CHAPTER V

DISCUSSION

The discussion of this research project is presented in two parts as follows:

I. Discussion of the results of the study

1. Shear bond strength values
2. Site of adhesive failure

II. Discussion of the materials and methods in the study

1. Varieties of the samples
2. Method of shear bond strength testing

I. Discussion of the results of the study

1. Shear bond strength values

The results in this study suggest that when high light intensity is used, the curing time can be reduced, but the longer the curing time, the higher the shear bond strength. The results agree with those of previous studies[8,14,25,27,34-38] and confirm that the efficiency of photo-polymerization depends on light intensity and curing time. Table 9 demonstrates the results of previous studies of curing time reduction using light-emitting diode curing units and halogen lamps for bonding orthodontic stainless steel brackets. Most of them[8,14,27,35,38] suggested a minimum curing time of 10 seconds using high-power light curing units (intensity 800 – 1,000 Mw/cm^2). One study[25] suggested a 6-second curing time using a high-power halogen lamp (intensity 3,000 Mw/cm^2). The high light intensity converts a great amount of camphorquinone to its free radical, and causes polymerization in a short time, whereas low intensity does not provide enough energy to penetrate the adhesives and activate the camphorquinone.[39]

As recommended by the manufacturer, the Mini-LED™ device, which contains a high-power light-emitting diode, can cure a 2 to 3 mm thickness of composite resin in 6 to 12 seconds. The results in this study suggest that the high-power light-emitting diode (intensity = 1,250 Mw/cm^2) can reduce the curing time to a minimum of 6 seconds per tooth (or 3 seconds per side) and achieve adequate shear bond strength for bonding orthodontic brackets at 6 to 8 MPa as recommended by Reynolds.[2] The mean shear bond strength values for the 2- and 4-second curing times were lower than 6 MPa. The reason might be that inadequate curing time results in inadequate polymerization of the adhesives. This, consequently, results in poor physical properties of the material, including bond strength and leads to bracket failure.[40]

However, the mean shear bond strength value obtained with the 6-second curing time was significantly lower than those obtained with the conventional halogen lamp at 40 seconds, whereas a minimum curing time of 8 seconds per tooth provided shear bond strength comparable to that obtained with the conventional halogen lamp.

Although the recommendation of the shear bond strength of 6 to 8 MPa as being acceptable for orthodontic brackets is widely used, the bond strength needed for orthodontic brackets still depends on many factors, for example, different archwires or individual mastication forces.[38] If the bond strength obtained from the conventional halogen lamp has been acceptable in clinical practice, the value obtained from the reduced curing time with the high-power light-emitting diode that produces comparable bond strength should be considered satisfactory.[38] In this study, the shear bond strength values obtained from the light-emitting diode (intensity = 1,250 Mw/cm^2) at 8 to 12 seconds were comparable to the values obtained from the conventional halogen lamp. This suggests that with the high-power light-emitting diode at 1,250 Mw/cm^2, the curing time can be reduced to a minimum of 8 seconds per tooth for bonding orthodontic stainless steel brackets. Total working time for the bonding process can be decreased. Consequently, risks of bracket failure from saliva contamination and bracket displacement can be decreased.

Table 9 Previous studies of curing time reduction for bonding orthodontic stainless steel brackets

Author	Light curing unit			Curing time (seconds)	SBS (MPa)		Etching system	Bonding systems	Teeth	Time after bonding
	Brand	Type	Intensity (Mw/cm^2)		Mean	SD				
Bishara *et al.*, 2003	Ortholux XT	QTH	> 400	20	5.1	2.5	37% P	Trans-bond XT (APC)	H, M	30 m
	Ultra-Lume LED 2	LED	> 400	20*	6	3.1				
Ip and Rock, 2004	XL 3000	QTH	400	10	9.3	2.5	37% P	Prime & Bond	H,1st PM	-
				20*	12	2.5				
				40	13.6	2.5				
	Optilux 501	QTH	800	4	8.5	0.9				
				10*	11.8	2.2				
				20	12.2	1.8				
Usumez *et al.*, 2004	XL 3000	QTH	550	40	13.1	3.1	37% P	Trans-bond XT	H, PM	24 h
	Elipar FreeLight	LED	400	10	9.1	3.1				
				20*	13.9	4.8				
				40	12.7	5.1				
Swanson *et al.*, 2004	Ortholux XT,	QTH	> 400	10	12.5	3.8	SEP (Trans-bond)	Trans-bond XT (APC)	H, M	24 h
				20	14.9	5.7				
				40	15.3	6.4				
	GC e-light	LED	-	10	8.1	6.3				
				20*	12.2	6.0				
				40	12.2	3.3				
	Elipar freeLight	LED	-	10*	13.5	5.1				
				20	14.8	3.2				
				40	15.6	5.6				
	Ultra-Lume LED 2	LED	-	10*	12.3	9.2				
				20	12.7	6.2				
				40	18.6	5.8				
Silta *et al.*, 2005	Optilux 501	QTH	> 400	6	3.31	2.31	SEP (Trans-bond)	Trans-bond XT (APC)	H, M	30 m
				10	4.82	2.51				
				20*	7.98	3.55				
	Ultra-Lume LED 5	LED	> 400	6	4.45	1.86				
				10	5.17	1.86				
				20*	7.03	1.50				
	Ortholux LED	LED	> 400	6	2.67	2.31				
				10	4.22	2.31				
				20*	5.44	2.23				
Staudt *et al.*, 2005	Optilux 501	QTH	1,000	40	19.2	6.9	35% P	Trans-bond XT	B, I	24 h
	Swiss Master Light	QTH	3,000	2	10.4	4.1				
				3	16.6	5.4				
				6*	20.1	6.6				
Mavro-poulos *et al.*, 2005	Optilux 501	QTH	> 900	40	19.2	6.8	35% P	Trans-bond XT	B, I	24 h
	Ultra-Lume LED 5	LED	> 800	5	9.5	4.9				
				10*	16.3	7.1				
	Ortholux LED	LED	1,000	5	11.3	4.3				
				10*	15.9	6.6				
Thind *et al.*, 2006	Ortholux XT	QTH	400	20	6.83	2.68	37% P	Trans-bond XT	H, PM	24 h
	Ortholux LED	LED	1,000	10*	6.70	2.25				

Table 9 (continued)

Author	Light curing unit			Curing time (seconds)	SBS (MPa)		Etching system	Bonding systems	Teeth	Time after bonding
	Brand	Type	Intensity (Mw/cm^2)		Mean	SD				
Gronberg *et al.*, 2006	Ortholux XT	QTH	400	20	20.6	4	37% P	Trans-bond XT	B, I	24 h
	-	LED	800	5	7.5	4.9				
				10*	11.76	5.6				
				20	14.8	6.1				
				40	17.5	6.9				

* Recommended minimum curing time and/or curing time with no significant differences in shear bond strength values

Abbreviation:

P = phosphoric acid

SEP = self-etching primers

H = human

B = bovine

I = incisor

PM = premolar

M = molar

m = minute

h = hour

Even though the mean shear bond strength values for the 8-, 10- and 12-second curing times were not significantly different from those in the control group, care should be taken when applying these results to clinical practice because the mean values derived were average values. Those values had a distribution, and each value was more or less than the mean value. Moreover, the distance from the light guide tip to the adhesives may vary when light curing in a patient's mouth, possibly affecting the curing time needed. Furthermore, the curing time might vary for different types of materials.

Initial shear bond strength of both light-cured and chemical-cured composite orthodontic adhesives was about half of the shear bond strength obtained after 24 hours from the time of bonding.[41] Bond strength of adhesives increases from five minutes to 24 hours after bonding. At five minutes, bond strength was about 60 to 70 percent of the bond strength at 24 hours. The bond strength at 24 hours and one month, and between three and six months, were not significantly different. Thus, timing between bonding and debonding should not be less than 24 hours after polymerization.[41] In this study, the shear bond strength values reported at longer than 24 hour after polymerization including the time for thermocycling. But clinically, archwires are usually inserted in a few minutes after the bonding process, when the adhesives has not reached its maximum bond strength. Two studies[34,37] suggested a curing time of 20 seconds, twice that used in others,[8,14,27,35,36,38] for bonding orthodontic stainless steel brackets when the de-bonding procedure was performed 30 minutes after bonding (Table 9). Therefore this factor should be considered when initial arch wires are tied in a patient's mouths.[41]

Intra-oral temperature changes from drinking, eating of hot or cold food, and breathing may induce thermal stresses. Thermal stresses result in mechanical stresses from thermal change and induce cracks through the bonded interface, thus changing gap dimension. The thermocycling procedure was aimed to simulate the oral environment.[42] Even though there is a controversy regarding the effect of thermocycling on bond strength,[43] the thermocycling procedure was applied in this present study to simulate the oral environment of human routine behavior. In this study, the shear bond strength values for Groups 3, 4, 5, 6, and 7, after 1,000 thermal cycles, were still in an acceptable shear bond strength range of 6 to 8 MPa.

2. Site of adhesive failure

The site of adhesive failure in this study was mostly at the tooth/adhesive interface, since most adhesives were removed with the brackets. However, the results showed an association between the adhesive remnant index scores and the curing time, with a tendency for adhesives to be left on the tooth surface after de-bonding when the curing time was decreased. The reason might be inadequate polymerization of adhesives in the bracket mesh base, due to enamel transillumination allowing light to reach the tooth/adhesive interface more than the bracket/adhesive interface.[8] In other words, with an increasing curing time, there is a greater tendency of adhesives being removed along with brackets at de-bonding. It supports that the greater polymerization of overall adhesives and adhesives in bracket mesh provides strongerinterlocking of composite in bracket base.[8] However, there has been a controversy regarding bond failure of adhesives. The first group suggested that the failure at tooth/adhesive interface was preferable than the failure at bracket/adhesive interface. This is because it made debonding and polishing easier than the failure at bracket/adhesive interface.[41] The remaining adhesives on tooth surface were undesirable because enamel damage occurred during removal of adhesive remnant from the tooth surface, and that it might increase chair-side time.[44] In contrast, the other group suggested that a tendency of enamel fracture would increase if a failure occur at the tooth/adhesive interface. The risk was increased when the higher force was needed to debond high strength adhesives.[38] In order to avoid the risk of enamel fracture, a tensile bond stress should not exceed 14.5 MPa.[45] Thus, an adequate bond strength that fails at tooth/adhesive interface would be ideally in orthodontics.[41]

II. Discussion of the materials and methods in the study

1. Varieties of the samples

Since the prevalence of dental flourosis is high in northern Thailand, and fluoride may affect the etch pattern and bond strength,[41] the teeth used in this present study must not have had any defect on the buccal enamel surface, including flourosis. The Tooth Surface Index of the Fluorosis/TSIF score[30] was used to exclude teeth with flourosis. Only teeth with a TSIF score '0' were acceptable.

As it is known that enamel changes with age, including its surface fluoride concentration, extracted human premolar teeth were used because they were more available than other teeth. Premolar teeth are extracted for orthodontic reasons from adolescent patients. Compared with premolar teeth, incisor teeth are usually extracted for periodontal reasons from older patients.[41] Besides, different buccal anatomy from different tooth types may be associated with inconsistent adhesive film thickness, and consequently alter bond strength characteristics.[46] Comparing the same tooth type in the upper and lower arches, there was a significant difference in shear bond strength between upper and lower premolar teeth.[47] However, the buccal surface anatomy of upper first and second premolar teeth is very similar.[47] Therefore, only upper first and second premolar teeth were selected for this study to minimize other factors that might affect the shear bond strength values.

2. Method of shear bond strength testing

The protocol for bond strength testing in orthodontics recommended by Fox *et al.*[41] was used in this study. The errors from the shear bond strength testing might be from many causes as follows:

1) Error from the bonding process

In the bonding process, the thickness of the bonding material on several samples might not be equivalent due to the different enamel contour of each tooth. Moreover, errors might result from the bonding technique. These problems were minimized by using adhesive pre-coated brackets to standardize the amount of adhesive on each bracket, and taking care in the bonding process. All bonding was performed by one operator.

2) Error from the curing unit

Curing devices have a limited lifetime. Light intensity declines over time because of light bulb degradation, especially in halogen lamps. To ensure that curing devices would give the desired light intensity, neither the light-emitting diode nor the conventional halogen lamp had been used before the experiment. Also, the light intensity of both the high-power light-emitting diode curing unit and the conventional halogen lamp curing unit was checked with their respective self- radiometers. Light intensity was checked before each activation on each sample. This study used the self-radiometer attached to each curing unit because variation in radiometric assessment depends on light tip diameter. Individual light meters with fixed-diameter apertures have small apertures for measuring peak intensity, whereas large-aperture light meters measure average intensity from the entire area of the light guide. So, different light intensity valued by light meter depends on different diameter of the light guides.[14]

3) Error from the de-bonding process

In the process of shear bond strength testing, care should be taken to ensure that the point of application and direction of the de-bonding force is the same for all specimens. In this study, to control the angulation of the mounted tooth in the polyvinylchloride ring and the direction of force applied to each sample, a 0.016 x 0.022 inch straight stainless steel wire was used during block preparation for de-bonding step. And during the de-bonding step, the de-bonding plate was placed closest to the bracket/adhesive interface to minimize the differences in point of force of application.

Limitation of the research

In this *in vitro* study, the shear bond strength values reported could not be directly transferred to the clinical situation, as in oral condition due to the aging of resin material, from intraoral temperature changes, and the stress from mastication.[48] Even though a thermocycling procedure was performed in this study, the effect of thermocycling on bond strength still depends on the bonding system used and the number of thermal cycles.[49] Moreover, it is quite difficult to do this experiment *in* *vivo* for several reasons. Large amount of samples made this experiment almost impossible to standardize the method in the same way. It would be difficult to control the time between bonding and de-bonding brackets for each individual. Another factor is the risk of bracket failure or bracket loss before de-bonding. In addition, variations of individual behavior, such as different mastication forces and different intraoral temperature changes during normal eating, might affect shear bond strength values.[42] Furthermore, clinical trials are costly and time consuming.