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SCIENTIFIC SECTION

The efficacy of a plasma arc light in orthodontic bonding: a randomized controlled clinical trial

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Objective: To evaluate the clinical performance of a plasma arc light (Ortho LITE, 3M Unitek, Monrovia, CA, USA) against a conventional tungsten–quartz halogen curing light (Visilux 2, 3M Unitek, Monrovia, CA, USA) for direct orthodontic bonding.

Design: A single centre prospective randomized controlled clinical trial.

Setting: The Orthodontic Department at St Luke's Hospital, Bradford, UK.

Subjects and methods: Forty-three consecutive patients requiring fixed appliances from the orthodontic waiting list. A split mouth technique was adopted; with quadrants randomly assigned to either the plasma arc light or the conventional halogen curing light and bonded directly with APC pre-adjusted edgewise brackets (3M Unitek, Monrovia, CA, USA).

Main outcome measure: Bracket failures.

Secondary outcome measures: Time taken to bond-up the appliances, patient sensitivity or discomfort during curing and time to replace failed brackets were investigated.

Results: No statistically significant difference in bracket failure rates over the full course of treatment was found between the plasma arc light (6.7%; 95% CI 4.5–10.0) and the halogen curing light (9.5%; 95% CI 6.8–13.1). There was no statistically significant difference in bracket survival times. The bond-up times were typically reduced by 204 seconds per patient with the plasma arc light. There were no differences in patient reported sensitivity or discomfort or rebond times.

Conclusion: The plasma arc light is a viable clinical alternative to the conventional halogen curing light with benefits for both the clinician and patient due to reduced bonding times.

Key words: Plasma arc light, conventional tungsten–quartz halogen light, orthodontic bonding, randomized controlled clinical trial

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Introduction

Visible light-cured adhesives are currently a popular method of orthodontic bonding. The main advantages over chemically cured adhesives are their ease of use, extended working time and command set.[1] This allows adequate time for bracket positioning followed by immediate ligation of the archwire.[2] Their main drawback is the extended curing time required to achieve polymerization of the adhesive. According to manufacturer's guidelines, conventional halogen curing lights take 20–40 seconds per bracket to adequately cure orthodontic composite resins. Reducing this length of cure would be beneficial not only to the orthodontist, by reducing chair-side time, but also to the patient by improving comfort during bonding. Faster curing times may also reduce the chance of moisture contamination, a common cause of bracket failures.

Recent advances in light curing technology have led to the development of new high intensity light curing units which claim faster curing times than conventional curing lights with no loss in bracket bond strength. The plasma

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arc light was introduced in the late 1990s in an effort to reduce curing times. It emits continuous frequency bands of light of much greater intensity than those of the conventional halogen light. This light is filtered to a narrower wavelength and the typical spectral radiometric output is between 440 and 490 nm, which is ideally suited for activation of camphorquinone (maximum absorption at 468 nm), the photoinitiator in most light-cured adhesives. The first published report on the plasma arc light for bonding and bleaching was by Cacciafesta *et al.* in 2000.[3] Since then researchers have been investigating the potential of the plasma arc light as an alternative to the conventional halogen curing light for orthodontic bonding.

In vitro research, with human premolars, has shown that the plasma arc light, when used for 3 seconds per tooth, produces a force to debond comparable to a 20-second cure with the conventional halogen curing light.[4] It would appear, however, that reducing this cure time to 2 seconds significantly lowers the bond strength and is not recommended.[5] A cure time of 6 seconds (3 seconds mesially and 3 seconds distally) is suggested for bonding stainless steel brackets to ensure complete polymerization of the adhesive.[5–7]

Clinical trials have supported the *in vitro* findings and the plasma arc light may be considered an advantageous alternative to conventional light curing as it significantly reduces the curing time without affecting the bond failure rate.[7–11] To date no studies have compared the plasma arc light and the halogen light until the completion of treatment. The aim of the present study was to assess the clinical performance of a plasma arc light compared to a conventional halogen light, by comparing the bracket failure rates upon completion of treatment, time to bracket failure, bond-up time, patient sensitivity or discomfort and time to rebond failed brackets. The null hypothesis being that there is no difference in the clinical survival rates of brackets bonded with a plasma arc light compared to those bonded with a conventional halogen light.

Materials and method

Participants

Forty-three patients were consecutively recruited from the waiting list at the Orthodontic Department at St Luke's Hospital, Bradford. They were eligible for the study if they fulfilled the following:

Inclusion criteria:

- subject required fixed appliance therapy using pre-adjusted edgewise appliances;
- no relevant medical history;
- subject would give consent to the trial.

Exclusion criteria:

- cleft lip and palate or osteotomy patients;
- patients with severe hypodontia;
- patients with extensive enamel hypoplasia.

Ethical approval

This was obtained from the Local Research Ethics Committee for Bradford Hospitals NHS Trust on the 27th March 2002 (LREC no. 02/02/093). Fully informed written consent of patients and parents was obtained at the start of treatment.

Sample size calculation

Based on Littlewood *et al.*,[12] a survival rate of 93.2% (6.8% failures) for the halogen curing light was assumed. A hazard ratio of 2 was taken to represent a clinically significant difference in bond failure rates between the curing lights. This represents a survival rate of 96.6% (3.4% failures) for the plasma arc light, a difference of 3.4% between lights. Following the methods of sample size determination of Machin *et al.*[13] for the log–rank test, it was determined that a sample size of approximately 622 brackets was required (α=0.05 and 80% power). Allowing for a 5% drop-out rate,[13] the sample size was increased to 654 brackets (327 per curing light). As the majority of cases would require extractions, potentially from both arches, the number of teeth bonded per patient was expected to be a minimum of 16. However this calculation assumed independence of brackets, whereas the brackets are clustered within a patient. This lack of independence could be formally included in the sample size determination by the inclusion of a design effect (inflation factor). Due to the low assumed rate of breakages, it was postulated that in this particular instance the design effect would be very small and an inflation factor of 5% (1.05) was used. Further, the chosen drop-out rate and estimated number of brackets bonded per patient, offered additional 'built-in' capacity. Thus a final sample size of 43 patients was adopted.

Assignment

The study was a split mouth design, bonding one quadrant using the plasma arc light (ORTHO Lite, 3M Unitek, Monrovia, CA, USA) and the contralateral quadrant of each arch using the conventional halogen curing light (Visilux 2, 3M Unitek, Monrovia, CA,

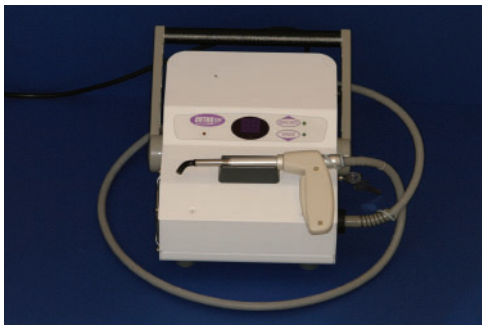

Figure 1 Plasma arc light (ORTHO Lite, 3M Unitek, Monrovia, CA, USA)

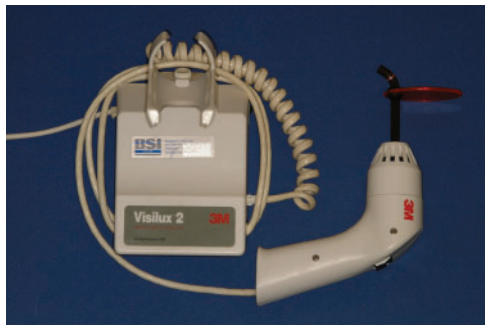

Figure 2 Conventional halogen curing light (Visilux 2, 3M Unitek, Monrovia, CA, USA)

USA). The assignment of the first quadrant to either the plasma arc light or halogen light was randomly allocated using random number tables and sealed in pre-ordered, opaque envelopes opened after the patient was accepted into the trial. The generator and executor of the randomization were separate individuals.

Bonding procedure

The same clinician (JR) used the following procedure bond all the brackets, one quadrant at a time:

1. cheek retractors and saliva ejector placed to allow clear access and dry field;
2. 20-second etch with 37% phosphoric acid liquid;
3. 20-second rinse followed by thorough oil free air-drying using a 3-in-1 syringe;
4. application of Transbond XT light cure adhesive primer (3M Unitek, Monrovia, CA, USA) to the acid-etched enamel surface and air dispersal;
5. adhesive pre-coated bracket (APC Adhesive Coated Appliance System, 3M Unitek, Monrovia, CA, USA) placed onto the buccal surface of the tooth at the midpoint of the long axis of the clinical crown.

Incisors, canines and premolars were bonded whilst molars were banded;

6. light polymerization with the relevant light-curing unit according to the manufacturer's guidelines:
   - ORTHO Lite (plasma arc light): brackets were cured for 3 seconds mesially and 3 seconds distally with the light guide held as close as possible without touching the appliance (Figure 1);
   - Visilux 2 (conventional halogen curing light): brackets were cured for 10 seconds from 2 mm distance on both the mesial and distal edges of the bracket (Figure 2).
7. a 0.012-inch nickel titanium aligning wire was placed at the same visit using individual elastomeric modules to secure the archwires in the bracket slots.

The time taken, in seconds, to bond each quadrant was recorded using a professional quartz analogue stopwatch:

(i) from the application of the etchant to the first tooth in the quadrant to the end of the curing cycle for the last tooth (total bond time),
(ii) the cure cycle only for that quadrant, from initiation of the curing cycle until completion for that quadrant (cure time).

Following bonding of each quadrant, the teeth and bonded brackets were shielded from the alternative light source with a pre-formed strip of aluminium foil moulded over the bonded quadrant. The foil strip was to ensure that the curing light used to bond the contralateral or opposing quadrants did not affect the polymerization of the composite resin adhesive of the previously bonded brackets. This ensured that no brackets could be exposed to both curing lights, which was of particular importance in the incisor regions due to the close proximity of adjacent brackets (Figure 3).

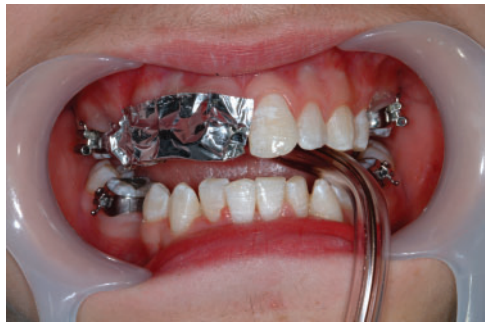

Figure 3 Aluminium foil isolation of a bonded quadrant

Blinding

Unfortunately it was not possible to blind the clinician to the type of light curing unit being used as they differ greatly in appearance and the curing cycle is noticeably shorter for the plasma arc light.

Data collection

Patients completed a visual analogue scale (VAS) for each curing light immediately following bond-up, to assess any difference in sensitivity or discomfort between the two lights during the curing procedure. Each subject was then monitored to debond. Due to the practicalities of casual appointments, debonded brackets were occasionally replaced by one of six operators who were all fully aware of the research protocol. However, the use of multiple operators for rebonding will affect the rebonding time values and therefore the results of this section must be interpreted with caution.

If a bracket failure occurred during treatment the following were recorded:

- date of failure;
- tooth where failure occurred;
- light used to bond and rebond the bracket.

Analysis

The difference in the percentage of failures for the two curing lights was assessed by a 95% confidence interval. A clustered (within patient) Cox proportional hazard model (including curing light type as the only covariate) was employed to investigate the difference in survival times. Assumptions and model fit were assessed via inspection of the Scheonfeld and Martingale residuals. All other measures were considered using descriptive statistics. All analyses were performed in S-Plus version 6.1 (Insightful Corporation, Basingstoke, Hampshire, UK).

Results

Profile of randomized controlled trial

Forty-three patients (age range 11–28 years) were recruited for the study (29 females and 14 males) and randomized to the split mouth design. Thirty-nine patients were followed to the end of treatment, four patients were lost to follow up, three due to transfer and one failed to complete treatment (Figure 4).

Bond failure rates

A total of 43 patients with 708 brackets were bonded, 354 with each curing light. In total 59 (8.3%) brackets failed, 24 (6.8%; 95% CI 4.6–9.9) with the plasma arc light and 35 (9.9%; 95% CI 7.2–13.4) with the halogen light. Thus the difference in the proportion of failures was 3.1% (95% CI –1.0–7.3). The 39 patients who were followed to debond had a total of 654 brackets bonded, 327 per curing light. The failure rates for the plasma arc light and halogen were 22 (6.7%; 95% CI 4.5–10.0) and 31 (9.5%; 95% CI 6.8–13.1) respectively (Table 1). The difference in failure rates was 2.8% (95% CI –1.5–7.0). Thus there was no statistically significant difference between the bracket failure rates for each curing light.

Survival time

Inspection of the residuals for the clustered Cox proportional hazards model showed that both the assumption of proportionality and model fit were adequate. The estimated difference between the two curing lights is a relative risk of failure at any given time point (equal to the hazard ratio) of 1.47. This was not statistically significant (P=0.19) (Figure 5).

Distribution of bond failures

The numbers of bracket failures per tooth type were very small, such that meaningful interpretation of this was not possible.

Appliance bond-up times

One hundred and seventy quadrants were bonded, 85 with the plasma arc light and 85 with the halogen curing light. The time for the total bonding procedure, from application of the acid etch until completion of the light cure cycle, and the cure cycle only were recorded for each quadrant. The mean bonding time per tooth was also calculated as some quadrants contained different numbers of teeth, depending on whether it was an

Table 1 Bracket failure rates with each curing light.

Curing light	Number of bonds	Number of failed bonds	% failure rate	95% CI
Plasma arc	327	22	6.7	(4.5–10.0)
Halogen	327	31	9.5	(6.8–13.1)

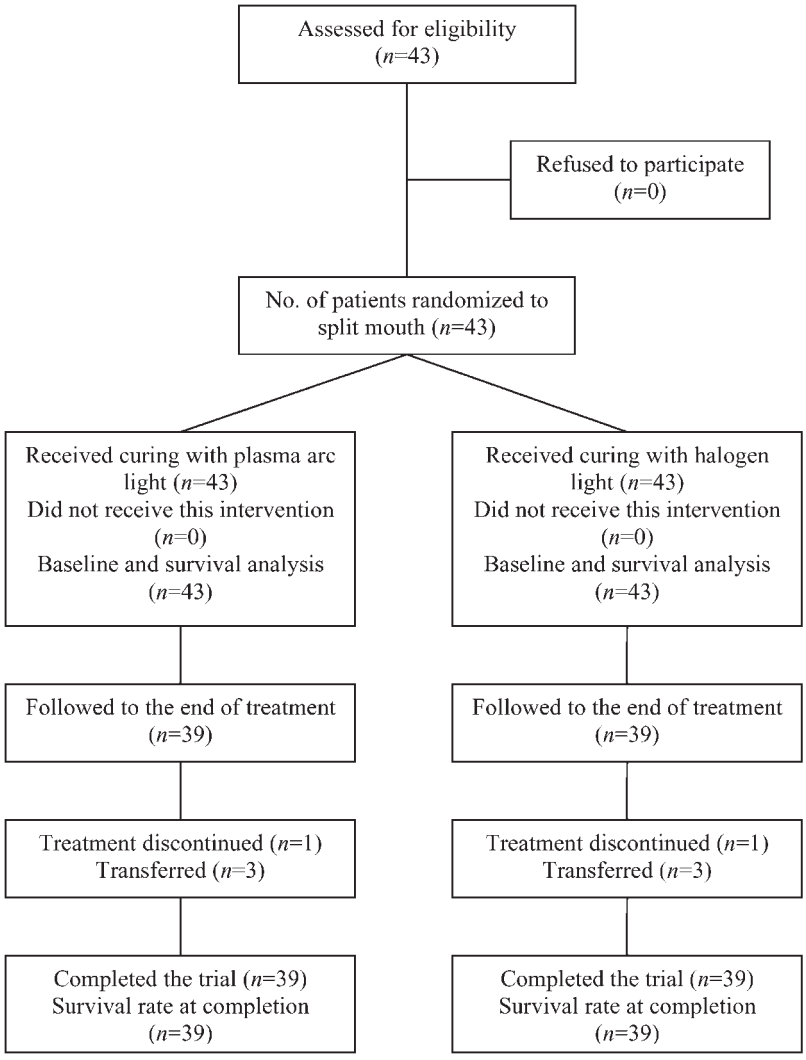

Figure 4 CONSORT diagram

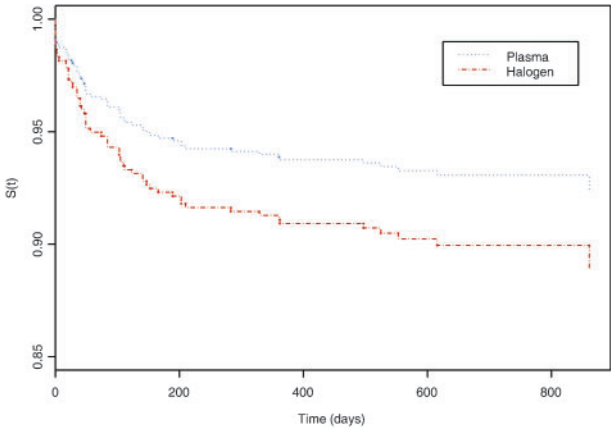

Figure 5 Cox proportional hazards model (clustered within patient). S(t) stands for survival proportion.

extraction or non-extraction case and to account for only matched teeth being investigated (Table 2). The plasma arc light was markedly faster than the halogen light in all of the bonding times investigated. The reduction in the mean total bond time per quadrant was 51 seconds.

Sensitivity or discomfort

The majority of patients reported no sensitivity or discomfort with either of the curing lights when assessed with a VAS. Five patients reported sensitivity with the plasma arc light (ranging from 0.5 to 4 on the VAS) and four patients with the halogen light (ranging from 2 to 7 on the VAS). As all but a few patients reported no sensitivity or discomfort with either of the curing lights, a formal statistical comparison was deemed not to be

appropriate; no clinically significant difference was found.

Rebond times

When a bond failure occurred, the time taken to replace a new bracket was recorded in seconds, as per the protocol. The mean rebond time with the halogen light was 163 seconds and 167 seconds for the plasma arc light.

Discussion

There were four main aims of this study: bond failures the time to bond-up the appliances, the time taken to replace any failed bonds and any sensitivity or discomfort experienced during curing with the plasma arc light and the halogen light.

There was no statistical difference in the bond failure between the two curing lights. Bond-up times were greatly reduced with the plasma arc light although no difference was found between the curing lights for replacing lost brackets. There was no clinical difference in patient reported sensitivity or discomfort between the curing lights. Clinically the plasma arc light performed equally as well as the halogen light with respect to bond failures with the advantage of reduced bonding times.

A prospective randomized design was selected to try to eliminate as much bias as possible, although weaknesses still exist. Unfortunately the operator could not be blinded to the curing lights. The random quadrant allocation should eliminate the possible bias of one side of the mouth being more prone to failures than the other. However, despite randomization of quadrants, the split mouth design does not eliminate the possibility that effects on one side of the mouth may still affect the opposite quadrant, where the two sides have been treated differently.

The use of pre-formed aluminium strips to shield bonded brackets from the curing light used in the contralateral or opposing quadrants was to ensure that no brackets could be exposed to both curing lights (Figure 3). This is particularly important in the incisor regions due to the close proximity of adjacent brackets.

The sample size was determined based on the assumption of independence. Brackets are clustered within each subject. The effect of ignoring this clustering would be an underestimation of the standard errors of the estimates. Thus, the effect of this lack of independence would result in an increased sample size being required. However, no formal design effect (inflation factor) was used, as for this particular scenario the design effect was considered to be very small. Informal allowances made for drop-out and variable number of brackets bonded per patient, were considered to also adequately cover the small inflation required for clustering. The (appropriately adjusted) standard errors of the clustered Cox proportional hazards model differed very little from those where the clustering was ignored. Thus supporting the *a priori* assumption of a relatively small effect of clustering in this particular study. It is postulated that this was due to the relatively low number of observed failures, in particular only seven of the 43 patients had three or more failures.

Conducting a retrospective calculation to determine the power of the study[13] (given the actual survival rates found and number of brackets bonded), indicated that the study had approximately 90% power to detect the estimated hazard ratio of 1.47.

It is often difficult to compare the results of clinical studies due to the wide variety of techniques, materials, research design and duration of the studies. The largest investigation on bond failures of stainless steel brackets bonded with a light-cured adhesive resin is by Millet *et al*.[14] They reported on 548 patients with 7118 bonded brackets and showed an overall failure rate of 6%. With regard to APC brackets, six-month clinical failure rates of 6.8% and 8.1% have been found.[12,15]

Although direct comparison is not possible, the bracket failure rate at 6 months with the halogen curing light in this study is similar at 8.5%. The six-month failure rate with the plasma arc light was lower at 5.7%. By completion of treatment the failure rates had risen to 6.7% with the plasma arc light and 9.5% for the halogen light but this difference was not statistically significant. Three randomized controlled trials, with comparable research methodology to this study, have shown failure rates of 3.9% (8) and 4.9% (7) for both lights and 4.3% failure rate with the plasma arc light and 5.4% with the halogen curing light.[9] The mean follow up time was between 11 months[8] and 1.1 years.[7] All of these studies

Table 2 Mean bonding times (in seconds) for each curing light.

Curing light	Total bond time per quadrant	Cure time per quadrant	Total bond time per tooth	Cure time per tooth
Plasma arc	372	41	89	10
Halogen	423	98	101	22

demonstrated no statistically significant differences in bracket survival rates between the curing lights.[7–9]

In comparison with other research, mean bond times of 65 seconds for the plasma light and 82 seconds per bracket for the halogen light have been reported.[8] These are both considerably less than the mean bond times recorded in this study but they failed to include the etching, rinsing and drying procedure in their bonding times. Operator inexperience in this study, with more time spent positioning the individual brackets, may also be a factor in the increased bonding times.

Bond failures were highest on the upper lateral incisors ($n=13$; 24.5%) which is in contrast to many studies where failure of brackets in the posterior regions is more common,[8,12] in particular the second premolars.[16] Although the failure rates in the maxillary ($n=29$; 9.0%) and mandibular ($n=24$; 7.3%) arches were comparable there was a slight trend for reduced failure rates in the mandibular arch, in particular the lower first premolars. This may, in part, be explained by the use of gingivally offset brackets in this study or the small number of failures. An *ex vivo* study showed a significant difference in the force to failure, between gingivally offset brackets and standard lower premolar brackets, when the force application is from an occluso-gingival direction.[6]

The mean rebond times for brackets cured with the plasma arc light were 163 seconds and those for the halogen light were 167 seconds. This difference of only 4 seconds is less than the expected 14 seconds when the manufacturers curing guidelines are adhered to. This is probably due to the fact that most time is spent preparing the tooth for replacement and positioning the bracket, not the actual light curing time itself. Even so, a time saving of 14 seconds is unlikely to be clinically significant and therefore the plasma arc light cannot be recommended based on saving chair-side time when rebonding single failed brackets. No other studies have reported the time required to replace failed brackets with either a plasma arc light or a halogen curing light.

To assess any difference in sensitivity or discomfort experienced during the curing cycles with the two lights, each patient scored a VAS following completion of the appliance bond up. A VAS is a line, usually 10 cm in length, the extremes of which are taken to represent the limits of the pain experience; one end is anchored with appropriate verbal descriptors such as 'no pain' and the other as 'severe pain'. Patients are asked to mark the line at a point corresponding to the severity of their pain and most patients who experience pain understand the concept and can quickly make the measurement. It has been shown that patients aged five years and older adapt well to its use.[17] In this study patients were asked to mark the VAS in relation to any sensitivity, pain or discomfort they experienced. Eighty-two per cent of patients reported no sensitivity or discomfort with either the plasma arc light or the halogen light. Three patients recorded sensitivity with the plasma arc light, two with the halogen curing light, and two with both. It was deemed that there was no clinical difference between the curing lights. It is difficult to explain why some patients experience sensitivity whilst others do not. This may be due to heat generation from the curing lights, anxiety with regard to the treatment or what could be termed a 'reverse' placebo effect or 'nocebo', where patients expect to experience discomfort purely due to the fact that a procedure is being performed. Variables such as emotions, attitude and personality factors can modify pain and discomfort sensations. These are complex experiences that include sensations evoked by noxious stimuli and the reactions to such stimuli. Reactions to these sensations vary among individuals and can depend on a patient's cultural background, past experiences and other forms of psychological input that gives meaning to a situation in which pain is experienced.[17] There has been no previous clinical research on sensitivity or discomfort experienced between the plasma arc light and the halogen curing light however these results appear favourable.

This study failed to show any evidence of a difference in bond failure rates between the plasma arc light (6.7%) and the conventional halogen curing light (9.5%). The time required to bond-up the appliances was significantly reduced with the plasma arc light, with a mean reduction of 51 seconds per quadrant. This would equate to over 3 minutes reduction in a full mouth bond-up, or over 5.5 minutes if molar bonds were also considered. This valuable saving in time is not only of benefit to the clinician, as chair-side time is reduced, but also to the patient in terms of comfort. Heat generation from the plasma arc light is a potential concern with regard to pulpal and soft tissue damage. However, this study found no difference in patient sensitivity between the curing lights with the majority of patients experiencing no discomfort during curing with either curing light.

The plasma arc light has been shown to be a viable alternative to the conventional halogen curing light with time saving benefits for both the clinician and the patient during the bond-up procedure. However, plasma arc light units are significantly more expensive than halogen curing lights, although the time saved during clinical practice can be offset against the increased initial cost. Curing light technology is advancing rapidly. The recent introduction of light emitting diodes (LED) curing lights offers a smaller, more portable alternative to the plasma arc light. LEDs are considerably cheaper

than plasma arc lights although their curing times are typically longer. Future research, in the form of randomized controlled trials, should be used to investigate these curing systems with an aim to identify which curing light proves superior with regard to clinical performance, patient comfort and cost effectiveness.

Conclusions

- There is no significant difference in bracket failure rate with the plasma arc light and the conventional halogen curing light.
- Appliance bond-up is markedly faster with the plasma arc light.
- There is no difference in patient sensitivity or discomfort between the plasma arc light and the conventional halogen curing light.
- There is no difference in rebond times between the plasma arc light and the halogen light.

Therefore, in conclusion the plasma arc light can be recommended for orthodontic bonding. Bond failures and patient comfort are no different than with conventional halogen curing lights but the plasma arc light has the advantage of reduced bonding times, which is of benefit to the patient and clinician.

Contributors

Joanne Russell, Simon Littlewood and Laura Mitchell were responsible for the study design; data interpretation; drafting; critical revision and final approval of the article. Joanne Russell was responsible for recruitment of participants, undertaking the clinical aspect of the study and data collection. Andrew Blance was responsible for study design; statistical analysis; critical revision and final approval of the article. Joanne Russell is the guarantor.

Acknowledgement

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