CHAPTER V

DISCUSSION

This study determined the shear bond strengths and the failure modes resulting from three self-etching (Xeno®III, ED PRIMER® and AdheSE®) adhesive systems in orthodontic bracket placement, and compared the findings with those values of one conventional phosphoric acid etching adhesive system. Failure modes were assessed from the failure sites and the amount of residual adhesives on debonded enamel surfaces. Three self-etching adhesive systems were chosen in this study because those were new materials that used extensively in restorative procedure. However, they had not been used in orthodontic bonding. Therefore, this study needed to prove that they could be used in orthodontic bracket placement.

From the results of this study, the means of shear bond strengths of three self-etching (Xeno®III, ED PRIMER® and AdheSE®) and the conventional phosphoric acid etching adhesive systems were 1.48, 3.98, 1.74 and 9.45 Mpa respectively. The conventional phosphoric acid adhesive system had significantly greater shear bond strength than three self-etching adhesive systems ($p<0.001$). It was difficult to compare this finding with other studies on shear bond strength due to the differences in the brackets, adhesives and experimental methods used. However, the results of this study are in accordance with the findings of the previous studies (Bishara *et al*., 1998; 1999; 2001; 2002; Yamada, 2002; Grubisa *et al*., 2004).

In restorative dentistry, the highest possible bond strength to tooth structure is desirable. In contrast, the orthodontic bond strength must be sufficient to retain the brackets but should allow easily clean-up of the adhesive when the case is completed and the brackets are removed. Reynolds (1975) and Power and Messersmith (2001) suggested that a minimal bond strength of 6 to 8 MPa was adequate for most clinical orthodontic needs because these values were considered to be able to withstand masticatory and orthodontic forces. The results from this study indicate that three self-etching adhesive systems did not have adequate shear bond strength for clinical orthodontic use, whereas the conventional phosphoric acid etching adhesive system had shear bond strength greater than the minimal bond strength values that are accepted for clinical orthodontic use. The shear bond strength of the conventional phosphoric acid etching adhesive system of this study was 9.45 MPa, approximating the values of the previous studies that were in the range of 9.8-12.0 Mpa (Bishara *et al*., 1998; 1999; 2001; 2002; Yamada, 2002; Grubisa *et al*., 2004). Three self-etching adhesive systems had significantly less shear bond strength than the conventional phosphoric acid adhesive system. It is possible that the composite resin (System1+) might not be compatible with those three self-etching adhesive systems. Xeno® III and AdheSE® self-etching adhesive systems had significantly less bond strengths than ED PRIMER® ($p<0.001$ and $p=0.001$ respectively). A possible reason is that those two adhesive systems polymerize with light activation. The polymerization might not be complete because the light might not reach the deeper parts of the etched enamel rods. ED PRIMER® polymerizes with a chemical activator, but in this study, it did not have adequate shear bond strength for clinical orthodontic use. It was interesting that 6 of 32 samples (18.75%) using ED PRIMER® had shear bond strengths greater than 6 MPa. Therefore, if factors that affected shear bond strength were controlled, ED PRIMER® might be usable in clinical orthodontics. Wide ranges and high standard deviations of shear bond strengths were found in all adhesive systems. This might be due to the differences in force magnitude for seating the bracket to the enamel surface and the differences of adhesive thickness that this study did not control. Retief *et al*. (1989) and Arici *et al*. (2005) found that the adhesive thickness had significantly different effect on the shear bond strength values. The shear bond strength decreased as thickness increased (Schechter *et al*., 1980). Moreover, differences in internal micro-structure of teeth might affect the shear bond strength values, although those study groups were generally in the same age. In principle, enamel is a non-reactive tissue. Once the ameloblasts complete their secretory activity, the final thickness of the enamel can not be altered throughout life, since the ameloblast then degenerate. However, changes of enamel occur as age progresses. Most changes are due to ionic exchange between the external environment and the tooth. As a result of age changes in the organic portion of enamel, presumably near the surface, teeth become harder and their resistance to decay increases and thereby the bond strength is reinforced (Bhashar, 1980; Jacobson, 2000).

Inclusion criteria for the samples in this study were four maxillary and mandibular premolar teeth that were extracted from each adolescent patient, in order to control factors such as age, sex, diet and oral environment. All samples were divided into four groups by the completely randomized block design. This allocation of samples decreased the bias from the different teeth.

Extracted human premolars were used as samples for testing because those were easy to collect and often were extracted for orthodontic treatment. One should be considered the tooth type that was tested when comparing the results of this study with those of other studies because significant differences have been reported in shear bond strength between different tooth types (Hobson *et al*., 1999; Linklater and Gordon, 2001). Those differences may relate to gross anatomical variability. The prismless enamel tended to be more common on posterior teeth (Whittaker, 1982). The different tooth types exhibited biological variation in their etch pattern after acid priming and influenced the bond strength values. The extent of etch achieved decreased toward the distal end of each arch and was significantly less on the first molars than the incisors (Mattick and Hobson, 2000). Therefore, the shear bond strengths of premolar teeth in this study did not refer to those values of the other teeth. However, Heringer *et al*., 1993 and Wang *et al*., 1993 did not find differences in bond strength between buccal and lingual/palatal surfaces of human premolar teeth.

Extracted teeth were stored in 0.1% thymol, an antimicrobial agent for inhibition of bacterial growth. It has been found that the different storage conditions resulted in significantly different shear bond strengths. Higher shear bond strengths were achieved using fresh teeth whereas teeth stored in thymol, methanol and glutaraldehyde had lower shear bond strengths. Fresh teeth and teeth frozen in distilled water had higher shear bond strengths than any other medium (Titley *et al*., 1998). Therefore, the values of the shear bond strengths in this study might to be lower than than they might be for fresh teeth.

Extracted premolar teeth were investigated within 6 months after extraction because there is no statistically significant difference in shear bond strength between teeth stored between 3 hours and 6 months (Reynolds and von Fraunhofer, 1976) and between 2 days and 6 months in thymol (Retief *et al*., 1989).

Shear bond strength was determined according to Fox *et al*. (1994). The instruments for debonding the brackets in this study were a debonding plate and a mounting jig made from stainless steel. The debonding plate and the mounting jig were strong and resisted breaking under the debonding force. A previous study, Joseph and Rossouw (1990) used 0.20 inch gauge stainless steel wire for debonding the brackets. Such a wire could be distorted during debonding. Therefore, it was deemed inappropriate for use in this study. Other instruments were available for debonding the brackets such as a knife edge (Sinha *et al*., 1995), a steel rod with one flatted end (Bishara *et al*., 1998; 1999; 2001; 2002), a sliding plate (Yamada, 2002) and a chisel edge plunger (Buyukyilmaz *et al*., 2002). However, there was no study that compared the effects of the using these instruments for debonding the brackets.

The failure modes in this study were assessed from the failure sites and the amount of residual adhesives on de-bonded enamel surfaces. The failure sites were divided into five locations: within the enamel, at the adhesive/enamel interface (0-25% of the residual adhesives left on the debonded enamel surfaces), within the adhesive (25-75% of the residual adhesives left on the debonded enamel surfaces), at the adhesive/bracket interface (75-100% of the residual adhesives left on the debonded enamel surfaces) and within the bracket. The failure sites of three self-etching and the conventional phosphoric acid etching adhesive systems were mostly found at the adhesive/enamel interface but were not found within enamel or within the bracket. The failure site at the adhesive/enamel interface was advantageous. The advantages were that 1) removing residual adhesives was much easier, 2) clinical time was reduced and 3) pain was decreased during removal of residual adhesives from debonded teeth (Pus and Way, 1980; Maijer and Smith, 1981; Thompson and Way, 1981; Kinch *et al*., 1989; Sinha *et al*., 1995). However, enamel fracture and enamel crack have been reported at the time of bracket debonding bond failure occurred at the adhesive/enamel interface. It is possible that the depth of etched enamel surface might be a contributing factor to the incidence of enamel fracture (Guess *et al*., 1988; Chaconas *et al*., 1989; Herris *et al*., 1992). In this study, enamel fractures or cracks were not found at de-bonding. It is possible that applying both self-etching adhesives and 37% phosphoric acid in 30 seconds on the enamel surface was not aggressive to cause fractures or cracks of enamel at debonding. However, this study did not determine the amount of enamel loss during enamel clean-up after removal of the residual adhesives. Therefore, this study could not evaluate enamel damage after removal of the residual adhesives. Failure sites were not found within brackets. This might indicate that stainless steel brackets were strong and resisted debonding force. Failure sites within brackets have often occurred with plastic or ceramic brackets (Sheykholeslam and Brandt, 1977; Power and Messersmith, 2001). The percentages of failure sites at the adhesive/enamel interface of three self-etching (Xeno® III, ED PRIMER® and AdheSE®) and one conventional phosphoric acid etching adhesive systems were 93.8, 56.2, 78.1 and 53.1 respectively, and the amount of residual adhesives on the debonded enamel surfaces when using those adhesive systems were 41.33, 78.09, 53.69 and 84.89 respectively. Xeno® III and AdheSE® self-etching adhesive systems had high percentages of failure at this site and small amounts of residual adhesives on debonded enamel surfaces, probably due to weak adhesion between adhesive and enamel. On the other hand, the conventional phosphoric acid etching adhesive system and ED PRIMER® had high percentages of failure at this site and large amounts of residual adhesives on deboned enamel surfaces, probably due to strong adhesion between adhesive and enamel.

In previous studies, the percentages of residual adhesives on the deboned enamel surface were estimated directly from stereozoom microscope (Bishara *et al.*, 1998; 1999; 2001; 2002; Yamada, 2002; Grubisa, 2004). This method was not precise In this study, the amounts of residual adhesives on the debonded enamel surface were determined from photographs taken from the Nikon stereozoom microscope at X15 magnification, and then the computer-generated transparent grid was used to determine the amount of residual adhesives. Each dot of the computerized transparent grid was subjectively observed residual adhesives and then calculated the percentages of residual adhesive per total debonded enamel surfaces area. The advantages of this method were more precise and reproducible. From the analysis of reliability of the measurement found that it was satisfied with a very high reproducibility ($r=0.996$, $p<0.001$). However, this method was time consuming and had systemic errors in photograph procedure. But the systemic errors in all photographs were equal because the distance of specimens to the stereozoom microscope and the placement of specimens were the same in all specimens. It must be remembered that the photographs were two dimensional views. Therefore, the thickness and form of three dimensions of residual adhesives on the de-bonded enamel surfaces could not be determined.

In summary, this study found that three self-etching (Xeno® III, ED PRIMER® and AdheSE®) adhesive systems were not adequate for clinical orthodontic use. The conventional phosphoric acid etching adhesive system is still appropriate for use in orthodontic bracket placement.

Limitation of this study

This study was an *in vitro* study. Application of the results of this study in clinical practice must consider various factors such as: (1) oral environment; (2) oral temperature that might be change by diet; (3) contamination before, during and after bonding; (4) crowding of teeth; (5) bracket position.

Further studies

1. Identify a self-etching adhesive system that can be successfully used to bond orthodontic brackets.

2. Evaluate the etched enamel pattern of the self-etching and the conventional phosphoric acid adhesive systems.

3. Determine the changes of shear bond strengths of the self-etching adhesive systems after bonding, during the initial phase in which arch wires are tied with brackets and during tooth movement in clinical work.

4. Determine the location, thickness and three-dimensional form of residual adhesives on debonded enamel surfaces.

5. Determine the amount of enamel loss during enamel clean-up after removal of residual adhesives.

6. Use computerized program for determination of the amount of residual adhesives on debonded enamel surfaces.