficult for hydrophilic monomers to displace water. The excess water will also dilute the adhesive solvent and cause phase separation of the monomer (Tay et al., 1996). Resin globules and blister-like spaces are formed on the dentin surface instead of resin tags, resulting in low bond strengths.

In clinical situations, it is difficult to perform the wet bonding technique because of the complexity of the cavity. Moreover, it is difficult to indicate the right degree of wetness. Thus, it is shown that the total-etch technique is a sensitive technique because it can be affected by both the overly dry and overly wet phenomena.

Self-etch Adhesive Systems

The self-etch adhesive system was first introduced in Japan. This adhesive system combined the etching and priming procedure to treat dentin and enamel simultaneously. The applications of self-etch adhesive are considered to be less technique sensitive (Frankenberger, Kramer and Petschelt, 2000; Tay and Pashley, 2001) and less time consuming than conventional adhesive systems because no etching and rinsing procedures are required. This results in the reduction of the problems from total-etch wet bonding technique, overly wet and overly dry phenomena, that decreases the bond strength.

Another advantage of the self-etch adhesive system is the potential for reducing post-operative pain (Unemori *et al.*, 2001; Goracci *et al.*, 2004), which can be explained by the hydrodynamic theory. According to this theory, once dentin is exposed, external stimuli cause dentinal fluid shifts across dentinal tubules which activate pulpal nerve and cause pain (Pashley and Carvalho, 1997). A clinical study by Unemori *et al.* (2001) found that dentin bonding agent that required acid etching of dentin had a significant prevalence of post-operative sensitivity. Self-etch adhesive systems had less post-operative sensitivity. This is because self-etch adhesive systems do not completely remove the smear layer. The resin infiltration of self-etch adhesive occurs simultaneously with the self conditioning process. The smear layer is incorporated into the hybrid layer. Since the resin monomer can penetrate into dentin at the same level of dentin decalcification (Goracci *et al.*, 2004), there would be no gap between resin material and dentin surface. Thus there is no gap or micro-leakage to allow the movement of dentinal fluid. Thermal stimuli or mechanical stimuli, that can cause a sudden movement cf dentinal fluid, can not be transferred when the dentinal tubules are occluded with smear plugs.

The self-etch adhesive systems primarily rely on acidic resin monomers for substrate conditioning such as phenyl-P (2-methacryloxy ethyl phenyl hydrogen phosphate) or MDP (10-methacryloyloxy decyl dihydrogenphosphate), that are dissolved in ethanol or acetone with an amount of water. Water in self-etch adhesives is an essential component to enable ionization of acidic monomers and demineralization of dental hard tissues (Tay and Pashley, 2001). Acidic resin monomers are used as both etchant and priming resins, thus reducing the likelihood of incomplete resin infiltration within the partially demineralized dentin because both processes occur in the same time. These bonding systems do not completely remove the smear layer. On the contrary, they use the smear layer as a bonding substrate.

Self-etch adhesives can be subdivided into mild, intermediate strong and strong self-etch adhesives, depending on pH and etching potential (Tay and Pashley, 2001; Van Meerbeek *et al.*, 2003; De Munck *et al.*, 2005). However, etching aggressiveness is not correlated with bonding effectiveness, as some mild and intermediate strong

adhesives approach the standard of etch and rinse adhesives (De Munck *et al.*, 2005). Mild self-etch adhesive systems usually have a pH of around 2. This adhesive partially demineralizes dentin and produces a shallow hybrid layer. The smear layers and smear plugs are reserved and are incorporated into the hybridized complex. Although mild self-etch adhesive interacts superficially with tooth substrate, an additional chemical bonding to hydroxyapatite may contribute to the favorable bonding effectiveness. Because of mild aggressiveness of adhesives, hydroxyapatite is not totally removed from the collagen fibrils. The residual hydroxyapatite may serve as a receptor for additional chemical bonding (Van Meerbeek *et al.*, 2001, 2003; Yoshida *et al.*, 2004). Carboxylic acid-based monomers such as 4-MET (4-metracryloyloxyethyl trimellitic acid) and phosphate-based monomers such as phenyl-P (2-methacryloxy ethyl phenyl hydrogen phosphate) and MDP (10-metracryloyloxy decry dihydrogenphosphate) have a chemical ionic bonding potential to the calcium of the remaining hydroxyapatite (Yoshida *et al.*, 2004).

Intermediary strong self-etch adhesives have a pH of around 1.5. The pH and the interfacial morphology of this adhesive group are in between the mild and strong aggressive self-etch adhesives. For the moderately aggressive type, the smear layers and the smear plugs are partially dissolved and remnant hybridized smear layers and smear plugs were seen only when the smear layer was thick.

Strong self-etch adhesives have a pH of around 1 or below. The more aggressive self-etch adhesive systems completely dissolve the smear layers and smear plugs and produce similar etching interfacial dentin and enamel morphology and a thickness of hybrid layers that the typical total-etch adhesive produce (Pashley and Tay, 2001; Tay and Pashley, 2001; Van Meerbeek *et al.*, 2001; De Munck *et al.*, 2005). The thickness of the hybrid layer produced by strong self-etch is thicker than that produced by mild self-etch. However, there is no correlation between the thickness of the hybrid layer and the bond strength (Burrow *et al.*, 1994; Prati *et al.*, 1998; Perdigao *et al.*, 2000; Van Meerbeek *et al.*, 2003; Cardoso *et al.*, 2004; De Munck et al., 2005). Studies found that thin hybrid layer (about 0.5 μm) produced by mild self-etch

adhesives can create high bond strengths of up to more than 50 MPa (Tay and Pashley, 2001; Zheng et al., 2001).

The hybrid layers and the relatively thick adhesive layer form an artificial elastic cavity wall between the shrinking restoration and the rigid dentin substrate. The elastic bonding area might act as a shock absorber between tooth and composite and compensate for the polymerization shrinkage of the restorative resin (Van Meerbeek et al., 1993, 2001; Chiba et al., 2004). Additionally, an adequately thick adhesive layer permits a limited polymerization inhibited by oxygen of the resin surface without impairing the resin-dentin bond. Thick adhesive layer also aids in absorbing masticatory forces, tooth flexure effects and thermal cyclic shocks (Van Meerbeek et al., 2001).

The concern of self-etch adhesives is that they are not aggressive enough to induce a highly retentive etch pattern on the enamel surface. Nevertheless, many studies (Kanemura, Sano and Tagami, 1999; Lopes et al., 2004) found that there were no differences in bond strengths to ground enamel treated with phosphoric acid total-etch systems and self-etch adhesive systems. Moreover a report from Kiremitci et al. (2004) showed that self-etch adhesive systems produced better bond strength to enamel when compared to other adhesive systems. But in intact enamel, self-etch adhesives produced lower bond strengths than did the bonding system with phosphoric acid (Kanemura et al., 1999).

Problems Related with the Use of Resin Composite

The procedure to restore a tooth with resin composites is considered both time consuming and technique-sensitive. One of the problems associated with the bonding procedure of direct resin composite restorations is clinical contamination. During clinical procedures of direct resin composites restorations, especially when the lesions are near gingival areas many forms of contamination such as saliva, blood, gingival fluid, mouth rinse (essential oil), aluminum chloride and bleaching gel can affect bond strength (Xie et al., 1993; Powers et al., 1995; Benderli et al., 1999; Kaneshima et al., 2000; Chiba et al., 2004; Park and Lee, 2004; Say et al., 2004).

Thus, during a direct restorative procedure especially in gingival areas, gingival retraction is required to achieve a clear gingival margin surface and to control sulcular seepage and hemorrhage (Donovan, Gandara and Nemetz, 1985). Techniques used to accomplish gingival deflection are mechanical, chemical and surgical or combinations of the three techniques (Donovan et al., 1985; Fazekas et al., 2002). Placement of a rubber dam is an ideal method to isolate the field of operation and control moisture (Kidd et al., 2003; Sturdevant et al., 2002; Shillingburg et al., 1997). However, the most commonly used gingival deflection method is gingival cord retraction (Donovan et al., 1985).

Topical anesthetic agents are sometimes used in gingival cord retraction procedures to avoid administration of local anesthetic injections. A topical anesthetic gel used for those purposes may not be totally rinsed off from the operation area because of its sticky and high viscosity properties. Additionally, its color still remains on the oral mucosa after rinsing with water several times. Consequently, topical anesthetic gel might affect bond strengths of dentin adhesives.

Topical Anesthetic Gel

Administration of local anesthesia via needle injections is routinely used to prevent pain and discomfort for dental procedures. Needle insertions of local anesthesia are frightening and anxiety-provoking procedures for many people. A survey in the States (Milgrom et al., 1995) reported that more than 25% of adults surveyed expressed at least one clinical fear of injections. Almost one in 20 respondents indicated avoiding, canceling or not appearing for dental appointments because of fear of dental injections.

Consequently, the dental profession has developed many techniques and materials to reduce perceptions of pain and anxiety including smaller needles and topical anesthetic agents. Topical anesthetic agents are mainly used in dentistry to deminish pain of local anesthetic injections (Holst and Evers, 1985; Vickers and Punnia-Moorthy, 1992; Tulga and Mutlu, 1999; Friskopp, Nilsson and Isacsson, 2001). Other indications for the use of topical anesthetic agents include drainage of intra-oral abscess, removal of loose deciduous teeth (Vickers and Punnia-Moorthy, 1992),

placement of rubber dam clamp (Roghani, Duperon and Barcohana, 1999), and scaling and root planing (Carr and Horton, 2001; Friskopp et al., 2001). In this study, the authors' purpose in the use of topical anesthetic gel is to reduce pain prior to the placement of gingival retraction cord in restorations of cervical lesions.

Topical anesthetic gels can be simply classified into two groups; water soluble and oil soluble (Gurney, 1966a). Oil soluble anesthetic agents can be slightly soluble in water and tissue fluids (Gurney, 1966a). The commonly used topical anesthetic agents such as lidocaine, benzocaine and tetracaine are water soluble (Gurney, 1966b). There are many different forms and contents of topical anesthetic agents such as 5% EMLA (Eutectic Mixture of Local Anesthetics) cream, 5% or 10% Xylocaine, 10% or 20% benzocaine gel, etc.

A study that compared the clinical effectiveness of the topical anesthetic agents, 5% EMLA cream, 10% cocaine, 10% lidocaine, 10% benzocaine and 1% dyclocaine, found that 5% EMLA had better performance than other topical anesthetic agents (Holst and Evers, 1985; Roghani et al., 1999). However, when 5% EMLA was compared with 20% benzocaine gel and other topical anesthetic agents, 20% benzocaine was more effective than 5% EMLA in reducing pain after 2-minute applications and when evaluated with a visual analogue scale (Tulga and Mutlu, 1999).

Effect of Contamination on Bond Strength

Good adhesion between tooth substrate and resin composite produces well-sealed margins and long lasting restorations (Burrow et al., 1994). On the other hand, poor adhesion can induce micro-leakage, marginal discoloration, gap formation and postoperative sensitivity, resulting in failure of the restorations.

In order to get an optimally bonded interface requires that the surface of the substrate must be clean (Craig and Powers, 2002). Thus, clinical contamination during bonding procedures can lower bond strength between resin composite and tooth structure. Many articles that studied the effects of contamination on bond strengths found that bond strengths were affected by many forms of contamination, however,

bond strength can be recovered or improved by immediately rinsing, re-etching and re-priming. (Powers *et al.*, 1995; Benderli *et al.*, 1999; Kaneshima *et al.*, 2000).

Although there are many studies about the effect of various contaminations on bond strength, there are very few reports about the effect of topical anesthetic gels on the bond strength of adhesives to dentin. The present study will investigate the effect of a topical anesthetic gel contamination on the bond strength of three bonding adhesive systems, all-in-one self-etch, two-step self-etch and one-bottle total-etching adhesive.

Bond Strength Testing Method

Adhesion of materials to tooth structure and resistance to adhesion failure are important in all dental restorations. High bond strengths contribute to the ability to withstand stresses and retention of the restoration. The strengths of the bonded system are measured by bond strength testing (Craig and Powers, 2002). Bond strength testing is one of the popular analyses used to evaluate dental materials (Bayne, 2002). The type of bond strength test is categorized in terms of the mechanical loading direction. Most bond strength tests are categorized as tensile or shear. The testing method is an important factor that affects the bond strength values (Tjan *et al.*, 1996).

In the shear bond strength testing method, after an application of adhesives, resin composite will be applied in a ring. The specimen will be subjected to shear force by using a wire loop, a knife-edge shear blade or a blunt shear bar. There is some variability with the type of blade used for shear testing method.

A micro-tensile bond strength testing method was introduced by Sano *et al.* (1994). This method involved applying adhesive to the flat dentin surface, which is covered with resin composite or a crown build-up. The bonded composite block is multiply serial sectioned. The resulting slabs are composed of an upper half of resin composite and a lower half of enamel or dentin with the bonded surface area being about 1-mm^2. Sano et al. (1994) found that with small bonded surface areas, higher bond strengths were obtained than large bonded surface areas. They concluded that the defect distribution for a larger bonded surface area might be more than that for a small bonded surface area.

The advantage of the micro-tensile method is that the bond strength is dependent on the bonded surface area (Schreiner *et al.*, 1998). When the bond strength was high in a micro-tensile test, the failure was found within the adhesive. In a shear test, the failure is usually found in the substrate. Thus, the micro-tensile test may indicate the true bond strength value of the material. The micro-tensile method produced a more definitive assessment of bond strength than the shear method (Schreiner *et al.*, 1998). Moreover, the micro-tensile test facilitates the failure analysis by a scanning electron microscope (SEM) because the surface area is about $1mm^2$ (Pashley *et al.*, 1995).

Failures of bonding agents can occur in dentin, resin material or mixed. Scanning electron microscopes (SEM) are used to identify the failure mode by determining the surface morphology and texture of material. The advantages of SEM over other imaging methods are; it provides more surface information because of its greater resolution, depth of field, and absence of light scattering.