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An *in vivo* study to compare a plasma arc light and a conventional quartz halogen curing light in orthodontic bonding

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SUMMARY The purpose of this study was to compare the effectiveness of a plasma arc lamp with a conventional tungsten quartz halogen lamp in orthodontic bonding. Twenty consecutive patients had their brackets bonded either with Transbond XT ($n = 10$) or Fuji Ortho LC ($n = 10$). In total, 352 teeth were bonded, 176 in each group. Using a randomized cross-mouth control study design, where diagonally opposite quadrants were assigned a particular treatment, the bonds were then either cured with the control light, namely a halogen lamp, or a plasma arc lamp. The halogen light was used for 20 seconds per tooth and the plasma arc lamp for 3 seconds per tooth. The measurement parameter used was bond failure and the patients were monitored for a period of 6 months following initial bond placement.

In the Transbond XT group, the proportion of bond failures was 3.41 per cent for both the halogen and the plasma arc lamp. For the Fuji Ortho LC group, the proportions were 11.4 and 10.2 per cent, respectively. No difference was observed with respect to in-service bond failure proportions between bonds cured with the plasma arc or the conventional halogen lamp, irrespective of the bonding agent. Use of the plasma arc lamp could therefore lead to considerable savings in clinical time. However, this must be weighed against the increased purchase price of the plasma arc lamp.

Introduction

Bonding orthodontic brackets with visible light-cured diacrylate adhesives has been in use since the late 1970s (Tavas and Watts, 1979). Light curing has proved popular due to the ease of use, enabling sufficient time for accurate bracket placement, command curing, and then early archwire placement. However, even with a minimum curing time of 10 seconds per interdental space, or 20 seconds per tooth (Pearson, 1995; Sunna and Rock, 1998), using a conventional tungsten quartz halogen light, the total time to cure the upper and lower arches from second premolar to second premolar can amount to as long as 220 seconds.

Various attempts have been made to speed up this curing process. For instance, a larger light guide has been suggested (Frost *et al.*, 1997). Almost doubling the size of the guide has been found to significantly reduce the length of the bonding procedure and yet there is little effect on the *in vitro* measured force to debond, or the observed *in vivo* bond failure rate.

Lasers have also been tested as a means of curing orthodontic adhesives. However, a 10 second per tooth curing time is still required in order to be as effective as 20–40 seconds per tooth light-curing time with a halogen lamp (Weinberger *et al.*, 1997; Kurchak *et al.*, 1997) and a major disadvantage of lasers is their very high purchase cost.

In recent years, the plasma arc lamp (Apollo 95E Dental Medical Diagnostics, Woodland Hills, California, USA) has been introduced in restorative dentistry in order to reduce the time needed to cure composite resin filling materials from 30–40 seconds down to as little as 1–3 seconds. Whereas conventional halogen lamps emit white light which is filtered to produce blue light with a wavelength of 400–500 nm and an energy level of approximately 300 mW, the plasma arc lamp has a much higher peak energy level of 900 mW with a narrower spectrum of 430–490 nm. It might be expected that use of a higher energy lamp could lead to an unwanted rise in tooth surface temperature. This has not been found to be the case. In fact, temperature rises have been found to be lower with the plasma arc lamp than with the halogen lamp, perhaps due to the shorter times involved in its use (Loney and Price, 2001). The Apollo 95E plasma arc lamp has pre-set curing times of 1, 2, and 3 seconds, as well as a 6 second step cure mode. However, there is also a recharge period of 2 seconds between each exposure. Even with this recharge period, compared with the halogen lamp, which would require 220 seconds to cure both upper and lower arches from second premolar to second premolar, the plasma arc lamp would require only 88 seconds with a 3 second exposure per tooth, including a 2 second recharge interval per 3 seconds.

This reduced bonding time would have a number of advantages:

1. Increased comfort for the patient.
2. Less chance of bracket drift prior to curing.

3. Less time for moisture contamination.
4. Less stress for the operator.
5. Cost saving by reducing surgery time.

There have been previous limited reports into the use of plasma arc lamps in orthodontic bonding, both *in vivo* (Silverman and Cohen, 2000) and *in vitro*. In the latter case, with both light-cured resin-modified glass polyalkenoate cements and light-cured composites, no difference was found between the measured force to debond when either a plasma arc or tungsten halogen lamp was used to initiate polymerization (Pettemerides *et al.*, 2001; Ishikawa *et al.*, 2001). Other work, however, has suggested that the use of the plasma arc lamp may reduce the effectiveness of the continued acid–base reaction in resin-modified glass polyalkenoate cements and, therefore, reduce the effectiveness of the long-term bond (Millar and Nicholson, 2001).

The aim of the present investigation was, therefore, to determine whether there were any differences in the rate of *in vivo* bond failure when orthodontic brackets were bonded using a light-cured composite or a resin-modified glass polyalkenoate cement, followed by curing with either a plasma arc lamp or a conventional tungsten quartz halogen lamp. A 6 month study period was used because previous research had demonstrated that bond failure rates between 0 and 6 months and 6 and 12 months after initial bond placement were not statistically significantly different (Choo *et al.*, 2001).

Materials and methods

Twenty consecutive patients requiring fixed appliances were selected to take part in this study. The inclusion criteria were that the patients required upper and lower fixed appliances and that there were no crowns, bridges or veneers anterior to the first permanent molars. The local ethics committee was contacted prior to the study concerning consent. The patients were randomly assigned to one of two groups. In one group the brackets were bonded using Transbond XT (3M Unitek, St Paul, USA), a visible light-cured filled diacrylate, and in the other group with Fuji Ortho LC (GC Corp., Tokyo, Japan), a resin-modified glass polyalkenoate cement. In each patient the bonding adhesive was cured using the plasma light or quartz halogen lamp in diagonally opposed quadrants. The allocation of both the patients to the bonding groups and the diagonally opposing quadrants was made using a random number table.

Pre-adjusted edgewise stainless steel 0.022 inch brackets were used on all the patients (Omni, GAC Int., Bohemia, USA). In each case, bonding was then performed as described below.

Transbond XT group

1. The teeth were pumiced using a slurry of pumice in water and a rubber cup in a slow speed handpiece, followed by washing and drying.
2. The dried enamel surfaces were then etched using 37 per cent *o*-phosphoric acid for 15 seconds and then rinsed with a water/air spray for a further 15 seconds.
3. The teeth were then dried with oil-free compressed air for 5 seconds until frosty white in appearance.
4. Transbond XT primer was applied to the enamel surface.
5. Transbond XT adhesive was applied direct to the bracket base.
6. In each case the bracket was placed on the tooth surface and firm, even pressure applied using a Mitchell's No. 4 trimmer. This was undertaken in order to minimize the adhesive film thickness. Excess adhesive was removed from around the margins using a dental probe.
7. The Transbond XT quadrants were light cured, with the light source dependent on the random assignment.

Fuji Ortho LC group

1. The teeth were pumiced and washed as in the Transbond XT group.
2. Light air drying for 5 seconds was then performed, but only in order to remove excess water from the tooth surface. Care was taken to ensure that the enamel was left moist.
3. Fuji Ortho LC capsules were activated and mixed for 10 seconds using an automated mixer and the cement syringed on to the bracket bases.
4. The brackets were positioned on the enamel surface as before, using firm even pressure. Excess cement was removed with a dental probe.
5. The Fuji Ortho LC samples were light cured in diagonally opposing quadrants as for the Transbond XT group.

The curing lights used in this study were a conventional tungsten quartz halogen lamp (Ortholux™ XT curing lamp, 3M Unitek) and a plasma arc lamp (Apollo 95E). Following bracket placement using the respective adhesives, light curing was performed as follows:

1. The teeth in the plasma arc lamp quadrants were exposed for 3 seconds in total by placing the light guide distal to the orthodontic bracket, occlusal (or incisal) to the bracket and then mesial to the bracket (and distal to the adjacent bracket) for 1 second at each site.
2. The teeth in the quartz halogen lamp groups were exposed for 10 seconds at each interdental space.

Once the brackets had been bonded in position, 0.012 inch nickel titanium archwires were placed. Lacebacks were not used. At subsequent appointments the following archwire sequence was used for each patient:

1. 0.016 inch nickel titanium.
2. 0.016 × 0.022 inch stainless steel.
3. Posted 0.019 × 0.025 inch stainless steel.

The same operator (APP) was responsible for placing all appliances. Any brackets that debonded during treatment were rebonded, but not necessarily with the same adhesive. Although the initial bond failure was counted, rebonds were subsequently excluded from the study. Data on bond failure were collected for the first 6 months following appliance placement.

Data analysis

Data were analysed using StatXact 3.0.2. (Cytel Software Corp., Cambridge, Massachusetts, USA) with exact non-parametric inference to allow for the low failure proportions. Significance was predetermined at $\alpha = 0.05$.

Results and data analysis

The summary data are illustrated in Tables 1–3. The data collected were categorical and therefore the proportions of bond failures were compared within each adhesive using the two light-curing lamps. With Transbond XT, the proportion of bond failures was 3.41 per cent for each of the two lamps. There was, therefore, no observed difference in bond failure over the 6 month experimental period between the plasma arc lamp and the conventional halogen lamp.

Table 1 Summary data of the 10 patients bonded using Transbond XT over 6 months.

	Number of teeth	Number of failures	Number of successes
Plasma light	88	3	85
Halogen light	88	3	85
Totals	176	6	170

Table 2 Summary data of the 10 patients bonded using Fuji Ortho LC over 6 months.

	Number of teeth	Number of failures	Number of successes
Plasma light	88	9	79
Halogen light	88	10	78
Totals	176	19	157

Table 3 Bond failures by adhesive, light source, and tooth. The percentages of the total bond failures by adhesive/light source are also illustrated.

	Light source					
	Plasma arc lamp			Halogen lamp		
Transbond		1 5	12%	3	2 5	12%
	2					
Fuji Ortho LC	222	22	36%	4333222	1 4	40%
	2 1	1 5		2		

With Fuji Ortho LC, the observed percentage of bond failures was higher at 10.23 per cent for the plasma arc lamp and 11.36 per cent for the halogen lamp. Due to the small sample sizes, the difference between the failure proportions for the two light sources was evaluated using exact inferential statistics. The difference in proportions was 0.0114, with 95 per cent confidence limits from –0.110 to 0.133 and an associated probability of 0.93. Therefore, once again, there was no statistically significant difference in the observed failure rate with the adhesive Fuji Ortho LC between the plasma arc lamp and the halogen lamp. On the basis of these results, the failures can be pooled over light source and within bonding system. The difference in failure proportion between Fuji Ortho LC and Transbond XT was 0.074 with 95 per cent confidence limits of 0.006 to 0.146 and an associated probability of 0.03. There was, therefore, a significantly higher proportion of failures with Fuji Ortho LC compared with Transbond XT.

The Kaplan–Meier survival analysis and log rank test (Figure 1) did not demonstrate a significant difference between the groups, probably due to the low number of overall failures in the study.

The bond failure data by tooth and adhesive/light source combination are illustrated in Table 3. Of the 25 bonds that failed in the study, 44 per cent were upper incisors, 20 per cent lower incisors, 16 per cent upper canines, 16 per cent upper premolars, and 4 per cent lower premolars.

Discussion

Previous *in vitro* studies have looked at the ability of different light sources to cure both conventional light-cured composites and resin-modified glass polyalkenoate cements. It would seem that the plasma arc lamp, the micro-xenon lamp, and the conventional halogen lamp are all able to cure both adhesives (Pettemerides *et al.*, 2001; Sfondrini *et al.*, 2001). However, from these studies, using either bovine teeth or extracted human premolar teeth, the curing time using the plasma arc

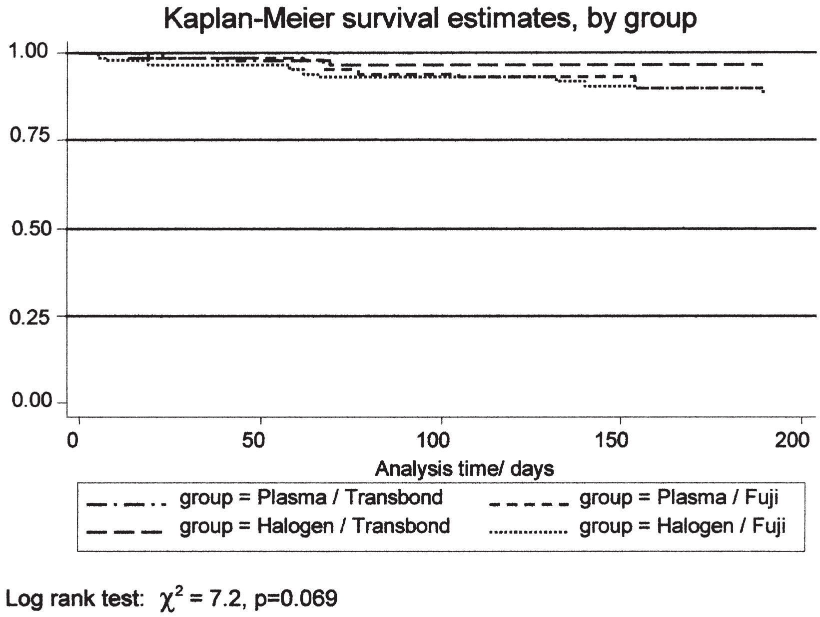

Figure 1 Kaplan–Meier survival probabilities and the log rank test for the four adhesive–curing light combinations.

lamp has varied from 6–9 seconds per tooth (Oesterle *et al.*, 2001) to as little as 3 seconds per tooth (Pettemerides *et al.*, 2001). It has also been suggested that a longer cure time of 6 seconds should be used on premolar teeth if the measured force to debond is to be brought to clinically acceptable levels, while only 2 seconds is required on incisors (Klocke *et al.*, 2002). The present investigation would seem to suggest that a very short 3 second curing time per tooth is sufficient to produce *in vivo* bond failure rates comparable with 20 seconds per tooth using the conventional halogen lamp. A longer cure time with the plasma arc lamp is also not required on premolar teeth as, in the case of both adhesives, premolars demonstrated fewer in-service bond failures than incisor teeth. This would mean that to bond the upper and lower arches from second premolar to second premolar would take approximately 88 seconds with the plasma arc lamp compared with 220 seconds with the halogen lamp, a saving of 132 seconds per bond up. The benefits of this reduced bonding time should, however, be assessed relative to the increased purchase price of the plasma arc lamp, which can be in the region of three to five times higher than a conventional halogen lamp.

Although no difference was found in the observed proportion of bond failures between the plasma arc and the halogen lamp, there was a difference between the two bonding agents. The failure rate of the resin-modified glass polyalkenoate cement was approximately three times higher than the light-cured diacrylate, Transbond XT. This may be related to two factors in the current investigation. First, the curing time was only 20 seconds per tooth with the halogen light and 3 seconds with the plasma arc light. The manufacturers of the resin-modified glass polyalkenoate cement recommend a 40 second curing time with the halogen lamp. In a previous *in vivo* study in which the curing time was 40 seconds per tooth with a quartz halogen lamp, no difference was observed in the bond failure rate over 6 months with the same adhesives (Choo *et al.*, 2001). Second, no enamel etchant/conditioner was used, and recent *in vitro* work has demonstrated a reduced force to debond in such cases when compared with enamel etching/conditioning (Valente *et al.*, 2002). An *in vivo* investigation in which the enamel was treated with a conditioner, but where the plasma arc lamp was still only used for 3 seconds per tooth, produced a very low bond failure rate of only 0.8 per cent over the test period of 4 months (Silverman and Cohen, 2000).

Consideration of the sites of bond failure shows a somewhat surprising series of results, with most bond failures occurring in the upper incisor region and least in the lower premolar regions. This contrasts with previous reports (Zachrisson, 1977; Newman, 1978; Mizrahi, 1982; Trimpeneers and Dermaut, 1996) where more lower than upper and more posterior than anterior bond failures were observed. The latter has been related to reduced clinical crown height and possible gingival seepage in the case of posterior teeth, along with occlusal forces on the buccal aspect of lower teeth. Why more anterior bonds should fail in the present investigation is unclear.

Conclusions

The results of this *in vivo* cross-mouth control study indicate that, over the 6 month experimental period, there was no difference in the observed bond failure proportions between bonds cured with the plasma arc lamp for 3 seconds per tooth and those cured with the conventional tungsten quartz halogen lamp for 20 seconds. This could lead to a potential time saving of approximately 132 seconds at the initial bond up appointment, when bonds are placed from second premolar to second premolar in both upper and lower arches. Using the recommended 40 second cure time instead of the test time of 20 seconds, with the resin-modified glass polyalkenoate cement and the halogen lamp, may have resulted in fewer bond failures in this study. It is possible that the plasma arc lamp may lead to an even greater time saving with the same material if the curing time for this lamp was 3 seconds, or even if it had to be doubled to 6 seconds in order to achieve the same rate of bond failure. This aspect requires further study.

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