Journal of Orthodontics/Vol. 28/2001/237–244

An *Ex Vivo* Investigation into the Use of a Plasma Arc Lamp When Using a Visible Light-cured Composite and a Resin-modified Glass Poly(Alkenoate) Cement in Orthodontic Bonding

A. P. PETTEMERIDES

Edgar Buildings Dental Practice, Edgar Buildings, Bath BA1 2EE, UK

A. J. IRELAND

Department of Orthodontics, Royal United Hospital, Bath BA1 3NG, UK

M. SHERRIFF, BSC

Department of Dental Biomaterials Science, Floor 17, Guy's Tower, London SE1 9KT, UK

Abstract

Objective: *To determine the usefulness of the plasma arc lamp in orthodontic bonding when used with both a light curable diacrylate and a resin modified glass poly(alkenoate) cement.*

Design: Ex-vivo *study.*

Method: *160 second premolar teeth were divided into 2 groups. 80 teeth had steel brackets bonded using Transbond XT and 80 were bonded using Fuji Ortho LC. One of four light curing regimes were used, with 20 specimens in each group: (i) 20 seconds curing with a halogen lamp; (ii) 1 second; (iii) 2 seconds or; (iv) 3 seconds with the plasma lamp.*

Outcomes: *Shear bond tested to failure and the force to debond (N) and locus of bond failure recorded in each case.*

Results: *Force to debond increases in the case of both bonding materials as the curing time with the plasma lamp increases. The force to debond with 1 and 2 seconds with the plasma lamp was significantly lower in each case. In all instances the force to debond was lower in the case of the resin modified glass poly(alkenoate) cement specimens. Locus of bond failure was unaffected by the method and length of light curing and was generally mixed mode.*

Conclusions: *Use of the plasma arc lamp in orthodontic bonding could result in significant time saving.*

Index words: Plasma Arc Lamp, Halogen Light.

Introduction

Light-cured orthodontic adhesives for bracket bonding have been used for many years (Tavas and Watts, 1979) and are reported to have a number of advantages over chemically-cured materials. These include: single paste application, consistent handling characteristics, easy removal of excess material following bracket placement, and a relaxed bonding procedure, leading to more accurate bracket positioning (Read, 1984). However, the possible disadvantages include not only the expense of buying the light source, but also the necessity to shine the light for 10–20 seconds at each inter-dental space during curing (Pearson, 1995; Sunna and Rock, 1998). Attempts have been made to speed up this curing process (Frost *et al*. (1997) by employing a larger light guide. Despite almost doubling the size of the guide, there appears to be little effect on *ex vivo* measured force to debond or *in vivo* bond failure rates. Increasing guide size does, however, significantly reduce the total time of the bonding procedure. Lasers have also been tested as a means of curing orthodontic bonding agents, although 10 seconds per tooth is still required in order to be as effective as 20–40 seconds with the halogen lamp (Kurchak *et al*., 1997; Weinberger et al., 1997).

In recent years, the plasma arc lamp has been introduced for use in restorative dentistry, whereas the conventional halogen lamp emits white light, which is subsequently filtered to produce blue light with a wavelength of 400–500 nm and an energy level of approximately 300 mW, the plasma arc lamp (Apollo 95E, Dental Medical Diagnostics, Woodland Hills, CA.) has a much higher peak energy level of 900 mW and a narrower spectrum around 430–490 nm. In restorative dentistry, composite filling material curing times of 30–40 seconds have been reduced to 1–3 seconds by the use of the plasma arc lamp. The plasma arc lamp has preset curing times of 1, 2, and 3 seconds, as well as a 6-second step-cure mode. There is, however, a recharge period of 2 seconds between exposures. Thus, a two-arch bond up from the distal of a second premolar to the contra-lateral second premolar in both arches, with a conventional halogen

Correspondence: A. J. Ireland

0301-228X/01/020000+00$02.00

curing lamp and a recommended 10-second cure time per interspace (20 seconds per tooth), would take 220 seconds. The same number of exposures, including a 2-second recharge interval, with the plasma arc lamp and a 1-second exposure, would take 52 seconds; a 2-second exposure would take 70 seconds and 3-second exposure would take 88 seconds.

The aim of this current *ex vivo* investigation was to test the effectiveness of the plasma arc lamp in curing a conventional light-cured composite bonding agent, Transbond XT and a resin-modified glass poly(alkenoate) cement, Fuji Ortho LC. The effect of curing time on measured force to debond was investigated along with the locus of bond failure.

Materials and Methods

One-hundred-and-sixty lower second premolar teeth, extracted for orthodontic reasons were used in this experiment and were divided into eight groups of 20 teeth. They were mounted in cold-cure acrylic blocks, using polythene moulds, with their buccal surfaces parallel to, and projecting slightly above the acrylic surface. The blocks measured 15 × 15 × 35 mm in size in order to fit into the custom-made shear bond testing jig (Figure 1). The brackets that were bonded to this exposed buccal enamel were 0·022-inch stainless steel lower second premolar brackets (Omni, GAC, Japan). Eighty teeth were bonded with Transbond XT (3M Unitek, St Paul, USA) and 80 with Fuji Ortho LC (GC Corp, Japan). Enamel preparation and bracket bonding was as follows

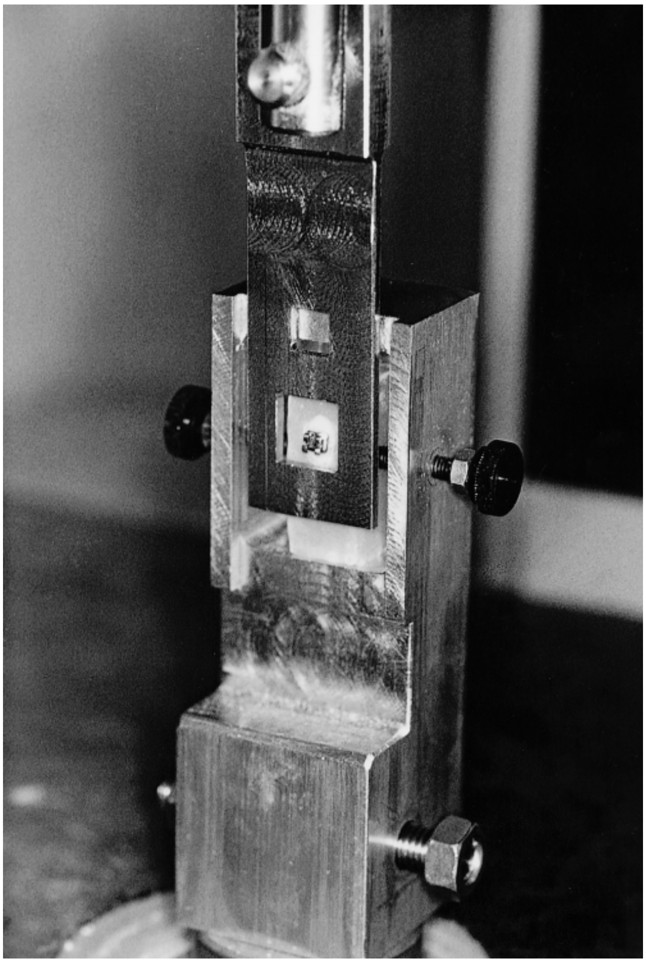


FIG. 1 The custom made testing jig.

Transbond XT Group

1. The dried tooth surfaces were etched with 37 per cent o-phosphoric acid liquid for 15 seconds.
2. Rinsed with an air/water spray for 15 seconds.
3. Dried with oil-free compressed air for 5 seconds until frosty white in appearance.
4. Transbond XT primer applied to enamel surface and bracket base.
5. Transbond XT adhesive applied direct to bracket base.
6. Brackets were then placed on the tooth surface and firm even pressure applied using a Mitchell's trimmer. This was done in order to minimize the adhesive film thickness, as in clinical practice. Excess adhesive was removed from around the margins using a dental probe
7. The Transbond XT samples were light cured and then shear bond tested to failure after 5 minutes.

Fuji Ortho LC Group

1. The dry tooth surfaces were primed for 20 seconds with GC Ortho conditioner [10 per cent poly(acrylic acid)].
2. Rinsed with an air/water spray for 15 seconds.
3. Light air drying for 5 seconds was performed only in order to remove excess water from the tooth surface. Care was taken to ensure the enamel was left moist.
4. Fuji Ortho LC capsules were activated and mixed for 10 seconds, and the cement syringed onto the bracket base.
5. Brackets were positioned on the enamel surface as before using firm even pressure. Excess cement was removed using a dental probe.
6. The Fuji Ortho LC samples were light cured and shear bond tested to failure after 5 minutes.

In each of these two main groups, 20 specimens of Transbond XT bonded brackets and 20 specimens of Fuji Ortho LC bonded brackets were cured using one of the following light curing regimens:

1. Halogen lamp (Ortholux™ XT curing lamp, 3M, St Paul, USA) for 10 seconds mesial and 10 seconds distal to the bracket on the tooth.
2. Plasma arc lamp: 1 second in total (1 second at the cusp tip above the bracket).
3. Plasma arc lamp: 2 seconds in total (1 second mesial to the bracket and 1 second distal to the bracket).
4. Plasma arc lamp: 3 seconds in total (1 second mesial to the bracket, 1 second distal to the bracket, and 1 second at the cusp tip).

Shear bond testing was performed using a custom made testing jig in a Lloyd 2000R testing machine with the cross-head speed set at 2mm/minute. The debond force (N) was recorded in each case, as was the Adhesive Remnant Index (ARI) score (Årtun and Bergland, 1984).

Results and Data Analysis

The data were analysed using Stata Release 6 (Stata Corporation, College Station, Texas, USA) and StatXact 3.0.2 (Cytel Corporation). In all analyses, significance was predetermined at $\alpha = 0{\cdot}05$, and the null hypothesis was that force to debond is independent of both material and light source. Scatter plots of the raw force to debond data for each bonding material as a function of light source are given in Figures 2 and 3, and univariate summary statistics

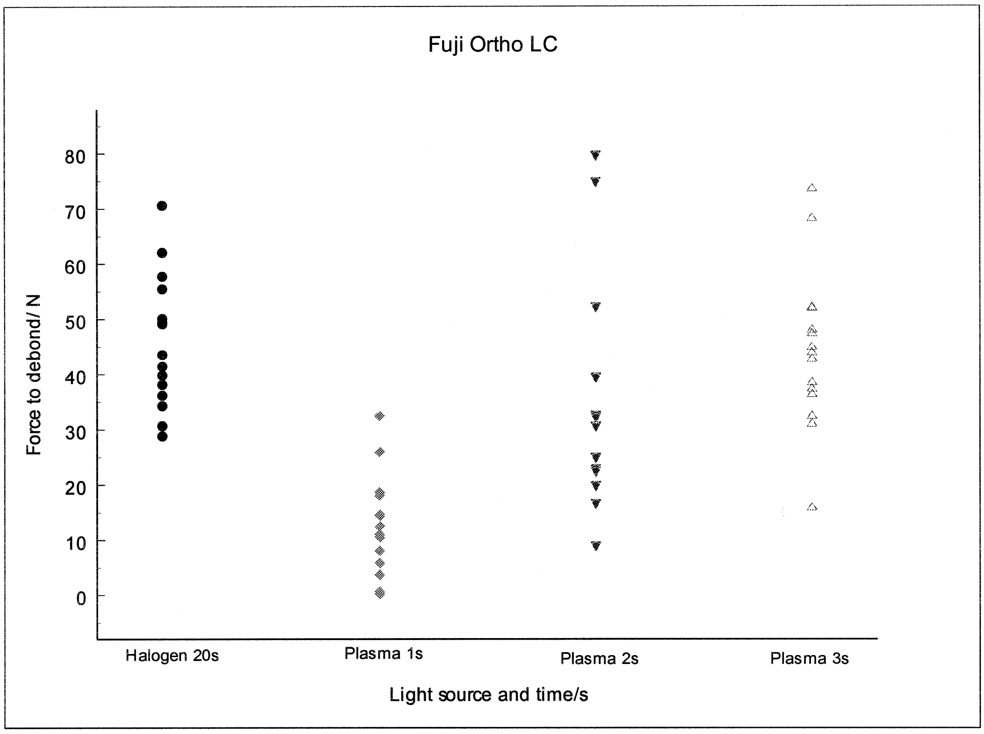


FIG. 2 Scatter plot of force to debond in Newtons of Fuji Ortho LC and the two curing lights: the halogen lamp for 20 seconds, and the plasma arc lamp at 1, 2, and 3 seconds.

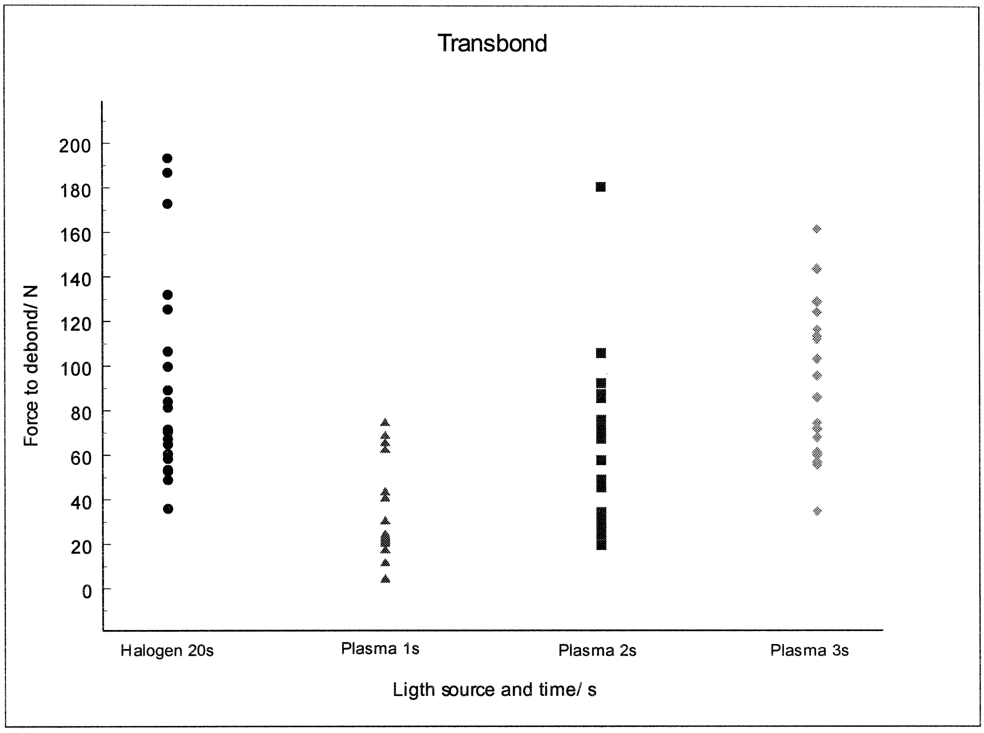


FIG. 3 Scatter plot of force in Newtons required to debond Transbond and the two curing lights: the halogen lamp for 20 seconds, and the plasma arc lamp at 1, 2, and 3 seconds.

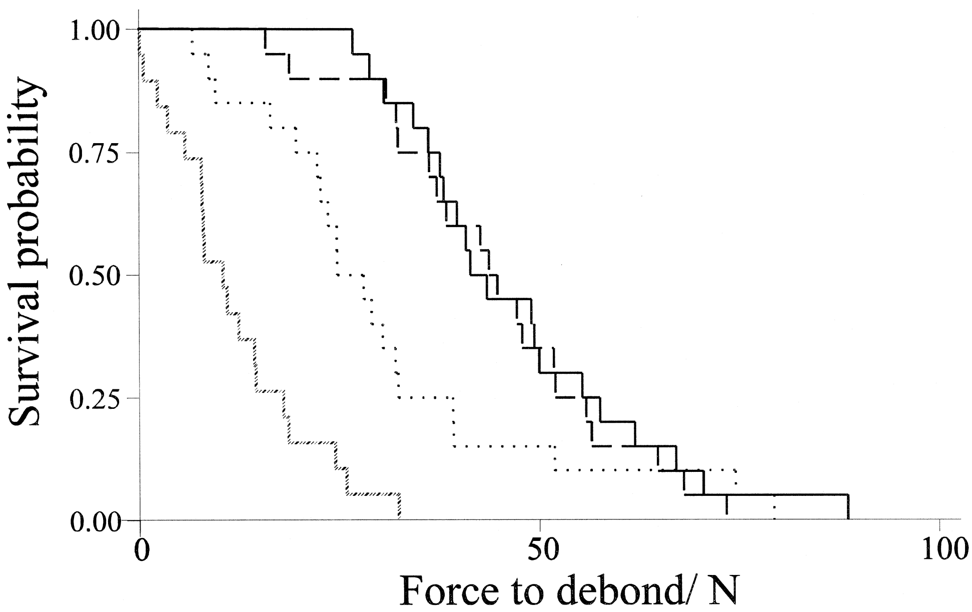
in Table 1. The Shapiro–Francia test showed that the raw bond strength data was not normally distributed; however, a square-root transformation resulted in normally distributed data. Kaplan–Meier survival plots for the two bonding agents are shown in Figures 4 and 5. There was no difference between the halogen lamp for 20 seconds and plasma arc lamp for 3 seconds.

A two-way analysis of variance showed there to be significant main effects of light-source and bonding agent, but no significant interaction term (Table 2). This is con-

TABLE 1 *Univariate summary statistics*

Material	Light/time	*n*	BS	s1	p1	SBS	s2	p2
Fuji Ortho	Halogen/20	20	47·5	15·8	0·124	6·8	1·1	0·530
	Plasma/1	19	12·0	8·8	0·273	3·2	1·4	0·946
	Plasma/2	20	30·8	19·2	0·001	5·3	1·6	0·211
	Plasma/3	20	44·6	15·1	0·964	6·6	1·2	0·686
Transbond	Halogen/20	20	92·8	46·6	0·016	9·4	2·3	0·132
	Plasma/1	18	32·0	22·1	0·037	5·3	2·0	0·252
	Plasma/2	19	64·4	37·7	0·011	7·7	2·2	0·303
	Plasma/3	20	90·7	33·6	0·444	9·4	1·8	0·712

n = Sample size. BS, force required to debond in N. s1, SD of force required to debond. p1, Probability associated with the Shapiro–Francia test for normality of force required to debond. SBS $\sqrt{}$force required to debond. s2, SD of BS. p2, Probability associated with the Shapiro–Francia test for normality of SBS.



	Light source and time /s	Log rank	Pr>X^2
	Halogen 20s	30.62	0.001
	Plasma 1s	3.93	
	Plasma 2s	17.18	
	Plasma 3s	27.27	

FIG. 4 Kaplan–Meier survival probabilities and log rank tests for Fuji Ortho LC and the two light curing units: the halogen lamp at 20 seconds, and the plasma arc lamp at 1, 2, and 3 seconds.

firmed in the plot of cell means for all light source-material combinations (Figure 6). A retrospective analysis of the analysis of variance indicated a power >90 per cent for the main effects in the model. Linear contrasts were used to compare light sources and materials (Table 3). It can be seen from these contrasts that: (i) the halogen lamp at 20 seconds per tooth is significantly different from the combined plasma arc lamp times; (ii) the halogen lamp is significantly different from the plasma arc at both 1 and 2 seconds per tooth; (iii) there is no significant difference between the halogen lamp at 20 seconds and plasma arc lamp at 3 seconds; and (iv) the two bonding agents are significantly different.

The Kruskal–Wallis one-way analysis of variance (Table 4) showed that the locus of bond failure was unaffected by the light source and curing time. Figures 7 and 8 illustrate the adhesive remnant scores for each material, and light

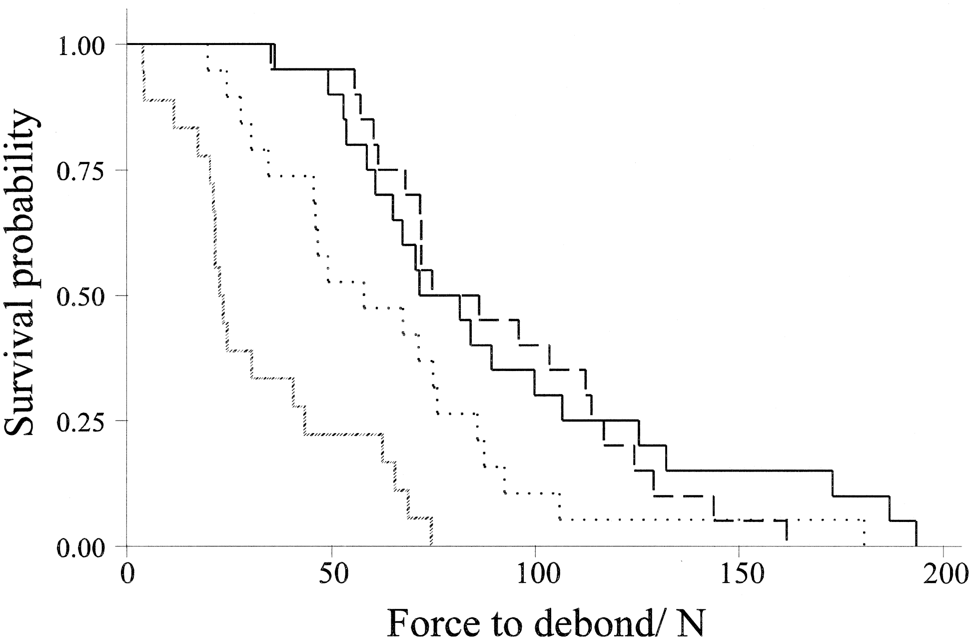
TABLE 2 *Analysis of variance following square root transformation of the force to debond data. There is no significant material*light interaction*

Source	Partial SS	d.f.	MS	*F*	Prob > *F*
Model	612·59	7	87·51	28·99	0·001
Material	239·02	1	239·02	79·18	0·001
Light	363·65	3	121·22	40·15	0·001
Material*light	2·19	3	0·73	0·24	0·867

TABLE 3 *Contrasts*

Contrast	*F*	*P*–value
Halogen versus all plasma arc sources	40·83	0·001
Halogen versus plasma 1	120·27	0·001
Halogen versus plasma 2	20·75	0·001
Halogen versus plasma3	0·09	0·764
Fuji Ortho versus Transbond	71·11	0·001

F value of *F* statistic with 1 and 148 degrees of freedom. *P*, probability associated with *F*.



	Light source and time /s	Log rank	Pr>X²
(solid line)	Halogen 20s	29.34	0.001
(hatched line)	Plasma 1s	4.95	
(dotted line)	Plasma 2s	15.72	
(dashed line)	Plasma 3s	26.99	

FIG. 5 Kaplan–Meier survival probabilities and log rank tests for Transbond and the two light curing units: the halogen lamp at 20 seconds, and the plasma arc lamp at 1, 2, and 3 seconds.

source and time combination, which shows bond failure to be largely mixed mode in each case.

Discussion

The results of this *ex vivo* experiment demonstrate that, whereas light-curing times of 1 and 2 seconds with the plasma arc lamp produces significantly lower force to debond than 20 seconds with the halogen lamp, the results with the plasma arc lamp at 3 seconds were not significantly different. This is particularly well illustrated in the Kaplan-Meier survival probability plots (Figures 4 and 5). Not only did the light source and curing time have a significant effect, but as might be expected, there was a significant effect of material on force to debond (Table 2). At each curing interval the measured force to debond with the light-cured diacrylate (Transbond XT), was greater than with the resin-modified glass poly(alkenoate) cement Fuji Ortho LC (Figure 6). Lower observed force to debond with light-cured resin-modified glass poly(alkenoate) cements compared with diacrylates has been reported previously (Bishara *et al.*, 1999; Choo, 1999).

Extrapolation of *ex vivo* results to the *in vivo* situation is fraught with difficulties. The major problem being that the optimum bond strength for clinical use is still unknown, even though some have suggested minimum bond strength values of 60–80 kg/cm^2 (Reynolds, 1979) for clinical use. In this current experiment the measured force to debond with Transbond XT was significantly greater than with Fuji Ortho LC, at all the light-curing times and with both light sources. It is known that light-cured resin-modified glass poly(alkenoate) cements can be used clinically with considerable success (Silverman *et al.*, 1995), even though the measured force to debond is lower than that observed with diacrylate bonding adhesives. It is possible therefore that

TABLE 4 *Kruskal–Wallis one-way analysis of variance of the Adhesive Remnant Index (ARI) scores*

Light source and time/s	Bonding agent	Observations	Observed statistic	$P > \chi^2$
Halogen 20s	Fuji Ortho LC	20	1·30	0·73
Plasma 1s		20		
Plasma 2s		20		
Plasma 3s		20		
Halogen 20s	Transbond	20	0·57	0·90
Plasma 1s		20		
Plasma 2s		20		
Plasma 3s		20		

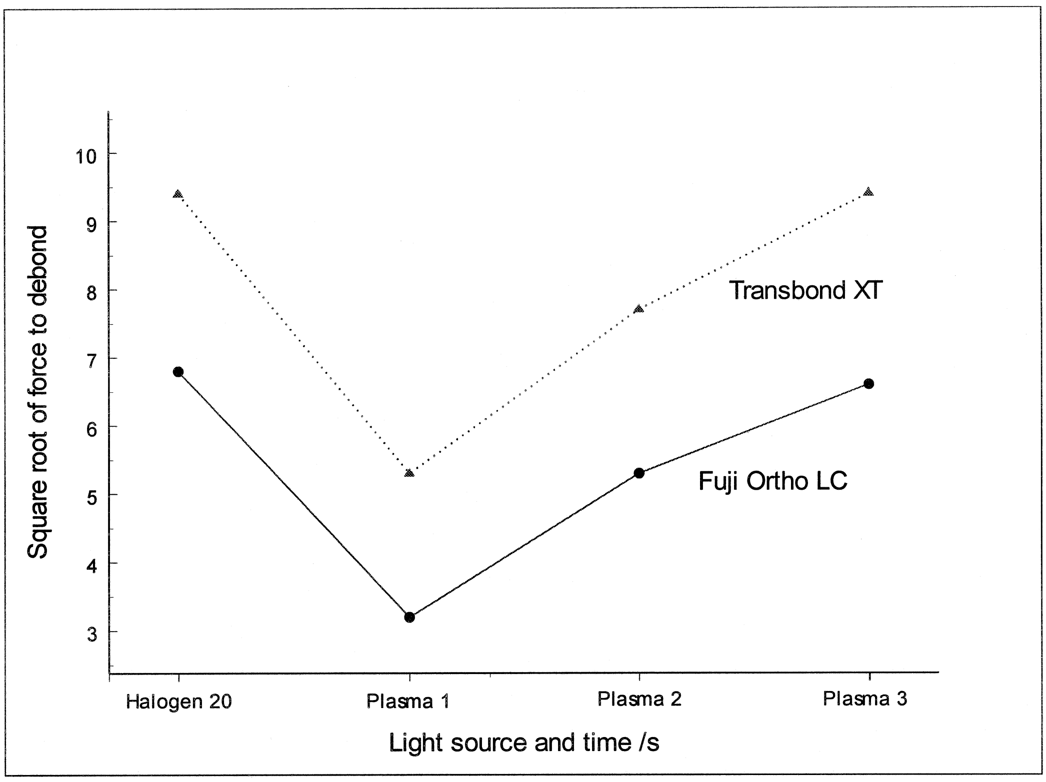


FIG. 6 Plot of the cell means of square root of force to debond for all material light combinations. The fact that the lines do not cross indicates no material*light interaction.

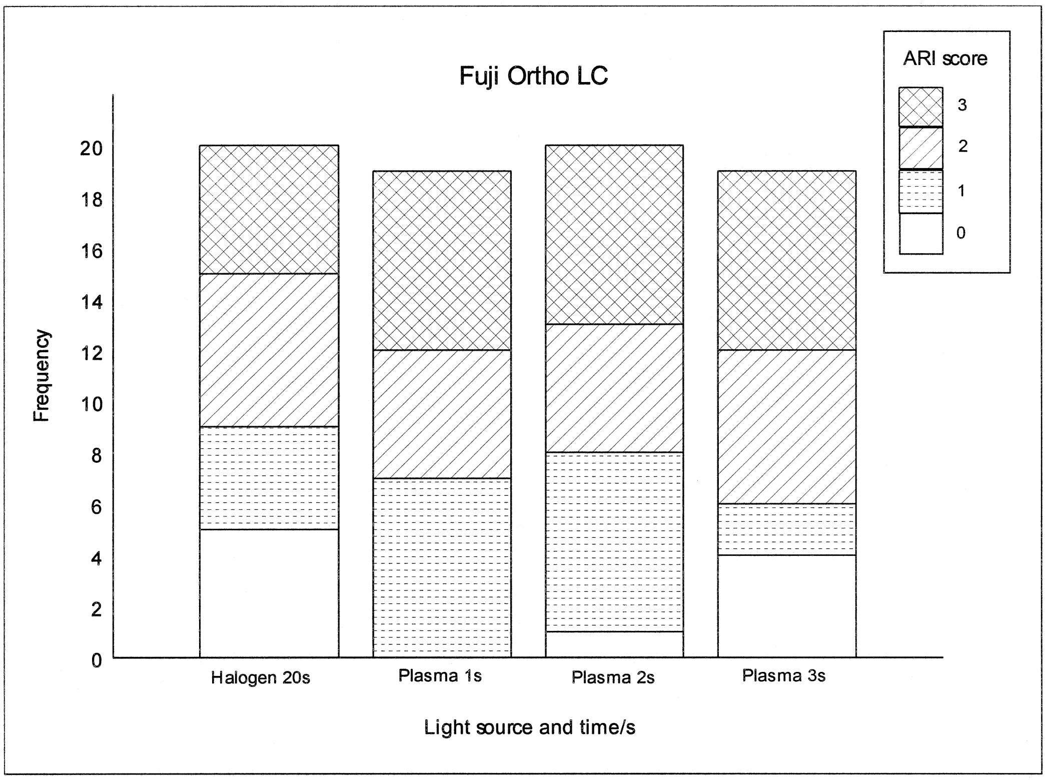


FIG. 7 Frequency plot of the Adhesive Remnant Scores (ARI) of Fuji Ortho LC and the two curing lights: the halogen lamp for 20 seconds, and the plasma arc lamp at 1, 2, and 3 seconds.

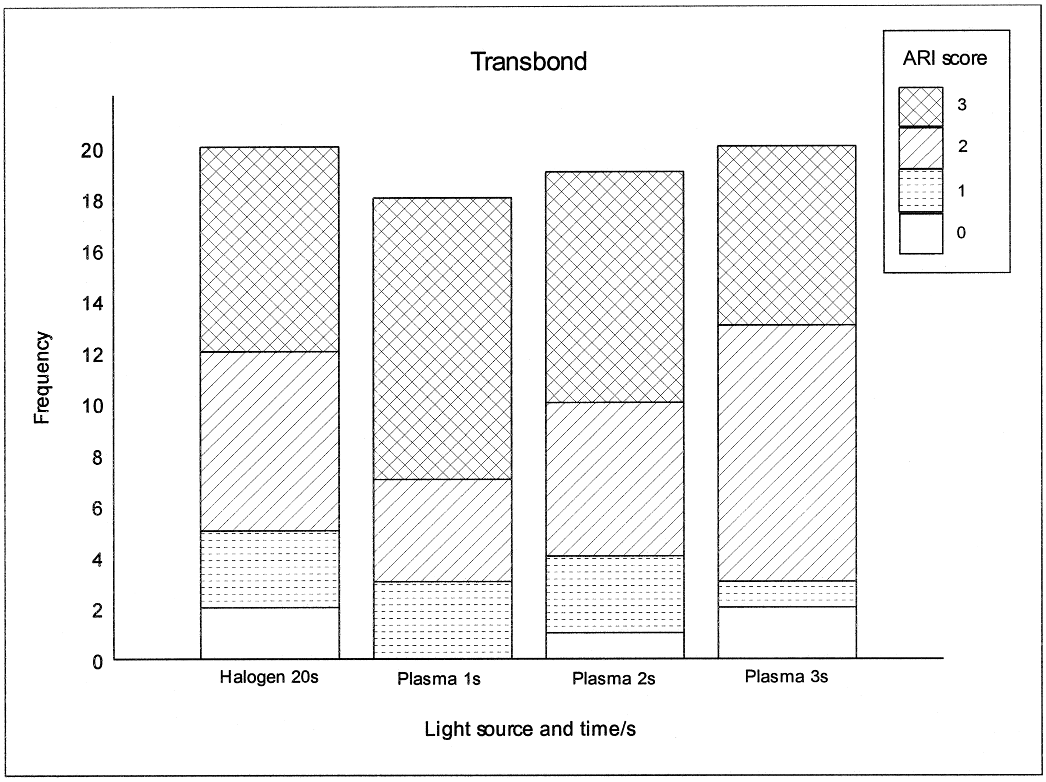


FIG. 8 Frequency plot of the Adhesive Remnant Scores (ARI) of Transbond and the two curing lights: the halogen lamp for 20 seconds, and the plasma arc lamp at 1, 2, and 3 seconds.

the plasma arc lamp may be used successfully *in vivo* with an even shorter curing time, of perhaps 2 seconds per tooth, when used with Transbond XT. Not only will this save clinical time, but it will also make the bonding procedure more tolerable for the patient and certainly easier for the clinician in cases where moisture control is a problem.

The locus of bond failure, as determined by the ARI scores, was unaffected by the light source or curing time (Table 4) and was largely mixed mode (Figures 7 and 8). Therefore, whatever the light source and curing time, clean-up time at debond will be unaffected.

Although the plasma arc lamp may have a number of advantages in clinical orthodontics over the conventional halogen lamp, it has one major disadvantage. At present the plasma arc lamp is approximately six times the cost of the halogen lamp, although this price difference may reduce with time.

Conclusions

Under the conditions of this experiment the following conclusions were reached:

1. The Apollo 95E plasma arc lamp, when used for 3 seconds per tooth, produced a force to debond comparable with 20 seconds curing with the Ortholux™ XT Curing Lamp. This may lead to a considerable time saving during orthodontic bonding procedures.
2. The measured force to debond increased significantly as did the curing time with the plasma arc lamp from 1 to 3 seconds.
3. At all light-curing times the measured force to debond with Fuji Ortho LC was significantly lower than with Transbond XT. As a result, it is possible that a curing time of 2 seconds per tooth with the plasma arc lamp may be acceptable when used with Transbond XT.

The locus of bond failure, as measured by the Adhesive Remnant Index score, was unaffected by the nature of the light source or length of the curing time.

A prospective randomized clinical trial is planned in order to assess the performance of Transbond XT and Fuji Ortho LC when cured with the Apollo 95E plasma arc lamp and the Ortholux ™ halogen lamp.

Acknowledgements

The authors would like to thank David Rees of T.O.C. Bristol, 3M Unitek UK and GC Corp. UK for their help, and Professor A. Harrison for his permission to use the testing facilities at Bristol Dental School. We would also like to thank the Shirley Glasstone-Hughes Memorial Scholarship for funding this project.

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