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Effect of curing time on the bond strength of a bracket-bonding system cured with a light-emitting diode or plasma arc light

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SUMMARY The purpose of this study was to assess the influence of two light units, a light-emitting diode (LED) and a plasma arc light (PAC), on the shear bond strength (SBS) of brackets bonded to enamel.

Ninety bovine teeth were divided into six groups, according to the light-curing unit and exposure times used. In the LED (Ortholux; 3M-Unitek) group, the specimens were light cured for 5, 10, and 15 seconds. In the PAC (Apollo 95E; DenMed Technologies) group, the specimens were light cured for 3, 6, and 9 seconds. The brackets were bonded with Transbond XT (3M-Unitek), stored in distilled water at 37°C for 24 hours and then submitted to SBS testing in a universal testing machine. The adhesive remnant index (ARI) was used to evaluate the amount of adhesive remaining on the teeth.

According to analysis of variance and Tukey multiple comparisons test, the highest mean SBS was obtained with the LED at 15 seconds (16.68 MPa), which did not significantly differ from the LED 10 (14.76 MPa) or 5 (13.92 MPa) second groups ($P > 0.05$). The LED 10 and 5 second groups were not significantly different from the PAC 9 second group (12.66 MPa) or from the PAC 6 second group (9.96 MPa). The lowest mean SBS was obtained with the PAC 3 second group (8.29 MPa), which did not differ significantly from the PAC 6 second group. The method of light curing did not influence the ARI, with score 3 predominant.

The LED at 5 seconds and the PAC at 3 seconds provided sufficient mean SBS to resist either orthodontic or masticatory forces.

Introduction

With acid etching of enamel it became possible to attach orthodontic accessories directly onto the enamel surface (Buonocore, 1955; Reynolds, 1975). At the end of the 1970s, light-cured resin materials were developed for bonding brackets and were widely accepted due to their advantages in comparison with self-cured materials. These advantages include the control of working time, application of a single paste, more accurate bracket placement, reduced risk of contamination, easy removal of excess bonding material, and immediate insertion of the orthodontic arch wire (Sfondrini *et al.*, 2002, 2004).

The light-emitting diode (LED) is a new technology for light polymerization in orthodontics. The advantages of LED are coincidence of peak irradiance of the light with camphorquinone (Nicholls, 2000; Swift, 2002), a lamp duration time of approximately 10 000 hours (Mills *et al.*, 1999), no heat generation, and resistance to impacts (Mills *et al.*, 1999; Dunn and Taloumis, 2002); the appliance consumes little power and can be run on rechargeable batteries, allowing it to have a lightweight ergonomic design (Wiggins *et al.*, 2004).

The plasma arc light (PAC) was introduced as an alternative for fast polymerization. This appliance emits high-intensity irradiation, over 1000 mW/cm^2, enabling polymerization in a shorter period of time. Although this unit needs a filter system, it enables light to be filtered in a narrow wavelength. While the light generates a considerable temperature increase in the tooth, this does not harm the dental pulp during the short exposure period required in orthodontics (Rueggeberg, 1999; Pettemerides *et al.*, 2001; Sfondrini *et al.*, 2002, 2006; Nomoto *et al.*, 2004).

Irrespective of the light unit used, it should be capable of adequately polymerizing the material, the polymerization capacity of which is directly related to the light power as well as irradiation time. If the resin material is adequately polymerized, a higher bond strength is expected in comparison with a material with a lower degree of conversion.

Many studies have used shear testing to evaluate the bond strength of bracket bonding systems (Sfondrini *et al.*, 2002, 2006; Uşümez *et al.*, 2004; Gronberg *et al.*, 2006; Yu *et al.*, 2007), and bovine teeth have been used as a substitute for human enamel in some studies (Nkenke *et al.*, 1997; Prietsch *et al.*, 2007).

The purpose of the study was to compare the shear bond strength (SBS) of metal brackets bonded to bovine enamel with an orthodontic resin using two light sources (LED and PAC) with different exposure times.

Materials and methods

To calculate the sample size required for the study, the standard deviation from a pilot investigation was used. A sample size of 15 specimens for each group was expected to provide 90 per cent power to detect a difference in means of 4 MPa between the groups.

A total of 90 primary bovine incisors teeth were extracted and kept frozen for a maximum of 3 months. Selection criteria for the teeth included intact dental enamel, without the presence of caries, fractures, or cracks visible to the naked eye. To obtain the specimens, the teeth were sectioned at the cemento-enamel junction and embedded in acrylic resin. The bracket bonding area was clinically determined by inspection in the flattest portion of the buccal surface of the crown, closest to its centre.

The teeth were randomly divided into six groups ($n = 15$) according to the type of light unit and exposure time.

After prophylaxis with pumice, the enamel was etched for 15 seconds with 37 per cent phosphoric acid, rinsed for 10 seconds with distilled water, and air-dried for 10 seconds. Transbond XT primer (3M-Unitek, St Paul, Minnesota, USA) was applied to the etched enamel. Transbond XT composite resin was applied on the stainless steel mandibular incisor bracket base (ref. 10.30.205; Morelli, São Paulo, Brazil), which was placed on the tooth with a holding pincer with sufficient manual pressure to allow the excess material to flow at the margins of the bracket. The excess material was removed with an exploratory probe.

In the LED 5, 10, and 15 second groups, the resin was light cured with an Ortholux LED (3M-Unitek). In the LED 5 second group, the light was placed only in an incisal direction for 5 seconds; for the LED 10 second group, it was placed in a mesial and distal direction for 5 seconds each while in the LED 15 second group, it was placed in a mesial, distal, and incisal direction for 5 seconds each.

In the PAC 3, 6, and 9 second groups, the resin was light cured with an Apollo 95E (DenMed Technologies, Orange, California, USA). In the PAC 3 second group, the light was placed only in an incisal direction for 3 seconds; for the PAC 6 second group, it was placed in a mesial and distal direction for 3 seconds each and in the PAC 9 second group, in a mesial, distal, and incisal direction for 3 seconds each.

Light curing with both units was performed by maintaining the curing tip of the appliance as close to the bracket as possible without displacing it, forming an angle of approximately 45 degrees with the buccal face of the tooth. The light intensity of the appliances was monitored with radiometers (Demetron-Kerr, Orange, California, USA) for the LED and (Litex/Dentamerica, City of Industry, California, USA) for the PAC. The characteristics of the two light unit are shown in Table 1.

The bonding was performed by a single operator (CMD) who was not blind to the group. The specimens were stored in distilled water at 37°C for 24 hours and submitted to SBS testing in a universal testing machine (Emic DL2000; São José dos Pinhais, Paraná, Brazil) at a crosshead speed of 0.5 mm/minute. SBS values in megapascals (MPa) were calculated from the peak load at failure divided by the specimen surface area. After bond strength testing, all specimens were visually examined with a stereomicroscope (Olympus Corp., Tokyo, Japan) at ×10 magnification to assess the fracture pattern and adhesive remnant index (ARI; Årtun and Bergland, 1984): score 0, no composite resin left on the tooth; score 1, less than half of the composite resin left on the tooth; score 2, more than half of the composite resin left on the tooth; and score 3, all composite resin left on the tooth, with a distinct impression of the bracket mesh.

Analysis of variance (ANOVA) and the Tukey multiple comparison test ($\alpha = 0.05$) were used to determine SBS values. The ARI results were submitted to the Kruskal–Wallis test ($\alpha = 0.05$). The data were processed and analysed using the Statistical Package for Social Sciences version 10.0 (SPSS Inc., Chicago, Illinois, USA).

Results

ANOVA showed statistically significant differences among the groups ($P < 0.001$; Table 2). Tukey multiple comparison test showed that the LED 15 second group (16.68 MPa) had the highest mean SBS, not differing significantly from the LED 10 (14.76 MPa) and LED 5 (13.92 MPa) second groups. The LED 10 and 5 second groups did not differ significantly from the PAC 9 second group (12.66 MPa), which did not differ significantly from the PAC 6 second group (9.96 MPa). The lowest mean SBS was obtained with the PAC 3 second group (8.29 MPa), which did not differ significantly from the PAC 6 second group (Table 3).

No significant differences in ARI scores among the groups ($P = 0.979$ Kruskal–Wallis). There was a higher frequency of score 3 (65.6 per cent), followed by score 2 (32.2 per cent). Only in two specimens was Score 1 observed

Table 1 Characteristics of the light-emitting diode (LED) and plasma arc light (PAC) units.

Appliance	Type	Wavelength (nm)	Light intensity (mW/cm^2)	Tip diameter (mm)
Ortholux™	LED	430–480*	800	8
Apollo® 95E	PAC	460–490*	1800	8

*According to the manufacturers' specifications.

Table 2 Analysis of variance.

Sources of variation	Sum of squares	DF	Mean square	*f*	*P*
Among the groups	728 931	5	145 786	16.54	0.000
Within the groups	740 505	84	8816		
Total	1 469 436	89			

(2.2 per cent). There was a fracture in the enamel and dentine in three specimens, one from LED 5 second group and two from LED 15 second group (Table 4).

Discussion

The results of the present study show that there was a gradual increase in mean SBS as light-curing time increased for both light units. Peutzfeldt and Asmussen (2005) also found an increase in SBS with an increase in light-curing time. Time and bond strength relationship is probably due to the higher rates of monomer/polymer conversion that occur with the increase in light-curing time. Other authors have reported similar findings (Uşümez *et al.*, 2004; Mavropoulos *et al.*, 2005; Staudt *et al.*, 2005; Gronberg *et al.*, 2006; Yu *et al.*, 2007).

One factor that also contributes to the level of polymerization is light power. There must be a minimum light power, at a specific wavelength, to initiate the polymerization reaction, in addition to a time interval, so that the reaction extends to the deeper layers of the material and attains its maximum properties (Mills *et al.*, 1999; Jandt *et al.*, 2000; Dunn and Taloumis, 2002; Tarle *et al.*, 2002). Rueggeberg (1999) reported that the higher the light power, the greater the number of photons reaching the composite resin and the higher the number of free radicals available for the conversion of monomer into polymer. In this study, the LED unit had a mean power of 800 mW/cm^2 and the PAC unit 1800 mW/cm^2.

All mean SBS presented lower values in the PAC groups when compared with the values in the LED groups. Statistically, the mean SBS were considered equivalent between the LED 5 and 10 second groups with the PAC 9 second group. A different behaviour was observed by Thind *et al.* (2006) in that the group light cured with an LED for 10 seconds showed equivalent values to the group light cured with a PAC for 6 seconds. The study of Yu *et al.* (2007), with exposure times differing from those of the present investigation (4, 6, and 8 seconds for the LED as well as for the PAC), reported statistical equivalence between 4 seconds of light curing with a PAC and 8 seconds with a LED.

Rueggeberg (1999) and Rahiotis *et al.* (2004) stated that, in addition to irradiation intensity and exposure time, the total energy released (energy density) in polymerization was also a factor involved in the conversion of monomer into polymers in composite resins. In the present study, the total energy released in the group cured with the LED was lower than in the group cured with the PAC, and the mean SBS was higher for the LED groups. These results are contrary to those of Rueggeberg (1999), Rahiotis *et al.* (2004), and Peutzfeldt and Asmussen (2005), who observed that the higher the SBS values, the greater the total energy during polymerization. However, Niepraschk *et al.* (2007), who assessed the degree of conversion of monomer into polymer by means of infrared spectrophotometry, concluded that the degree of polymerization of the resin had a greater relationship with the time of exposure to light than to its power, confirming the result of the present study.

The PAC 3 second group, with a shorter exposure time, showed the lowest mean SBS value (8.29 MPa), which was not statistically significant different from the PAC 6 second group (9.96 MPa). However, even with the lowest mean, this group showed adequate bond strength for the majority of clinical situations, in accordance with the values proposed by Reynolds (1975), which are between 6 and 8 MPa.

Several studies have tested the *in vitro* bond strength of brackets light cured with a PAC and reported that a minimum exposure of 2 (Sfondrini *et al.*, 2001), 3 (Oesterle *et al.*, 2001; Pettemerides *et al.*, 2001), or 4 (Yu *et al.*, 2007) seconds produces acceptable bond strength values. These

Table 3 Bond strength mean values (MPa) in the experimental groups using a light-emitting diode (LED) or plasma arc light (PAC) and different exposure times.

Group	*n*	Mean (MPa)*	SD	Coefficient of variation (%)
LED 15 seconds	15	16.68^{A}	4.44	26.60
LED 10 seconds	15	14.76^{AB}	2.43	16.47
LED 5 seconds	15	13.92^{AB}	2.97	21.36
PAC 9 seconds	15	12.66^{BC}	2.51	19.80
PAC 6 seconds	15	9.96^{CD}	2.53	25.37
PAC 3 seconds	15	8.29^{D}	2.41	29.03

*Different letters indicate statistically different mean values ($P < 0.05$).

Table 4 Adhesive remnant index (ARI) score in the experimental groups using a light-emitting diode (LED) or plasma arc light (PAC) with different exposure times.

Group	ARI, *n* (%)				Total
	Score 0	Score 1	Score 2	Score 3	
LED 5 seconds	0 (0)	1 (6.7)	4 (26.7)	10 (66.7)	15 (100.0)
LED 10 seconds	0 (0)	0 (0)	5 (33.3)	10 (66.7)	15 (100.0)
LED 15 seconds	0 (0)	1 (6.7)	4 (26.7)	10 (66.7)	15 (100.0)
PAC 3 seconds	0 (0)	0 (0)	6 (40.0)	9 (60.0)	15 (100.0)
PAC 6 seconds	0 (0)	0 (0)	4 (26.7)	11 (73.3)	15 (100.0)
PAC 9 seconds	0 (0)	0 (0)	6 (40.0)	9 (60.0)	15 (100.0)
Total	0 (0)	2 (2.2)	29 (32.2)	59 (65.6)	90 (100.0)

findings also confirm the *in vivo* study of Cacciafesta *et al.* (2004). On the other hand, Klocke *et al.* (2002) recommended minimum light curing of two cycles for 3 seconds to reduce the risk of bracket debonding. Oesterle *et al.* (2001) reported that although only 3 seconds of polymerization is effective, 6–9 seconds of activation with a PAC produces the same or a higher level of bond strength than 40 seconds with a quartz–tungsten–halogen light.

Among the groups light cured with the LED, the lowest mean SBS was obtained with a time of 5 seconds. These findings corroborate the results of Mavropoulos *et al.* (2005) and Gronberg *et al.* (2006), in which a minimum time of 5 seconds resulted in SBS values sufficient to resist the forces exerted by both orthodontic forces and mastication. A divergent result was found by Yu *et al.* (2007), in which light curing with a LED for 4 and 6 seconds showed lower SBS values; the values were considered to be satisfactory only when light cured for 8 seconds.

There was no significant difference in ARI scores among the groups, with the predominant score being 3 (65.6 per cent). This indicated that the majority of failures after debonding occurred at the bracket–adhesive interface, with material remaining adhered to the surface, allowing adequate removal of composite resin and, consequently, preservation of the enamel from possible trauma (Thind *et al.*, 2006; Prietsch *et al.*, 2007; Yu *et al.*, 2007).

The results of this study suggest that the light unit does not affect the location of orthodontic bond failures since the majority of these occurred at the bracket–composite resin interface (score 3) with both light units. Gronberg *et al.* (2006) and Yu *et al.* (2007) reported that this failure location could indicate incomplete resin polymerization at the base of the bracket as a result of the short period of light exposure. This could, however, diminish the probability of damage to the enamel during debonding, which is advantageous.

Fractures have been reported in enamel when bond strength values exceed 13.5 (Retief *et al.*, 1970), 10 (Nkenke *et al.*, 1997), or 9.7 (Retief, 1974) MPa. On the other hand, Thind *et al.* (2006) did not observe any sign of fracture in enamel even with bond strength values of 15.7 MPa. In the present study, fractures in the enamel and dentine were observed when a bond strength value of over 20 MPa was reached. Thind *et al.* (2006) reported that the combination of the direction of the fracture line along the enamel–adhesive interface, the presence of defects in the enamel surface, and high bond strength forces could increase the risk of fractures during debonding. Zachrisson (1977) also mentioned that differences in the composition of the enamel could be one of the reasons for bond failure. Thus, in this study, the presence of defects in the enamel surface could be one factor that contributed to the occurrence of fractures in the enamel and dentine.

Bovine teeth were used because extracted human teeth are becoming increasingly difficult to obtain due to the progress in conservative dental treatment. According to Nakamichi *et al.* (1983), bovine teeth are useful in adhesion testing as substitutes for human teeth. They found no statistically significant difference between bovine and human teeth in relation to the adhesive strength, although the mean values were always slightly lower with bovine teeth.

One limitation of the present research was that it was an *ex vivo* study, which cannot completely reproduce the complex interaction process of the oral cavity (Oilo, 1992; Eliades *et al.*, 1999). Pickett *et al.* (2001) and Murray and Hobson (2003) found that bond strength values *in vivo* tend to be lower than those found *ex vivo* as a result of biodegradation that occurs in the oral cavity. Another limitation was the use of a universal testing machine under a constant crosshead speed of 0.5 mm/minute for bracket removal. According to Eliades and Brantley (2000), this load speed is generally used, although it does not correspond to clinical conditions since debonding *in vivo* occurs at a higher speed.

Despite the above limitations, the results of the present study suggest that both LED and PAC technology can be used in bracket bonding with reduced light-curing time without affecting the SBS of the brackets and dental enamel. From a clinical point of view, this reduction is advantageous due to the shorter chair time, allowing the orthodontist to attend a larger number of patients and thus compensating for the higher expenditure on purchasing the units. Furthermore, this reduction in resin setting time results in a lower risk of contamination by saliva, thus increasing bond strength and reducing the rate of orthodontic bracket debonding.

Conclusions

Based on the analysis of the data obtained in this study, it was concluded that:

1. There was statistical equivalence of bond strength values between the LED 5 and 10 second groups with the PAC 9 second group.
2. The use of LED and PAC light units results in a decrease in light-curing time of the composite resin, Transbond XT, to 5 seconds with LED and 3 seconds with PAC, with bond strength values clinically acceptable for orthodontic treatment.
3. The method of light curing did not influence the ARI, and score 3 was predominant.

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