CHAPTER 5

DISCUSSION

The effect of simulated pulpal pressure on the microtensile bond strength of dental adhesive used for restoration of primary incisor teeth was investigated in this study. In vital teeth, they have spontaneous outward flow of dentinal fluid through the exposed dentin due to significant amount of intrapulpal pressure. The average value of this pressure in vital teeth has been reported by Brown (1964) is approximately 30 mmHg or 40.79 cmH_2O, by Pashley (1981) is 24.1 mmHg or 32.6 cmH_2O, by Mitchem (1988) is 25 mmHg or 34 cmH_2O, by Ciucchi (1995) is 24 mmHg or 32.5 cmH_2O and by Vongsavan and Matthews (1992) is 11 mmHg or 15 cmH_2O. However, in the experiment of Vongsavan and Matthews (1991) on cat teeth suggested that the pressure of -15 cmH_20 was needed to be applied to prevent the Evan’s blue dye to penetrate the dentinal tubule. This study found that the bond strengths between the group of dry teeth and -30 cmH_2O were not significantly different, although the latter group tended to have lower bond strength values. This suggests that at the pressure of -30 cmH_2O the moistness of dentin surface is close to dry dentin surface.

The pulpal pressure in vital teeth is not constant. It depends upon the pulpal condition. Increasing in local and systemic blood pressures due to local inflammation from bacteria or restorative procedure or other systemic conditions may lead to an increase in pulpal pressure (Stenvik *et al.*, 1972). Since blood vessels become vasodilation and increasing their permeability. These reactions result in an increase in pulpal fluid volume and eventually increase in pulpal pressure (Heyeraas and Kvinnsland, 1992). The pressure of +30 cmH_2O was aimed to represent the inflamed pulpal condition which had higher pulpal tissue pressure. This group had the lowest bond strength value as the result of more fluid flow out of dentinal tubules and eventually weakened the adhesive bond strength.

On the other hand, decreasing local blood pressure by injection of local anesthetic solutions containing vasoconstrictor may decrease the pulpal pressure (Cauvin and Kirkendol, 1980). Thus, intrapulpal pressure should be considered in *in vitro* studies. In this study we selected to simulate the intrapulpal pressure range from -30 to +30 cmH_2O to be tested for evaluate the effect of bonding agent on the extracted tooth specimens. This range corresponds to the suggestion of Pashley (1995) which stated that bonding and storage of dentin specimens should be done at simulated pulpal pressures of 15-33 cmH_2O. This study showed that the results obtained at +30 cmH_2O were the lowest and were significantly different from other groups, while the group of 0 and -30 cmH_2O obtained higher bond strength values. This suggests that at the higher pulpal pressure the dentinal fluid can be pushed out and moist the dentin surface more than at the lower pulpal pressure. Therefore, the more pressure was applied, the lower the bond strengths obtained.

The fluid droplets were observed on the cut dentin surfaces in primary incisors during simulated intrapulpal pressure by connected water manometer to the samples *in vitro* by using impression and replica technique (Rangcharoen et al 2010). Their result suggested that dentin surface was wet by pulpal outward fluid flow through dentin tubules present on the dentin surface. These emerging fluid droplets were also observed in primary teeth *in vivo* (Den-Udom et al., 2004). The volume of fluid was increased with time and was reduced after infiltrated of local anesthesia with vasoconstrictor. Corresponding with the study of Vongsavan and Matthews (1991), spontaneous outward flow of dentinal fluid which was a resulted of pulpal tissue fluid pressure was greater than atmospheric pressure in cat canine *in vivo.*

Several studies demonstrated that the bond strengths of some dentin bonding systems are influenced by physiologic pulpal pressure and suggest that dentin permeability or dentin wetness may be important variables that can influence the bond strength of bonding materials (Tao and Pashley, 1989). The study of Chiba (2006) reported moisture affected to bonding agents by decreasing adhesive bond strength. We also found that the wetness of dentin surface due to outward of dentinal fluid is a crucial factor for determine the success of resin restoration which few studies have taken it into their account. However, previous studies reported diminished in dentinal bond strength when testing bond strength of adhesive materials *in vitro* with simulating physiologic conditions (Mitchem *et al.*, 1988). The studies of Kanca (1992) reported that intrapulpal pressure can lead to the change of dentinal bond strength. As with the study of Prati and Pashley (1992) reported similar finding including the higher permeability and wetness in deep dentin when testing bond strength of adhesive materials *in vitro* with the intention of simulating *in vivo* conditions. These corresponded to the study of Moll and Haller (2000) which found that continuous intrinsic moisture in the form of hydrostatic pulpal pressure adversely affects the efficacy of dentin bonding systems, while limited extrinsic moisture by moist bonding is acceptable. In deeper dentin, increasing in the density and diameter of dentinal tubules leads to increasing of intrinsic water content of dentin. These factors may reduce the bond strengths and the longevity of the restoration (Prati *et al.*, 1991; Pashley, 1991). Therefore, the intrinsic wetness of dentin which results from the perfusion of dentinal fluid should be considered when bonding to deep dentin (Itthagarun and Tay, 2000).

Wet bonding technique plays a role in new bonding procedure. The advantages of a wet bonding technique are related to the ability of water to keep the demineralized collagen network open during primer infiltration. However the fluid flow through dentin may result in large amounts of water on the bonded surface, thus impeding the optimal interaction between the adhesive and the dentin substrate (Moll *et al.*, 2005; Hosaka *et al.*, 2007; Sauro *et al.*, 2007). Resin monomers are prevented from infiltrating the dentinal tubules and demineralized collagen network by perfusion of dentinal fluid, thus preventing resin tag and hybrid layer formation (Moll and Haller, 2000).

However, intrapulpal pressure may interfere with the bond strength of some adhesive systems to dentin, depending on their composition and approach (Cardoso *et al.*, 2008). In addition, the presence of dentinal tubules on the dentin surface tend to dilute the dentin conditioner, decreases its potential for demineralization of the intertubular and peritubular dentin and eventually lower the bond strength (Perdigao *et al.*, 1996). Cardoso and colleagues (2008) found that the tensile bond strength of total-etch adhesives were reduced more than self-etch adhesive under simulated intrapulpal pressure. This corresponds to the studies of Moll and colleagues (2005) that dilution of primer monomers by the increased outward flow of water after phosphoric acid-etching decreases in bond strength of the etch and rinse approach. Because acid etching increases dentin permeability and dentin wetness, successful bonding of adhesive resins to acid-etched dentin requires the use of hydrophilic resins that bond equally well to both peritubular and intertubular dentin (Pashley, 1992). However, the hydrophilic component of adhesive resins applied on dentinal tissue may also promote outward fluid shifts (Sauro *et al.*, 2007). Thus, the outward movement of dentinal fluid under pulpal pressure may probably diffuse polymerized hydrophilic adhesives, impede monomer infiltration into the demineralized collagen matrix, and contaminate the bonding surface with water.

Most adhesive systems contain a relatively high concentration of solvents and hydrophilic monomers to improve wetting and spreading of adhesives on dentin. Such highly hydrophilic co-monomers produce highly hydrophilic polymers that permit movement of water molecules from dentin across the adhesive layer. HEMA (2-hydroxyethyl methacrylate), a component of Single Bond which were used in this study is one of these monomers. HEMA are capable of absorbing water within the adhesive and hybrid layers, thus water remains entrapped at resin-dentin interfaces. Whereas it makes the complete evaporation of water difficult, because an increased in HEMA concentration lowers the vapor pressure of water. Thus, the residual water may interfere with polymerization of the adhesive monomers. However demineralized dentin surface must be kept moist during adhesive procedures in order to promote proper resin monomer infiltration into the exposed collagen fibrils (Van and Shaka, 1998). Thus, some water is crucial to prevent the collagen network from collapsing (Pashley *et al.*, 1993), while an excessive moisture condition contribute to reduce the mechanical properties of the adhesive layer (Jacobsen and Soderholm, 1995). As demonstrated in this study, lower bond strength values to the primary teeth could be obtained from the groups which simulated intrapulpal pressure when compared to the group of dry teeth. This suggests that there was fluid filled in the dentin matrix even at 0 cmH_2O or -30 cmH_2O.

Regional differences in dentin anatomy and permeability have a significant influence on dentin bond strength (Inoue *et al.*, 2003). In the center of dentin surface, the sizes of dentinal tubules are larger and the lengths of dentinal tubules are shorter (Garberoglio and Brannstrom, 1976; Koutsi *et al.*, 1994). Thus, the fluid should be easier flow through the dentinal tubules than those from peripheral area. Moreover, the direction of dentinal tubule on the cut dentin surface depends on its location (Cagidiaco *et al.*, 1997). Therefore, the structural differences of cut dentin surfaces may influence the structure of the resin-dentin interface and the bond strength of resin to dentin. Previously, in a study of regional bond strengths to cervical wedge-shaped cavity using self-etching/priming systems, the authors reported that the bond strengths of these systems was higher to the occlusal wall than to the gingival wall (Ogata *et al.*, 1999). The orientation of tubules within the occlusal wall was parallel to the interface, while the gingival wall was perpendicular to the interface. Moreover, in a study of effect of tubule orientation on hybrid-layer formation, the authors reported that the orientation of the dentinal tubules had an effect on the formation of the hybrid layer (Schupbach *et al.*, 1997). In the areas with perpendicular tubule orientation, there were thicker hybrid layer and longer resin tags than those with parallel tubule orientation. However, occlusal dentin has greater regional variability of dentin wetness than in proximal or buccal dentin due to variable orientation of dentinal tubules (Prati *et al.*, 1991; Prati and Pashley, 1992). With this reason, it can lead to uncontrolled error occurring from bonding, when using dentin disk in the study of adhesive bond strength. Thus, the flatted dentin surfaces from incisal edge were used in this study.

Sound teeth were used in the study while carious teeth are not ideal models for comparison of the micromorphology of resin-dentin interfaces in primary and permanent dentition (Elkins and McCourt, 1993). The carious structures are influenced by different stages of disease progression which lead dentinal tubules to be irregular and occluded by re-precipitation of some of the dissolved mineral salts. In addition, the formation of tertiary dentin occurs at the pulpal aspect of the tubules affected by caries. Both the occlusion of the tubules and the tertiary dentin formation will reduce the permeability of dentin, thus inward and outward flow of dentinal fluid cannot be controlled. With this reason, the carious teeth are not reliable (Nor *et al.*, 1996). From previous bond strength studies found that microtensile bond strength to caries-affected dentin is lower than to sound dentin but hybrid layers are thicker than those in sound dentin (Scholtanus *et al.*, 2010).

There were several studies which had demonstrated an inverse relationship between the adhesive bond strength and the intrapulpal pressure. Pioch *et al.* (2001) compared shear bond strength of different bonding agents with and without simulated pulpal pressure, they concluded that pulpal pressure simulation decreases bond strength of all bonding agents and revealed a shallower penetration of the adhesives into dentin surface in samples with pulpal pressure by confocal laser scanning microscopy analysis at dentin-adhesive interface. Although, the bond strength test method (shear bond strength) of their study was different from our study (microtensile bond strength), the outcomes were similar. Moll *et al.* (2005) evaluated microtensile bond strength of self-etching adhesive systems with simulated pulpal pressure. The simulated pulpal pressure reduced microtensile bond strength of all adhesive in their study. In addition, Sauro *et al.* (2007) compared the microtensile bond strength of self-etching adhesives under and without simulated pulpal pressure. They reported that simulated pulpal pressure significantly reduced bond strength values, but the amount of this reduction was not the same for different bonding agents. They claimed to the differences in hydrophilic natures of adhesive monomers, while blisters and water channels of HEMA-based adhesives were responsible for inducing greater stress at the interface between the adhesive film and overlying resin composite. The only HEMA free adhesive tested had the least reduction in bond strength values due to pulpal pressure simulation. From these results, decreasing in bond strength due to pulpal pressure simulation has been expected in our study.

Although the result of this study corresponds to other previous studies, it can be noted that bond strength values, in primary teeth, obtained from this study was lower than previous studies, in permanent teeth. Moreover, some reports indicated lower bond strengths of bonding to dentin in primary teeth compared with dentin of permanent teeth. However, no information is available regarding differences in the micromorphology of the resin-dentin interface that may explain these lower bond strengths (Nor *et al.*, 1996). Nevertheless, the results of bond strength comparing between primary and permanent teeth in several studies were still controversy (Fagan *et al.*, 1986; Bordin-Aykroyd *et al.*, 1992).

From this study suggested that the presence of hydrostatic pulpal pressure in the vital tooth would reduce the microtensile bond strength in primary teeth. Dry teeth group had the highest microtensile bond strength of all groups. However, there is no significant different (P=0.164) between dry tooth and -30 cmH_2O groups. From these results may be described by the study of the permeability of cat dentin *in vivo* and *in vitro*, the authors found Evans' blue solution could penetrate through exposed dentinal tubules of extracted teeth but it could not found on exposed dentin surface *in vivo* (Vongsavan and Matthews, 1992). This showed that there was pressure inside the tooth which led fluid to flow outward. This causes the dentin surfaces moist which can interfere bonding capacity and reduce the bond strength of adhesives (Prati and Pashley, 1992).