การเปรียบเทียบกำลังยึดติดแบบเฉือนที่ระยะเวลาการบ่มที่ต่างกันด้วยเครื่องฉายแสงไดโอดเปล่งแสงกำลังสูงสำหรับการยึดแบร็กเกตทางทันตกรรมจัดฟัน

Comparison of Shear Bond Strength at Various Curing Times with a High-power Light Emitting Diode Curing Unit for bonding Orthodontic Brackets

ชลฎา รัตนาวิวัฒน์พงศ์[1], ธีระวัฒน์ โชติกเสถียร[2], วิกันดา เขมาลีลากุล[2], สุภัสสรา ศิรบรรจงกราน[2], จรรยา อภิสริยะกุล[2]
[1]นักศึกษาปริญญาโทและวุฒิบัตร สาขาทันตกรรมจัดฟัน ภาควิชาทันตกรรมจัดฟันและทันตกรรมสำหรับเด็ก คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่
[2]ภาควิชาทันตกรรมจัดฟันและทันตกรรมสำหรับเด็ก คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่
Chonlada Rattanawiwatpong[1], Dhirawat Jotikasthira[2], Wikanda Khemaleelakul[2], Supassara Sirabanchongkran[2], Janya Apisariyakul[2]
[1]Postgraduate student in Orthodontics, [2]Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University

ชม.ทันตสาร 2554; 32(1) : 69-76
CM Dent J 2011; 32(1) : 69-76

บทคัดย่อ

วัตถุประสงค์ของงานวิจัยนี้เพื่อเปรียบเทียบกำลังยึดติดแบบเฉือนของสารยึดติดทางทันตกรรมจัดฟัน ที่ได้รับการบ่มด้วยเครื่องฉายแสงไดโอดเปล่งแสงกำลังสูงที่ระยะเวลาการบ่มที่ต่างกัน นำแบร็กเกตโลหะเหล็กกล้าไร้สนิมที่มีสารยึดติดเคลือบอยู่ก่อนมายึดบนฟันกรามน้อยบน 140 ซี่ และบ่มด้วยเครื่องฉายแสงไดโอดเปล่งแสงกำลังสูงที่ความเข้มแสง 1,250 มิลลิวัตต์ต่อตารางเซนติเมตรเป็นเวลา 2, 4, 6, 8, 10 และ 12 วินาทีสำหรับแต่ละกลุ่ม กลุ่มควบคุมใช้เครื่องฉายแสงแฮโลเจนความเข้ม 300 มิลลิวัตต์ต่อตารางเซนติเมตรบ่มเป็นเวลานาน 40 วินาที ค่าความแข็งแรงของการ

Abstract

The aim of this study was to compare shear bond strength of adhesives cured by a high-power Light Emitting Diode (LED) curing unit at various curing times. Adhesive pre-coated stainless steel brackets were bonded on 140 human upper premolars with a high-power LED curing unit at 1,250 Mw/ cm^2 for 2, 4, 6, 8, 10 or 12 seconds. A conventional halogen lamp with light intensity at 300 Mw/ cm^2 was used for 40 seconds to cure the adhesive in a control group. Shear bond strength was measured on de-

Corresponding Author:

จรรยา อภิสริยะกุล
อาจารย์ ภาควิชาทันตกรรมจัดฟันและทันตกรรมสำหรับเด็ก
คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่

Janya Apisariyakul
Lecturer, Department of Orthodontics and Pediatric Dentistry,
Faculty of Dentistry, Chiang Mai University,
Chiang Mai 50200, Thailand.
E-Mail: japisari@yahoo.com

ยึดติดต่อแรงเฉือนถูกวัดขณะทำลายพันธะ การวิเคราะห์ทางสถิติพบว่ากลุ่มควบคุมมีความแข็งแรงของการยึดติดต่อแรงเฉือนมากกว่ากลุ่ม 2, 4 และ 6 วินาที แต่ไม่แตกต่างจากกลุ่ม 8, 10 และ 12 วินาที โดยสรุป ระยะเวลาการบ่มด้วยเครื่องฉายแสงไดโอดเปล่งแสงกำลังสูงอย่างน้อย 8 วินาทีต่อซี่ให้ความแข็งแรงของการยึดติดต่อแรงเฉือนเทียบเท่ากลุ่มที่ได้รับการบ่มด้วยเครื่องฉายแสงแฮโลเจนระยะเวลา 40 วินาที

คำสำคัญ: เครื่องฉายแสงกำลังสูง, ระยะเวลาการบ่ม

bonding. Statistical analysis revealed that the mean shear bond strength values recorded for the 2-, 4- and 6-second groups were significantly less than the control group. The values for the 8-, 10- and 12-second groups were not significantly different from those for the control group. In conclusion, a minimum of 8 seconds curing time per tooth using a high-power LED curing unit provides shear bond strength comparable to that for adhesives cured with a conventional halogen lamp for 40 seconds.

Keywords: high-power curing unit, curing time

Introduction

At present, the bonding technique using brackets is commonly used in fixed orthodontic treatment. Adhesives, both self-cured and light-cured, are used to bond orthodontic brackets. The ‘time-control’ feature of light-cured adhesives makes them better and more widely used than self-cured adhesives. This feature provides more time for dentists to accurately position the brackets, and makes removing uncured excess adhesive easier. However, because of the low power density of conventional halogen lamps, a minimum curing time of 20 seconds per side from this light is needed for light-cured adhesives to reach adequate bond strength for bonding orthodontic brackets.(1) This causes a long working time for full arch bracket placement. Curing time reduction improves the efficacy of bracket placement by reducing the risks of bracket failure from saliva contamination and bracket displacement.(2) There are many ways to reduce the bonding time, for example, the use of self-etching primers, the use of adhesive-coated brackets, and the use of high-power light sources.(1,3-5)

A light-emitting diode (LED) is a semi-conductor device that generates and emits blue light without using a filter. It reaches a peak wavelength of 460 nm,(6) which is matched to the peak absorption wavelength of camphorquinone initiator used in most visible-light-cured adhesives.(6) An LED has more advantages than a halogen lamp.(1,6-9) The LED light has a narrower spectrum (440 to 480 nm) than the halogen lamp (400 to 500 nm).(6-7) The peak wavelength of the LED is closer to the peak absorption wavelength of camphorquinone than is that of the halogen lamp. The LED can achieve the same effectiveness in polymerization as the halogen lamp at the same intensity level.(1,8) The low power consumption of LEDs makes the LED usable as a cordless handpiece.(6) Moreover, the LED has a longer lifetime (approximately 10,000 hours) than the halogen lamp (approximately 100 hours), because of little degradation and no heat generation.(1,6,8-9)

The high-power light sources can reduce the curing time because the efficiency of photo-polymerization depends on the light intensity and the curing time. The curing time can be reduced if a higher intensity is applied.[6] According to ISO standards (ISO: 10650, 1999), a light intensity of 300 Mw/cm^2 is minimally required to achieve adequate polymerization of a 2 mm thickness of composite resin.[10] However, since the thickness of orthodontic adhesives is less than 2 mm, shorter polymerization time for bonding brackets may be adequate.[11] A curing time of 10 seconds with a high-power LED curing unit (intensity 800 and 1,000 Mw/cm^2) has been suggested to provide shear bond strength comparable to that for adhesives cured with the conventional halogen lamp.[1,12-13] However, LED technology in dentistry has improved with the increase in power density. Curing times shorter than 10 seconds with a higher light intensity than 1,000 Mw/cm^2 of LED might be adequate for bonding orthodontic stainless steel brackets. The purposes of this study were: 1) to compare shear bond strength of adhesives cured by a high-power LED curing unit at various curing times for bonding orthodontic stainless steel brackets, and 2) to measure the Adhesive Remnant Index (ARI) on enamel surfaces after de-bonding brackets bonded with adhesives at various curing times.

Materials and methods

One hundred and forty human upper premolar teeth, extracted for orthodontic reasons, were collected and stored in a 0.1% thymol solution. Only teeth with a sound buccal enamel surface were included. Teeth were categorized randomly into seven groups of 20 specimens each. Each specimen was polished with fluoride-free pumice for 10 seconds, washed with oil free water, and the excess water was removed with an oil-free air stream. The buccal enamel surface was etched and primed with a self-etching primer (Transbond™ Plus Self Etching Primer, 3M Unitek, Monrovia, California, USA). Pre-coated maxillary premolar stainless steel brackets were used (APC™ II Gemini Twin brackets, 3M Unitek, Monrovia, California, USA). Brackets used in Groups 1 to 6 were light-cured with a high-intensity LED light. Those in Group 7, a control group, were light-cured with a conventional halogen light. Light sources used and curing times in each group are given in Table 1. The curing times were divided equally for mesial and distal surfaces. According to the manufacturers, a mini-LED™ (Satelec® Acteon Group, Merignac, France) generated visible blue light with intensity of 1,250 Mw/cm^2.[14] And a Spectrum 800 halogen lamp (Dentsply/Caulk, Milford, Delaware, USA) was set to provide visible blue light with intensity of 300 Mw/cm^2.[10] The light intensity was checked before each activation using the light units' built-in radio-meters. After bonding, the teeth were incubated in distilled water at 37°C for 24 hours, and thermocycled at 5° and 55°C for 1,000 cycles. A universal testing machine (Model number 5566, Instron Calibration Laboratory, Norwood, Massachusetts, USA) was used to measure the de-bonding force in units of megapascals (MPa). A de-bonding stainless steel plate applied the shear force to the bracket in an occluso-gingival

Table 1 *Light sources and curing times for each group.*

ตารางที่ 1 *ชนิดของแหล่งกำเนิดแสงและระยะเวลาการบ่มสำหรับแต่ละกลุ่ม*

		LED (*Intensity = 1,250 Mw/cm^2*)						Halogen (*Intensity = 300 Mw/cm^2*)
Group		1	2	3	4	5	6	7 (control)
Curing time	seconds/tooth	2	4	6	8	10	12	40
	seconds/surface	1	2	3	4	5	6	20

direction at a crosshead speed of 0.5 mm/min.

After de-bonding, adhesive remnant on each bracket base was measured using photographs captured with a digital single-lens reflex camera (Canon 300D, Canon Incorporated, Tokyo, Japan) with a Canon macro lens (Canon EF 100 mm f/2.8 MACRO USM) at 1 x magnification. The adhesive remnant was scored according to the adhesive remnant index (ARI) scores(15) as follows:

'0' = No adhesive left on the tooth

'1' = Less than half of the adhesive left on the tooth

'2' = More than half of the adhesive left on the tooth

'3' = All the adhesive left on the tooth, with a distinct impression of the bracket mesh

The differences in shear bond strength values among the groups were analyzed using a one-way analysis of variance (ANOVA) followed by a multiple comparisons (Tukey's) test. Both tests were determined at a significance level of $p < 0.05$. Descriptive analysis was used to determine the frequency of ARI scores.

Results

The mean shear bond strength values for Groups 1 to 7 increased as the curing time was extended (Table 2). The control group had the highest shear bond strength value. The one-way ANOVA revealed significant differences in mean shear bond strength values among the seven groups (Table 3). Tukey's test revealed significant differences in mean shear bond strength between groups (Table 4). The mean shear bond strength in the control group was significantly different from those in Groups 1, 2 and 3.

The frequencies of the ARI scores with percentages are shown in Table 5. The ARI scores showed that in more than half of the samples in Groups 3, 4, 5 and 6 and in the control group, most adhesives remained on the bracket bases on de-bonding. In Groups 1 and 2, ten out of twenty samples (50%) had an adhesive remnant index score of 1.

Discussion

The results in this study suggest that when high light intensity is used, the curing time can be reduced. The longer the curing time, the higher the shear bond strength. The results support previous studies and confirm that the efficiency of photo-polymerization depends on light intensity and curing time.(6) Previous studies(1,11-13,16) about curing time reduction for bonding orthodontic stainless steel brackets suggested a minimum curing time of 10 seconds using high-power LED curing units or high-power halogen lamps (intensity of 800-1,000 Mw/cm^2). One study(17) suggested a 6-second curing time using a high-power halogen lamp (intensity 3,000 Mw/cm^2). The high intensity converts a great amount of camphorquinone to its free radical, then causes polymerization in a short time, while low intensity does not provide enough energy to penetrate the adhesives and activate the camphorquinone.(18)

The results in this study suggest that the high-power LED (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.(19) The mean shear bond strength values for the 2- and 4-second curing times were lower than 6 MPa. The reason might be that the decreased curing time of the adhesive results in lower conversion of monomer to polymer.(11) This, consequently, results in poor physical properties of the material, including bond strength, and leads to bracket failure.(11) However, the mean shear bond strength value obtained for

Table 2 *Means, standard deviations and ranges of shear bond strength in each group.*
ตารางที่ 2 *ค่าเฉลี่ย ส่วนเบี่ยงเบนมาตรฐานและระยะของกำลังยึดติดแบบเฉือนในแต่ละกลุ่ม*

Group	Curing time (seconds/ tooth)	Shear bond strength (MPa)	
		Mean±SD	Min - Max
1	2	4.5±2.1	1.05-8.00
2	4	5.3±2.7	1.46-11.10
3	6	6.6±2.6	3.57-12.98
4	8	7.2±2.7	1.58-11.90
5	10	8.4±2.7	2.80-13.24
6	12	8.8±3.4	1.47-14.11
7 (control)	40	9.6±2.5	3.11-12.69

Table 3 *Results of analysis of variance (ANOVA) of mean shear bond strength.*
ตารางที่ 3 *ผลการวิเคราะห์ความแปรปรวนของค่าเฉลี่ยกำลังยึดติดแบบเฉือน*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	419.425	6	69.904	9.548	.000*
Within Groups	973.720	133	7.321		
Total	1393.145	139			

*Significant differences at $p < 0.05$

Table 4 *Statistically significant differences of mean shear bond strength using Tukey's test.*
ตารางที่ 4 *ค่ากำลังยึดติดแบบเฉือนที่แตกต่างกันอย่างมีนัยสำคัญทางสถิติโดยใช้การทดสอบตูร์เกร์*

Group	1	2	3	4	5	6	7 (control)
1							
2							
3							
4	*						
5	*	*					
6	*	*					
7 (control)	*	*	*				

*Significant differences at $p < 0.05$

Table 5 *Frequencies of ARI scores (percentages in parentheses).*
ตารางที่ 5 *ความถี่ของคะแนน ARI (ร้อยละแสดงในวงเล็บ)*

Group \ ARI score	0	1	2	3
1	0 (0%)	10 (50%)	10 (50%)	0 (0%)
2	0 (0%)	10 (50%)	8 (40%)	2 (10%)
3	2 (10%)	12 (60%)	5 (25%)	1 (5%)
4	5 (25%)	11 (55%)	4 (20%)	0 (0%)
5	3 (15%)	14 (70%)	3 (15%)	0 (0%)
6	3 (15%)	14 (70%)	3 (15%)	0 (0%)
7 (Control)	2 (10%)	14 (70%)	4 (20%)	0 (0%)

the 6-second curing time was significantly lower than values obtained from the conventional halogen lamp at 40 seconds, whereas a minimum curing time of 8 seconds per tooth provided shear bond strength comparable to that provided by 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.(13) 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 high-power LED that produces comparable bond strength should be considered satisfactory.(13) In this study, the shear bond strength values obtained from the LED (intensity = 1,250 Mw/cm^2) at 8, 10 and 12 seconds were comparable to the values obtained from the conventional halogen lamp. This suggests that with the high-power LED 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.

The site of adhesive failure in this study was mostly at the tooth/adhesive interface, since most adhesives were removed with the brackets. One possible reason is that the self-etching primer produces a reduced etched pattern compared with that of the conventional total etching system.(20) The resin tags with the self-etching primer are thin and less uniform than those etched with the conventional etching system. This results in a reduction of the micromechanical bond of the primers to the etched enamel surfaces.(21) Thus, less adhesives remain on the tooth than on the bracket at the time of de-bonding.(20) However, there was 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 adhesive in the mesh bracket base, due to enamel transillumination allowing light to reach the tooth/adhesive interface more than the bracket/adhesive interface.(12) In other words, with an increased curing time, there is a greater tendency of adhesives to be removed along with brackets at de-bonding. This possible reason supports the notion that the greater polymerization of adhesives, particularly the adhesive in the bracket mesh provides stronger interlocking of composite in the bracket base.(12) There has been a controversy regarding bond failure with adhesives. One theory is that failure at the tooth/adhesive interface is preferable to failure at the bracket/adhesive interface.(22) This is because such failure makes de-bonding and polishing easier than with failure at the bracket/adhesive interface. Adhesives remaining on the tooth surface are undesirable because enamel damage can occur during removal of adhesive remnants from the tooth surface, and the removal of adhesive remnants might increase chair-side time.(23) In contrast, an opposing theory is that the tendency for enamel fracture would increase if failure occurred at the tooth/adhesive interface.(13) This theory holds that the risk is increased when higher force is needed to de-bond high strength adhesives. In order to avoid the risk of enamel fracture, tensile bond stress should not exceed 14.5 MPa.(24) Thus, an adequate bond that fails at the tooth/adhesive interface would be ideal in orthodontics.(22)

Conclusions

The high-power light emitting diode (intensity = 1,250 Mw/cm^2) may reduce the curing time for bonding orthodontic stainless steel brackets to a minimum of 8 seconds per tooth. The shear bond strength values achieved were comparable to the values obtained from the conventional halogen lamp at 40 seconds per tooth. And there was a tendency for adhesives to be left on the tooth surface after de-bonding when the curing time was decreased.

Acknowledgements

The authors would like to thank the Graduate School, Chiang Mai University and the Faculty of Dentistry, Chiang Mai University for the research scholarship. We wish to thank Dr. M. Kevin O Carroll, Professor Emeritus of the University of Mississippi School of Dentistry, USA, and Faculty Consultant at Chiang Mai University Faculty of Dentistry, Thailand, for his assistance in the preparation of the manuscript.

References

1. Mavropoulos A, Staudt CB, Kiliaridis S, Krejci I. Light curing time reduction: in vitro evaluation of new intensive light-emitting diode curing units. *Eur J Orthod* 2005; 27: 408-12.
2. Serra G, Brugnera A, Elias CN, Bolognese AM. Effect of argon laser curing on the shear bond strength of metal brackets bonded with light-cured glass ionomer cement. *Am J Orthod Dentofacial Orthop* 2005; 128: 740-3.
3. Aljubouri YD, Millett DT, Gilmour WH. Laboratory evaluation of a self-etching primer for orthodontic bonding. *Eur J Orthod* 2003; 25: 411-5.
4. Cooper RB, Goss M, Hamula W. Direct bonding with light cured adhesive precoated brackets. *J Clin Orthod* 1992; 26: 477-9.
5. Bishara SE, Oonsombat C, Soliman MMA, Warren JJ, Laffoon JF, Ajlouni R. Comparison of bonding time and shear bond strength between a conventional and a new integrated bonding system. *Angle Orthod* 2005; 75: 237-42.
6. Wiggins KM, Hartung M, Althoff O, Wastian C, Mitra SB. Curing performance of a new-generation light-emitting diode dental curing unit. *J Am Dent Assoc* 2004; 135: 1471-9.
7. Mills RW, Jandt KD, Ashworth SH. Dental composite depth of cure with halogen and blue light emitting diode technology. *Br Dent J* 1999; 186: 388-91.
8. Campregher UB, Samuel SM, Fortes CB, Medina AD, Collares FM, Ogliari FA. Effectiveness of second-generation light-emitting diode (LED) light curing units. *J Contemp Dent Pract* 2007; 8: 35-42.
9. Owens BM, Rodriguez KH. Radiometric and spectrophotometric analysis of third generation light-emitting diode (LED) light-curing units. *J Contemp Dent Pract* 2007; 8: 43-51.
10. International Organization for Standardization Specification, ISO 10650 (1999) Detal equipment-powered polymerizable activators, Geneva, Switzweland.
11. Swanson T, Dunn WJ, Childers DE, Taloumis LJ. Shear bond strength of orthodontic brackets bonded with light-emitting diode curing units at various polymerization times. *Am J Orthod Dentofacial Orthop* 2004; 125: 337-41.
12. Gronberg K, Rossouw PE, Miller BH, Buschang P. Distance and time effect on shear bond strength of brackets cured with a second-generation light-emitting diode unit. *Angle Orthod* 2006; 76: 682-8.

13. Thind BS, Stirrups DR, Lloyd CH. A comparison of tungsten-quartz-halogen, plasma arc and light-emitting diode light sources for the polymerization of an orthodontic adhesive. *Eur J Orthod* 2006; 28: 78-82.
14. Acteon Group. 2005. “Mini L.E.D.TM.” [online]. Available http://www.acteongroup.info/pdf/Miniled_02521_ Q3.pdf (29 January 2008).
15. Artun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. *Am J Orthod* 1984; 85: 333-40.
16. Ip TB, Rock WP. A comparison of three light curing units for bonding adhesive pre-coated brackets. *J Orthod* 2004; 31: 243-7.
17. Staudt CB, Mavropoulos A, Bouillaguet S, Kiliaridis S, Krejci I. Light-curing time reduction with a new high-power halogen lamp. Am *J Orthod Dentofacial Orthop* 2005; 128: 749-54.
18. Elvebak BS, Rossouw PE, Miller BH, Buschang P, Ceen R. Orthodontic bonding with varying curing time and light power using an argon laser. *Angle Orthod* 2006; 76: 837-44.
19. Reynolds IR. Letter: ‘Composite filling materials as adhesives in orthodontics’. *Br Dent J* 1975; 138: 83.
20. Bishara SE, Gordan VV, VonWald L, Olson ME. Effect of an acidic primer on shear bond strength of orthodontic brackets. *Am J Orthod Dentofacial Orthop* 1998; 114: 243-7.
21. Murfitt PG, Quick AN, Swain MV, Herbison GP. A randomised clinical trial to investigate bond failure rates using a self-etching primer. *Eur J Orthod* 2006; 28: 444-9.
22. Fox NA, McCabe JF, Buckley JG. A critique of bond strength testing in orthodontics. *Br J Orthod* 1994; 21: 33-43.
23. Al Shamsi A, Cunningham JL, Lamey PJ, Lynch E. Shear bond strength and residual adhesive after orthodontic bracket debonding. *Angle Orthod* 2006; 76: 694-9.
24. Bowen RL, Rodriguez MS. Tensile strength and modulus of elasticity of tooth structure and several restorative materials. *J Am Dent Assoc* 1962; 64: 378-87.