SCIENTIFIC SECTION

A comparison of three light curing units for bonding adhesive pre-coated brackets

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Objective: To compare the effectiveness of three curing lights of different types.

Design: Prospective randomized laboratory investigations.

Materials and method: Adhesive pre-coated orthodontic brackets were bonded to 9 groups of extracted premolars and the adhesive was cured using three different curing lights, each at three different times. Bond strength was tested using a shear/peel method.

Results: The plasma light had 3 times the light intensity of the standard quartz halogen light. The curing times recommended by the manufacturers were 2 seconds for the plasma light, 10 seconds for the high intensity quartz halogen light and 20 seconds for the standard one. Mean debond stresses with these cure times were 9.36, 11.77 and 12.00 MPa, respectively, $p<0.04$. Increasing the plasma light cure to 4 seconds increased the mean debond stress to 11.19 MPa, similar to that for the other lights, $p=0.62$.

Conclusions: Use of a plasma light confers worthwhile time savings when bonding orthodontic brackets, whilst producing bonds of equivalent strength to those found with quartz halogen lights.

Key words: Orthodontic adhesive, light cure

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Introduction

Composite resins form the basis of most orthodontic adhesives. In clinical use, it is important that material used to bond attachments to etched enamel surfaces can change quickly from a fluid to a solid state. Setting polymerization may be achieved either by chemical interaction between components of a resin system or by photo-initiation, the uptake of energy by exposure of resin to a suitable light source.

The optimal setting reaction for a chemically cured orthodontic adhesive is one that allows the clinician to place several brackets from one mix, but then produces rapid polymerization.[1] This is a difficult balance to achieve; if curing time is prolonged to allow more time for bracket positioning it may be necessary to delay archwire placement while waiting for the recommended minimum bond strength of 4.9 MPa to be achieved.[2] A setting time that is too short puts undue time pressure on accurate bracket positioning and may also result in the placement of brackets using adhesive that has already partly set.

Light cured resins do not set until light of suitable wavelength and intensity is applied to produce free radicals by disruption of double bonds in the alpha diketone initiator. A wavelength between 460 and 480 nm, within the blue end of the visible spectrum, is used at an intensity that allows it to pass through the enamel and produce rapid setting. A light intensity of 300 mW cm^{-2} has been recommended as the minimum level required to produce complete curing of composite resin.[3]

Another advantage of light curing is that it has made possible the production of adhesive pre-coated (APC) brackets (3M Unitek, PO Box 1, Bradford, BD5 9UW, UK). These allow the quality and quantity of the adhesive to be controlled.[4]

Two types of bulb are used in dental curing lights: tungsten quartz halogen bulbs and xenon plasma arcs. The setting time recommended for quartz halogen lights, which have been in use for longer than plasma lights, is usually around 20 seconds, although it has been demonstrated that curing for 40 seconds improves bond strength.[4] Quartz halogen lights are relatively inexpensive and widely used, but have two disadvantages. First,

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the bulbs, filters and reflectors in the optical system degrade with time, and so reduce light output. Secondly, the power density of the light decreases dramatically with distance; to be fully effective the light guide must be as close as possible to the material that is to be cured.

A xenon plasma arc works on the principle that, when electricity is passed through xenon gas, ionization produces a plasma of charged particles that emit blue-white light at low pressure and wavelengths similar to daylight at high pressure. A properly filtered xenon arc is an effective source for curing composite resins rapidly and times as low as 2 seconds per bracket have been suggested.[5] Studies that have compared shear bond strengths produced using a tungsten quartz halogen light or a xenon plasma arc have reported no statistically significant differences.[6,7] The plasma light therefore offers a considerable advantage in that it reduces adhesive setting time per tooth from 20–40 to as low as 2 seconds.

The present study was set up to examine the effect on bond strengths between orthodontic brackets and etched enamel after light-sensitive adhesive was cured using different curing lights, including a xenon plasma arc.

Method and materials

Three curing lights were tested:

- Apollo 95E plasma light (DMDS, 12–17 Upper Bridge Street, Canterbury, CT1 2NF, UK);
- Optilux 501 high intensity halogen light (Kerr UK Ltd., Mallard Road, Peterborough PE3 8YP, UK);
- XL 3000 halogen light (3M Unitek, PO Box 1, Bradford BD5 9UW, UK); this is a conventional dental curing light of a type that has been in use for several years and has been used in previous studies by one of the authors.[4,8]

The radiometer incorporated into the Optilux 501 was used to measure the intensity of each light. Since the meter had a stated accuracy of 100 mW cm^{-2}, three readings were taken from each light and rounded to the nearest 100 mW cm^{-1}.

One hundred and thirty-five upper first premolar teeth were collected and stored in distilled water. They were then autoclaved at 127°C for 20 minutes as recommended by Shaffer *et al.*[9] The teeth were then divided by a process of physical randomization into 9 groups of 15 teeth. Throughout subsequent specimen preparation processes, the teeth were kept moist so that desiccation did not affect the enamel surface.

Each tooth was sectioned at the amelo-dentinal junction using a water-cooled diamond disc before being mounted in acrylic resin contained in a 1.5-cm brass cylinder. Teeth were mounted so that the buccal surface was uppermost to allow bracket bonding.[8]

An adhesive pre-coated (APC™) first premolar straightwire bracket was bonded to each premolar crown following the procedure below:

- polish the enamel surface with pumice in a bristle brush for 5 seconds;
- rinse with atomized water spray for 15 seconds;
- dry with compressed air for 15 seconds;
- etch with 37% orthophosphoric acid for 30 seconds;
- rinse with atomized water spray for 30 seconds;
- dry with oil-free dry compressed air for 15 seconds;
- apply Prime and Bond™ resin to the etched surface;
- seat bracket on the FACC[10] and apply firm pressure to squeeze out surplus resin, and remove excess;
- cure for the appropriate time (Table 1).

Bond strengths were tested on an Instron machine using the shear-peel method recommended by Fox *et al.*[10] according to which brackets were pulled from the teeth by a loop of stainless steel wire under the tie-wings. The crosshead speed was 5 mm min[1].[4]

Power calculation

Evans *et al.* (2002)[11] suggested that a group size of 15 samples was required to provide a power of 80% at the 95% probability level when comparing 3 groups using ANOVA. This was used in the present study.

Results

Results for light intensity measurements are shown in Table 2. The Apollo plasma light was 3 times as intense as the standard quartz halogen XL 3000.

Results for each curing time with the respective lights are shown in Table 3 and Figure 1. Analysis of variance using the General Linear Model program in Minitab Version 13.1 suggested that the effect of both light type and curing time on debond stress was statistically significant (p=0.000). Further analysis of the differences between the light sources without the curing time variable revealed that there were no differences between the debond stresses with respect to the

Table 1 Curing times used with each light unit

Light unit	Manufacturer's recommended time (seconds	Actual times tested (seconds)				
		2	4	10	20	40
Apollo 95E	1–3	*	*	*		
Optilux 501	10		*	*	*	
XL 3000	20			*	*	*

Table 2 The intensities of the three lights tested (mW cm^{-2})

Sample	Light unit		
	Apollo 95E	Optilux 501	XL 3000
1	1100	700	400
2	1200	800	400
3	1200	800	400
Modal intensity	1200	800	400

three lights (p=0.28; Table 4), although curing time was a significant variable (p=0.00; Table 5).

The interactions between the 3 light units and curing time were not significant according to ANOVA (p=0.14).

Table 6 shows debond stresses with the Apollo, Optilux and XL3000 lights used at the manufacturers' recommended curing times of 2, 10 and 20 seconds, respectively. The mean debond stress after 2 seconds exposure to the Apollo was significantly lower than the means for the other 2 lights (p=0.004). However, an increase in exposure time for the Apollo from 2 to 4 s increased the mean debond stress by 20% from 9.36 to 11.19 MPa, very close to the debond stresses recorded using the other lights as recommended. The Apollo light is therefore able to produce equivalent bond strengths in 40 and 20% respectively of the times needed by the other two curing units.

Discussion

During the period when teeth were being collected prior to testing, they were stored in distilled water. To prevent cross-infection risks, teeth were sterilized by autoclaving, a process that does not appear to affect the results of bond strength testing.[12]

Table 3 Means, standard deviations and ranges for debond stresses (MPa) for each light unit

Light unit	Time (seconds)	No.	Mean (MPa)	SD	Min	Max
Apollo 95E	2	15	9.4	2.1	6.6	15.4
	4	15	11.2	2.1	7.9	16.0
	10	15	14.3	2.5	10.7	18.5
	All	45	11.6	3.0	6.6	18.5
Optilux 501	4	15	8.5	0.9	7.4	10.6
	10	15	11.8	2.2	7.9	14.6
	20	15	12.2	1.8	9.1	15.0
	All	45	10.8	2.4	7.4	15.0
XL 3000	10	15	9.3	2.5	5.6	14.3
	20	15	12.0	2.5	2.5	8.4
15.5	40	15	13.6	2.5	10.9	17.9
	All	45	11.6	3.0	5.6	17.9
Overall mean		90	11.34	2.13	5.6	18.5

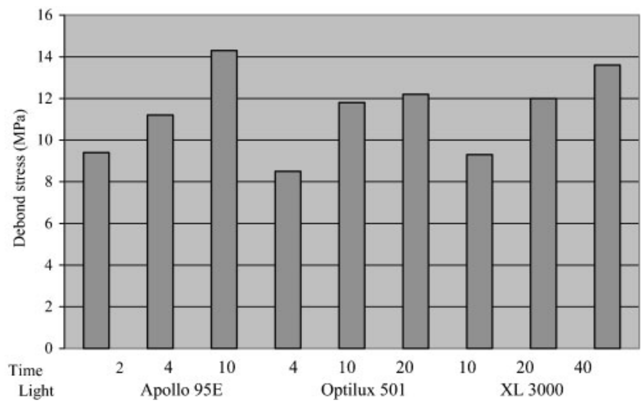

Figure 1 Mean debond stresses for each light unit and curing time

As can be seen from Table 2, the curing times recommended by each manufacturer do not reflect light source intensity in a direct arithmetical way. For example, the recommended curing time range of 1–3 seconds for the Apollo plasma light is 10% of that recommended for

Table 4 Results of ANOVA for the effect of light source upon debond stress

Light	No.	Mean debond stress (MPa)	SD
Apollo 95E	45	11.60	3.03
Optilux 501	45	10.79	2.36
XL 3000	45	11.63	3.00

F=1.31, p=0.275.

Table 5 Results of ANOVA for the effect of curing time upon debond stress

Time (seconds)	No.	Mean debond stress (MPa)	SD
2	15	9.35	2.16
4	30	9.83	2.12
10	45	11.79	3.11
20	30	12.05	2.12
40	15	13.59	2.50

F=8.87, p=0.000.

Table 6 Debond stresses for each light unit used for the manufacturer's recommended time, plus the Apollo for 4 seconds

Unit	Time (s)	Mean debond stress (MPa)	SD
(a) Apollo 95E	2	9.36	2.13
(b) Apollo 95E	4	11.19	2.11
(c) Optilux	10	11.77	2.17
(d) XL 3000	20	12.00	2.46

ANOVA for a,c,d, F=6.18, p=0.004. ANOVA for b,c,d, F=0.48, p=0.624.

the XL3000, although the Apollo has an intensity only 3 times greater. The reason for this lies in the complex nature of the chemical reactions associated with photolytic setting, which is initiated when light breaks bonds to create free radicals and start the polymerization chain reaction. Setting reactions do not stop when the light is turned off, the process continues for some time, although the rate declines as the concentration of unbroken double bonds declines, whilst the viscosity of the matrix rises to inhibit diffusion. The degree of conversion, that is how far the reaction polymerization has gone, is not proportional to the illumination exposure (intensity × time) due to the above considerations.[13]

The trend towards higher debond stresses with longer curing times for each of the three lights indicates that polymerization was advanced by additional light exposure, although it may not have been complete. However, this consideration may be irrelevant since even the lowest group mean of 8.5 MPa comfortably exceeds the recommended minimum value for orthodontic bonding.[2] A mean bond strength of 9.3 MPa was produced by exposure to the Apollo plasma light for only 2 seconds and that the standard deviation was in line with values for other groups. An increase in exposure time to 4 seconds with the Apollo light produced an equivalent mean bond strength to those found when the standard and high intensity quartz-halogen lights were used at the manufacturers' recommended exposure times of 10 and 20 seconds, respectively.

A curing time of 2 seconds per tooth implies a total light exposure requirement of 32 seconds to bond 6 incisors plus two premolars in each arch, a common situation in orthodontic treatment. Use of a conventional light in association with a 20 seconds exposure would require 3 minutes 20 seconds of light exposure. The additional time may appear innocuous at first sight, but it is of considerable importance in aiding the maintenance of moisture control, which is so important for good adhesive retention at an acid-etched surface.

Conclusions

- Using a plasma light, a 2 seconds exposure to adhesive pre-coated (APC) orthodontic brackets produced a mean bond strength within the range recommended for clinical orthodontic use, although it was lower than that produced by the standard and high intensity quartz halogen lights when they were used as recommended.
- Use of the plasma light for 4 seconds produced a mean bond strength of 11.19 MPa, equivalent to the quartz halogen lights at 10 and 20 seconds, respectively.
- Use of a plasma light confers useful time saving in orthodontic bonding with no diminution of bond strength when compared to longer polymerization times using quartz halogen lights.

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Authors and Contributors

BI and PR designed and planned the study together. TH designed and made attachments for the Instron machine. BI carried out the laboratory work and PR analyzed the results. PR is the guarantor.

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