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The effect of a light-emitting diode on shear bond strength of ceramic brackets bonded to feldspathic porcelain with different curing times

Selma Elekdag-Turk*, Y. Sinasi Sarac**, Tamer Turk* and Duygu Sarac**
Departments of *Orthodontics and **Prosthodontics, Faculty of Dentistry, University of Ondokuz Mayis, Samsun, Turkey

SUMMARY The aim of this study was to evaluate different curing times of a light-emitting diode (LED) unit on shear bond strength (SBS) of ceramic brackets bonded to feldspathic porcelain.

Ceramic brackets were bonded with a light-cured adhesive to 96 feldspathic porcelain facets. Air-borne particle abrasion was performed using 25 μm aluminium trioxide (Al_2O_3) with an air abrasion device from a distance of approximately 10 mm at a pressure of 2.5 bars for 4 seconds, then the porcelain surfaces were etched with 9.6 per cent hydrofluoric acid for 2 minutes. After surface preparation of the porcelain specimens, silane was applied. In groups 1 and 2, the adhesive was cured with a quartz–tungsten–halogen (QTH) unit for 10 and 20 seconds, respectively. The LED was used in the standard mode for 3, 5, and 10 seconds for groups 3, 4, and 5, respectively. For the other three groups, the LED was used in the fast mode for 3, 5, and 10 seconds, respectively. The SBS of the brackets was measured on a universal testing machine. The adhesive remnant index (ARI) scores, damage to the porcelain, and fracture of the ceramic bracket bases were determined.

No significant differences were observed for SBS between the eight groups ($P = 0.087$). There was no significant difference between the groups' ARI scores, porcelain damage, and bracket base fracture ($P = 0.340$, $P = 0.985$, and $P = 0.340$, respectively). There was a greater frequency of ARI scores of 0 for all groups. Fifty per cent of the porcelain facets displayed damage. Nineteen ceramic bracket base fractures were observed.

No significant difference was found for the SBS of the groups with QTH and LED units and curing times. It is reliable to use LED with a 3-second curing time since it provided adequate bond strength for ceramic brackets bonded to porcelain surfaces.

Introduction

Bonding with light-cured adhesives has become popular among orthodontists because of their ease of use and the time they allow for precise bracket positioning (Oyama *et al.*, 2004; Mavropoulos *et al.*, 2005).

The most common visible light-curing unit still used by orthodontists is the quartz–tungsten–halogen (QTH) unit (Mavropoulos *et al.*, 2005). Nevertheless, this technology has limitations (Yoon *et al.*, 2002; Silta *et al.*, 2005) with the QTH less than 1 per cent of the total energy input is converted into light, the rest is generated as heat. This heat causes degradation of the bulb, filter, and reflector over time. With an ageing light-curing unit, adhesives will be less well cured, with poorer physical properties, and an increased risk of bond failure (Cacciafesta *et al.*, 2002). Halogen bulbs have a limited effective lifetime of around 50 hours (Mills *et al.*, 1999). To overcome these limitations of QTH, Mills (1995) proposed using solid-state light-emitting diode (LED) technology. As electrical current flows through the semiconductor chips, it is converted into light, with little energy lost as heat. LEDs have an expected lifetime of several thousand hours without significant degradation of light intensity over time (Stahl *et al.*, 2000).

Nowadays, there is a worldwide trend for more adults to request orthodontic treatment. Furthermore, due to superior biocompatibility and aesthetic appeal, all ceramic materials are preferred as restorative materials (Anusavice, 1996). Thus, the orthodontist is often faced with bonding ceramic brackets to feldspathic porcelain, which is generally used for contouring the all-ceramic copings (Anusavice, 1996). Bonding to porcelain is a challenge, as optimal bonding, shown to be 6–8 MPa (Reynolds, 1975), must be achieved to prevent bond failure.

With the introduction of LED, bond strengths of metal brackets cured with this light source and QTH have been evaluated (Cacciafesta *et al.*, 2002; Dunn and Taloumis, 2002; Bishara *et al.*, 2003; Swanson *et al.*, 2004; Usumez *et al.*, 2004; Cacciafesta *et al.*, 2005; Mavropoulos *et al.*, 2005; Silta *et al.*, 2005). However, these investigations had variable curing times such as 6, 10, 20, and 40 seconds with QTH and 5, 6, 10, 20, and 40 seconds with LED. Research investigating the bond strength between ceramic brackets and porcelain surfaces is limited (Whitlock *et al.*, 1994; Kocadereli *et al.*, 2001; Harari *et al.*, 2003). No studies evaluating the relationship between bond strengths of ceramic brackets and curing time with QTH and LED or evaluating different curing times with LED to bond ceramic brackets to porcelain were found in the literature.

The purpose of this study was to evaluate the effects of different curing modes and curing times of an LED on the bond strength of ceramic brackets to feldspathic porcelain.

Material and methods

Porcelain facets

Ninety-six feldspathic (Vitadur Alpha; Vita Zahnfabrik, Bad Säckingen, Germany) porcelain specimens (10 × 10 × 3 mm) were fabricated and glazed according to the manufacturer's recommendations and mounted with autopolymerizing acrylic resin (Meliodent; Heraeus Kulzer Ltd, Newbury, Berkshire, UK).

One type of surface conditioning was applied to all specimens. Air-borne particle abrasion was performed using 25 μm aluminium trioxide (Al_2O_3) with an air abrasion device (TopTec; Bego, Bremen, Germany) from a distance of approximately 10 mm at a pressure of 2.5 bars for 4 seconds. The porcelain surfaces were then etched with 9.6 per cent hydrofluoric acid (Porcelain Etch Gel; Pulpdent, Watertown, Massachusetts, USA) for 2 minutes. After surface preparation of the porcelain specimens, silane (Bond Enhancer; Pulpdent) was applied.

Brackets used

Ceramic brackets for upper central incisors (Fascination 2; Dentaurum, Ispringen, Germany) were used. The base of this polycrystalline ceramic bracket is button structured and silane coated. The bracket base area is 9.43 mm^2.

Curing light

Ninety-six feldspathic porcelain surface-conditioned specimens were randomly divided into eight groups, each containing 12 specimens. Adhesive primer (Transbond™ XT; 3M Unitek, Monrovia, California, USA) was applied to the conditioned porcelain surfaces. A light-cure microfilled resin (Transbond™ XT; 3M Unitek) was applied to the bracket base. The bracket was positioned manually on the porcelain surface. Excess composite was removed with an explorer. The surface conditioning and bracket placement were performed by one operator (SET).

Conventional QTH (Hilux 200; Benlioglu Dental Inc., Ankara, Turkey) and LED (Ledmax 1055; Benlioglu Dental Inc.) units were used with different curing times. In groups 1 and 2, the curing time for QTH was 10 and 20 seconds, respectively, directly through the bracket. The QTH had a light intensity of 600 mW/cm^2 and a wavelength of 400–500 nm. LED was used in the standard mode for 3, 5, and 10 seconds for groups 3, 4, and 5, respectively, and for groups 6, 7, and 8, the LED was used in the fast mode for 3, 5, and 10 seconds, respectively (Table 1). The light intensity of the LED was 1500 mW/cm^2 for the fast curing mode and 1200 mW/cm^2 for the standard curing mode. For both curing modes, the wavelength was 440–490 nm. During light exposure, the light guide tip was placed perpendicular and immediately above the bracket with the colour-coded holders in place. The distance between the light guide tip and bracket base was approximately 5 mm.

Shear bond strength

All specimens were stored in distilled water at 37 ± 2°C for 1 week and were thermocycled 500 times between 5 and 55°C with a dwelling time of 30 seconds. Shear bond testing was performed with a universal testing device (Lloyd LRX; Lloyd Instruments Ltd, Fareham, Hants, UK) at a crosshead speed of 1 mm/minute. The bond strengths were calculated in megapascals.

Residual adhesive and bracket base fracture

The surfaces of the porcelain facets were examined with a stereomicroscope (Stemi 2000-C; Carl Zeiss, Göttingen, Germany) at a magnification of ×10 to determine the amount of composite resin remaining according to the adhesive remnant index (ARI; Årtun and Bergland, 1984), and to assess the damage to the porcelain facets. Furthermore, the porcelain facets were examined for any ceramic bracket remnants, i.e. for any ceramic bracket base fractures.

Statistical analysis

Shear bond strength (SBS) data were subjected to one-way analysis of variance (ANOVA) to test for differences between the groups. The chi-square test evaluated differences in ARI scores, porcelain facet damage, and ceramic bracket base fractures between the groups. All statistical analyses were performed at the 0.05 level of significance.

Results

Descriptive statistics and the results of the one-way ANOVA comparing the SBS of ceramic brackets bonded to porcelain facets with the two different light sources are given in Table 2. There was no evidence to suggest a difference in SBS between any of the eight groups tested ($P = 0.087$).

Frequency distribution and the results of the chi-square analysis of the ARI scores, porcelain damage, and fracture of ceramic bracket bases are given in Table 3. There was no significant difference between any of the groups' ARI scores, damage to porcelain, or fracture of ceramic bracket bases ($P = 0.340$, $P = 0.985$, and $P = 0.340$, respectively). There was a greater frequency of ARI scores of 0 (no adhesive on the porcelain facet) for all groups, which indicated that failures were mainly at the adhesive–porcelain

Table 1 The groups in the study.

Group	n	Light-curing unit	Curing time (s)
QTH-10	12	QTH	10
QTH-20	12	QTH	20
LED-standard-3	12	LED (standard mode)	3
LED-standard-5	12	LED (standard mode)	5
LED-standard-10	12	LED (standard mode)	10
LED-fast-3	12	LED (fast mode)	3
LED-fast-5	12	LED (fast mode)	5
LED-fast-10	12	LED (fast mode)	10

QTH, quartz–tungsten–halogen; LED, light-emitting diode.

Table 2 Descriptive statistics and the results of one-way analysis of variance comparing shear bond strengths of the eight groups tested.

Group	Mean (MPa)	SD	Range (MPa)
QTH-10	15.72*	2.03	13.53–20.28
QTH-20	16.91*	3.09	12.87–20.45
LED-standard-3	14.22*	1.52	12.29–16.37
LED-standard-5	14.39*	1.41	12.03–16.19
LED-standard-10	14.40*	2.05	11.94–17.75
LED-fast-3	15.51*	2.14	12.21–18.47
LED-fast-5	15.53*	3.21	11.72–20.97
LED-fast-10	15.90*	2.13	12.48–20.19

QTH, quartz–tungsten–halogen; LED, light-emitting diode; SD, standard deviation.
*Groups not statistically different from each other ($P = 0.087$).

interface. Approximately 50 per cent of the porcelain facets displayed damage. Nineteen partial ceramic bracket base fractures were observed.

Discussion

The results show that type of light-cure unit and curing time did not affect SBS. Clinically, bonded brackets should be able to withstand forces generated by the treatment mechanics and occlusion and yet allow easy debonding without damage to the teeth (Ostertag *et al.*, 1991; Merrill *et al.*, 1994). A tensile bond strength value of 6–8 MPa would be adequate to resist treatment forces (Reynolds, 1975). In this study, the SBS values obtained with the QTH and LED at different curing times were above this clinically acceptable level.

The bond strength of ceramic brackets depends upon the retention mechanism of the bracket base and the type of adhesive. Nkenke *et al.* (1997) and Weinberger *et al.* (1997) reported that silanation of ceramic brackets results in significantly higher bond strength values, whereas Ostertag *et al.* (1991) and Merrill *et al.* (1994) stated that silanation of ceramic brackets does not result in higher bond strength when compared with mechanically retained ceramic brackets. Highly filled adhesives, such as Transbond XT

Table 3 Frequency distribution and the results of the chi-square analysis of the adhesive remnant index (ARI) and porcelain facet damage and bracket base fracture.

Groups	ARI score*†				Porcelain facet damage‡§		Bracket base fracture¶‖	
	0	1	2	3	0	1	0	1
QTH-10	9	3	—	—	5	7	9	3
QTH-20	10	2	—	—	5	7	10	2
LED-standard-3	12	—	—	—	5	7	12	—
LED-standard-5	11	1	—	—	5	7	11	1
LED-standard-10	10	2	—	—	7	5	10	2
LED-fast-3	8	4	—	—	6	6	8	4
LED-fast-5	9	3	—	—	6	6	9	3
LED-fast-10	8	4	—	—	6	6	8	4

QTH, quartz–tungsten–halogen; LED, light-emitting diode.
*$\chi^2 = 7.913$, $P = 0.340$.
†ARI scores: 0, no composite left on porcelain facet; 1, less than half of composite left; 2, more than half of composite left; and 3, all composite left.
‡$\chi^2 = 1.415$, $P = 0.985$.
§Porcelain facet damage: 0, no damage on porcelain facet; 1, crack on porcelain facet.
¶$\chi^2 = 7.913$, $P = 0.340$.
‖Bracket base fracture: 0, no ceramic bracket base fracture; 1, part of ceramic bracket base remained on porcelain facet.

light-cure adhesive, provide higher bond strength values (Zachrisson and Brobakken, 1978; Bishara *et al.*, 1995). Several studies have used Transbond XT adhesive with QTH for 10 seconds; SBS values obtained with mechanically retained polycrystalline brackets ranged from 10.4 to 28.5 MPa (Bishara *et al.*, 1997; Mundstock *et al.*, 1999; Klocke *et al.*, 2003; Theodorakopoulou *et al.*, 2004; Liu *et al.*, 2005; Speer *et al.*, 2005). In the present study, the SBS values were 15.72 and 16.91 MPa with QTH for 10 and 20 seconds, respectively. These two values are lower than the SBS values cited by Theodorakopoulou *et al.* (2004) of 21.67 MPa and Speer *et al.* (2005) of 28.5 MPa but higher than the SBS values obtained by Liu *et al.* (2005) of 11.83 MPa, Mundstock *et al.* (1999) of 13.27 MPa, Klocke *et al.* (2003) of 10.73 MPa, and Bishara *et al.* (1997) of 10.4 MPa. In the present study, curing with QTH for 10 and 20 seconds served as the control groups. These results show that curing with QTH for 20 seconds does not have any advantage when compared with curing for 10 seconds.

To test the effectiveness of LED, curing times of 3, 5, and 10 seconds were selected. For ceramic brackets, the recommended curing time with Transbond XT adhesive is 5 seconds with an LED. SBS values obtained with 3 and 10 seconds did not show any significant differences from those values obtained with 5 seconds of curing. The SBS values at 3, 5, and 10 seconds with the LED were not significantly different from those with a QTH at 10 and 20 seconds. Cacciafesta *et al.* (2002) and Silta *et al.* (2005) did not observe any significant differences between 10 and 6 seconds with QTH and LED units. Usumez *et al.* (2004) reported that the bond strength obtained with QTH for 40 seconds and LED for 20 and 40 seconds were not significantly different. Mavropoulos *et al.* (2005) stated that the bond strength obtained with QTH for 40 seconds and LED for 10 seconds did not show significant differences. However, significantly lower bond strength was reported with LED for 10 and 5 seconds by Usumez *et al.* (2004) and Mavropoulos *et al.* (2005), respectively. In those two studies, the light intensity of QTH was higher than that of the LED.

One factor affecting the degree of polymerization is the intensity of light. In the present study, the light intensity of the LED was higher than that of the QTH. Furthermore, the polymerization of light-cured resin depends not only on the quantity of light but also on the quality, such as wavelength (Yoon *et al.*, 2002). The majority of light-activated composites contain camphoroquinone (CQ), and its absorbance strongly affects polymerization (Yoon *et al.*, 2002). The 450- to 490-nm wavelength range is the optimal absorption bandwidth of CQ (Nomoto *et al.*, 1994). The emission bandwidth of the LED used in this study lies between 440 and 490 nm, which coincides with the optimal absorption bandwidth of CQ. Although the curing times with the LED (3 and 5 seconds) were shorter than those of the QTH (10 and 20 seconds), the similarity of SBS values for the LED and QTH units might be explained by the higher light intensity and precise wavelength of the LED.

Factors such as the orientation of the light tip might affect light intensity. For maximum light intensity, the light guide tip should be orientated perpendicular to the bracket base. If the light guide is tipped, the circular spot changes to an ellipse resulting in decreased light intensity (Oyama *et al.*, 2004). In the present study, the light tip was orientated perpendicular to the bracket base to minimize spot-area changes. Another factor affecting polymerization is light transmittance of the ceramic bracket. An extremely low percentage of light transmittance has been found for polycrystalline brackets as opposed to monocrystalline brackets (Eliades *et al.*, 1995). Furthermore, a decrease in light transmittance caused by the colour-coded holders was observed. In the present study, the colour-coded holders were not removed to simulate the clinical situation. Nevertheless, the bond strengths of the two units used with different curing times exceeded the minimum bond strength value of 6–8 MPa. Eliades *et al.* (1995) mentioned that a critical transmittance value exists which provides sufficient light intensity for adequate bond strength.

The results for the 3-second curing time with LED are very encouraging. The findings of laboratory studies should not be extrapolated to clinical performance but serve as an important preliminary screening tool before clinical validation (Swanson *et al.*, 2004). Thus, the effectiveness of a 3-second curing time with LED should be clinically tested.

A higher frequency of ARI score 0 was observed for all groups, indicating that no adhesive was left on the porcelain facets. This implies that the mode of failure was at the adhesive/porcelain facet interface, and that the risk of porcelain facet fracture is increased. Fifty per cent of porcelain facets in each group showed damage. Studies investigating the bond strength of ceramic brackets bonded to porcelain facets showed no damage caused by debonding (Whitlock *et al.*, 1994; Harari *et al.*, 2003). In those studies, mean tensile bond strengths ranged from 3.8 to 7.7 MPa and mean SBS from 1.8 to 7.5 MPa. In the present investigation, the SBS values ranged from 14.22 to 16.91 MPa. It is reported that if bond strengths between the porcelain facet and the composite resin are higher than 13 MPa, cohesive failures are observed at the porcelain facet (Thurmond *et al.*, 1994). Liu *et al.* (2005) and Mundstock *et al.* (1999) noted enamel fractures on five to six teeth bonded with polycrystalline brackets, respectively. Bishara *et al.* (1995) observed enamel cracks in 33.3 per cent of teeth after debonding. They stated that this was to be expected since the more the force applied during debonding, the greater the stress transmitted to the enamel surface and the higher the incidence of enamel cracks.

In the present research, partial bracket base fracture was observed in 19 out of the 96 ceramic brackets. The inherent brittleness of the ceramic bracket may cause it to fracture on debonding. Ceramic bracket materials elongate less than 1 per cent before fracturing and, hence, cannot be 'peeled' off the adhesive. Brackets that fracture on debonding usually leave significant amounts of ceramic material on the tooth (Merrill *et al.*, 1994).

Conclusion

Within the limitations of this *in vitro* study, the following conclusions were drawn:

1. No significant difference was found for the SBS of the groups with the QTH and LED units and curing times.
2. A greater frequency of ARI score 0 was observed for all groups, indicating that no adhesive was left on the porcelain facets. In each group, 50 per cent of porcelain facets showed damage.
3. It is reliable to use a LED with a 3-second curing time since it provides adequate bond strength for ceramic brackets bonded to porcelain surface.

Address for correspondence

Dr Selma Elekdag-Turk
University of Ondokuz Mayis
Faculty of Dentistry
Department of Orthodontics
55139 Kurupelit
Samsun
Turkey
E-mail: turkset@superonline.com

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