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ORIGINAL ARTICLE

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In vitro lingual bracket evaluation of indirect bonding with plasma arc, LED and halogen light

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Structured Abstract

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Objectives – Evaluate the shear bond strength (SBS) and the adhesive remnant index (ARI) of indirect bonded lingual brackets using xenon plasma arc light, light-emitting diode (LED) and conventional quartz-tungsten-halogen light.

Material and Methods – Lingual brackets were bonded indirectly to 60 premolars divided to three groups according to the curing light used: Group 1, plasma arc for 6 s; Group 2, LED for 10 s; and Group 3, halogen light for 40 s. After bonding, the specimens were subjected to a shear force until debonding. The debonding pattern was assessed and classified according to the ARI scores. The mean shear bond strengths were accessed by ANOVA followed by the Student-Newman-Keuls test for multiple comparisons. ARI scores were assessed using the chi-square test.

Results – The three groups showed significant differences ($p < 0.001$), with the averages of group 1 < group 2 < group 3. Groups showed no differences regarding ARI scores.

Conclusion – Bonding lingual brackets indirectly with plasma arc, during 60% of the time used for the LED, produced lower SBS than obtained with the latter. Using LED during 25% of the time of the halogen light produced lower SBS than obtained with the latter. These differences did not influence the debonding pattern and are clinically acceptable according to the literature.

Key words: dental bonding; light-cured; orthodontic brackets; orthodontics; shear bond strength

Introduction

Recent advances in materials and procedures have contributed to quality increase of lingual orthodontics, for example through indirect bonding (IDB) techniques, which have become more widely accepted and practiced by orthodontists (1). A major advantage of IDB is the high accuracy of bracket positioning that can be achieved (2, 3), which is essential for the success of lingual orthodontic therapy. Reducing chair time in lingual IDB techniques that use light curing (1, 4), could make this procedure more efficient. Thus, a shorter curing time for lingual brackets, with sufficient resistance, would represent a remarkable improvement in lingual IDB.

Conventional quartz-tungsten-halogen light is the most frequently used device for curing composites (5), even though it has several disadvantages. The light bulb has a limited effective lifetime and several factors may contribute for an inadequate polymerization output, such as presence of debris on the fiber tip, breakage of the tungsten filaments of the optical fiber, voltage variations, and dirty filters. In addition, only a minor amount of the total energy input is effectively converted into light, while the majority of the energy is transformed into heat (5, 6). Besides, the long time required for bonding brackets with conventional halogen light is a drawback to orthodontic clinical practice (7).

In view of the disadvantages of conventional halogen light, alternative light-curing devices were introduced in the market holding promise the reduction of chair time. High-power light-emitting diodes (LEDs) and the xenon plasma arc curing units are supposed to be safe and effective alternatives to the halogen lamps, offering a shorter curing time with similar shear bond strength (SBS) values to those obtained with the conventional halogen light (8, 9).

The use of LED technology to cure light-activated dental materials was proposed in 1995 (10) promising to overcome several disadvantages of the halogen light. The LED does not require the heated filaments used by halogen lamps. The electrical current is converted directly into a stable, efficient, long-lasting blue light with low wasted energy and heat generation. Due to a narrow band of light emitted, there is no need for filter systems (6), and it is estabilished that LED units are safe, efficient, resistant, and are highly durable (5, 11). More recently, second-generation or high power LEDs have been introduced in the market showing a power density of about 1000 mW/cm^2, higher than the 400 mW/cm^2 (11) of first-generation devices, suggesting an even shorter curing time due to the power density increase (12, 13).

A more powerful light source was developed in the mid 90s, called xenon plasma arc (14, 15). It produces light through the passage of an electric current through xenon gas, reaching a power density as high as $\geq$2000 mW/cm^2 (13, 16, 17). Although powerful, the ideal curing time of brackets with this light source is very controversial, since the recommend exposure time can go anywhere from 2 to 3 s/bracket (7, 16, 18), to 6 to 9 s (8, 14, 15, 17, 19–21). Even though a lack of standard in the methodologies of the published studies makes the comparison difficult among them, it has been shown that plasma arc used in a shorter time than conventional halogen light (7–9, 15–22) or LED (8, 9) can provide similar SBSs of brackets bonded to enamel.

Even though all the aspects of the efficiency of these two high-power curing devices have not yet been fully investigated for bonding brackets, the use of LED and plasma arc have increased considerably in orthodontics (23). The literature, however, lacks reports on plasma arc, LED and halogen light sources used in lingual IDB systems. Being so, it is relevant to compare the differences of SBS of lingual brackets when using these different light curing devices. Therefore, the aim of this paper was to evaluate *in vitro* the SBSs and the ARI of lingual orthodontic brackets using plasma arc, LED and conventional halogen light.

Material and methods

Due to the lack of available data regarding SBSs averages and standard deviations for lingual brackets in the literature, data referring to labial brackets (11, 22) was used for sample size calculation. With a significance level of 5% and a power of 80%, it was determined that the sample size in each group should be approximately 19 specimens. Thus, 60 maxillary human premolars, divided into three groups of 20, stored in 10% formalin, were used for this study. The teeth had no apparent caries, fractures, decalcifications, anomalies of form or defects on lingual enamel.

The teeth were randomly assigned to the three groups (Table 1), according to the different light sources and times used for bonding the brackets. In group 1 (G1), the plasma arc was applied for 6 s using the Apollo® 95E device (DenMed Technologies, Orange, CA, USA), in group 2 (G2), the LED was applied for 10 s with the Radii® device (SDI, Bayswater, Vic., Australia), and in group 3 (G3) the halogen light was applied for

Table 1. **Presentation of groups**

Group	Light source	Exposure time
G1	Xenon PAC	6 s
G2	LED	10 s
G3	Halogen light	40 s

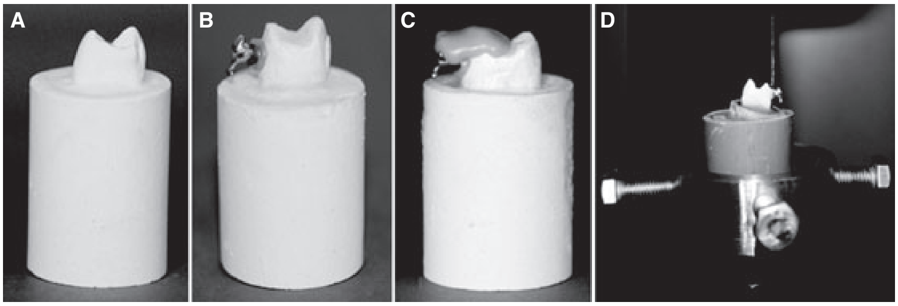

Fig. 1. (A) Die stone specimen. (B) Lingual bracket positioned on the die stone tooth. (C) Transference guide on the bracket and occlusal surface of the die stone tooth. (D) Specimen positioned in the MTS machine.

40 s with the XL 3000® device (3M Unitek, Monrovia, CA, USA).

Each tooth was vertically embedded in acrylic resin within PVC cylinders, of 1.25 cm of diameter by 3 cm height, up to the cemento-enamel junction in a way that only the crown was exposed. A guide was used to place the tooth's lingual surface perpendicular to the bottom of the cylinder.

Alginate impressions were taken from all specimens and type IV gipsite models were poured (Fig. 1A). The models were coated with separator, and left to dry out. Seventh generation lingual brackets (Ormco Corp, Orange, CA, USA) for maxillary premolars were then bonded to the lingual surfaces of the models. In order to standardize the height, angulation, torque and distance from the bracket base to the teeth for all teeth, the torque and angulation reference guide (TARG) machine (Ormco Corp) was used (Fig. 1B). All those compensations are possible due to a composite base which is produced when lingual brackets are positioned in the TARG machine. Z100® (3M/ESPE, St. Paul, MN, USA) composite was used for that purpose. After the brackets were properly positioned, the composite was cured with halogen light for 40 s and individual bonding trays were made using the composite-modified glass ionomer *Band-Lok*™ (Reliance Orthodontics Products, Itasca, IL, USA), according to Dr. T. Hiro's technique (24) (Fig. 1C).

The models were submersed in water for the removal of the bonding tray/bracket set and the sets were numbered to be bonded to the correspondent teeth afterwards. Composite flush was trimmed with low speed burs to standardize the area of the composite base to be bonded to each tooth. The composite bases were then lightly cleaned with acetone.

Before bonding, the teeth were cleaned with pumice/water in prophy rubber cups for 10 s, rinsed with water and air dried. The lingual enamel was etched with 35% phosphoric acid (3M/ESPE) for 30 s, rinsed with an air/water spray for 20 s, and dried with oil-free air. Transbond™ XT primer (3M Unitek) was applied to the enamel and the lingual brackets received a thin layer of Transbond™ XT orthodontic adhesive (3M Unitek) over their composite base. The base/bracket/bonding tray set were positioned to the correspondent teeth and cured by a single investigator. Composite flush was removed with a sharp explorer before curing.

Before curing the brackets, the power density of all light sources were tested with a curing radiometer (LITEX® power intensity meter; Dentamerica™, City of Industry, CA, USA) at the predetermined curing times. The specifications of the devices used in this study as informed by the manufacturers and the values obtained by the radiometer are presented in Table 2.

***Table 2.* Characteristics of the light-curing units used in the study**

Light type	Wavelength (nm)	Tip diameter (mm)	Power density (mW/cm^2)*	Power density (mW/cm^2)†
Xenon PAC units (Apollo® 95E; DenMed Technologies)	460–490	8	1600	2100
Light-emitting diode (Radii®; SDI)	430–480	8	1400	900
Quartz-tungsten-halogen (XL 3000®; 3M Unitek)	420–500	8	400	500

*Informed by manufacturer.
†Checked with a curing radiometer (LITEX® power intensity meter; Dentamerica™, City of Industry, CA, USA).

During curing, the tip of each device was held as close as possible to the bonding surface and light was delivered to the mesial of the tooth/composite base interface during half of the predetermined time, and to the distal side during the rest of the time. The trays were carefully removed using a low-speed cylindrical bur and the specimens were stored in distilled water at room temperature for 24 h.

The specimens were then subjected to an occluso-gingival shear force using a knife-edge blade adapted to a MTS 810 universal machine (Material Test System, MN, USA). The load was applied at the tooth/composite base interface at a speed of 1 mm/min (25) until bracket failure. During the procedure, the teeth were positioned with the lingual surface parallel to the direction of the shearing force (Fig. 1D). The maximum force at bond failure was recorded for each specimen in a computer coupled to the testing machine and calculated into MegaPascals (MPa).

After debonding, the tooth surfaces were examined under a stereomicroscope (Carl Zeiss, Jena GmbH, Germany; ×10 magnification) coupled to a digital camera (TK1380U CCD, JVC, Tokyo, Japan). The images were transferred to a computer connected to the stereomicroscope, and the Leica Qwin image-processing-and-analysis software (Leica Microsystems Imaging Solutions Ltda., Cambridge, England) was used to determine the amount of adhesive remaining on the bonding site (Fig. 2).

Four calibrated and independent examiners blindly assessed and classified the debonding pattern of the groups according to adhesive remnant index (ARI) (26). ARI scoring criteria were: 0, no composite remained on the tooth; 1, less than 50% of the composite remained on the teeth; 2, more than 50% of the composite remained on the teeth; and 3, all composite remained on the teeth. The final ARI score attributed to each specimen was the one chosen by the majority of the examiners and in the case of a tie, the lowest score was given.

The SBSs obtained with the different light types were transferred to the SPSS v.15.0 software (SPSS Inc., Chicago, IL, USA) for statistical analysis. Analysis of variance (ANOVA) was used for comparison of the averages and the Student-Newman-Keuls test was used for multiple comparisons among the groups. The ARI scores were evaluated using the chi-square test.

Results

One specimen from G2 and one from G3 were excluded due to technical problems with the computer coupled to the testing machine. Another specimen from G3 was discarded due to a fracture caused by a hidden caries lesion.

The average SBS for the plasma arc (G1) was 12.13 ± 6.1, for the LED (G2) it was 15.84 ± 4.7 MPa, and for the halogen light (G3) it was 19.72 ± 4.5 MPa (Table 3 and Fig. 3) ANOVA detected significant differences ($p < .001$) among the groups and the Student-Newman-Keuls test revealed that all three groups were different from each other, with G1 presenting the lowest average, followed by G2, which, in turn, had a

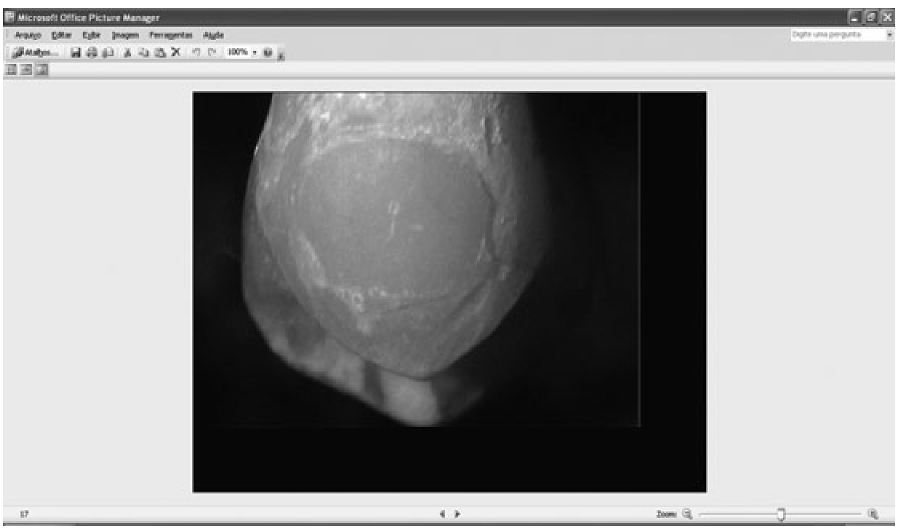

Fig. 2. Image magnified for analysis of the ARI scores.

Table 3. **Multiple comparisons of the shear bond strength means – Student-Newman-Keuls test for homogenous subsets of means**

Light source/significance level (p)	Homogenous subsets (α = 0.05) Subset 1	Subset 2	Subset 3
G1 (Xenon PAC – 6 s)	12.128		
G2 (LED – 10 s)		15.839	
G3 (Halogen light – 40 s)			19.719
p	1	1	1

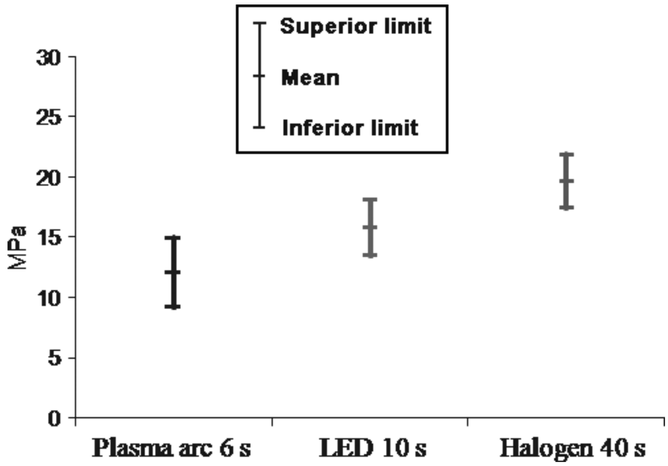

Fig. 3. Mean shear bond strength of each group and confidence intervals of the means.

Table 4. **Frequency distribution of ARI scores* of experimental groups**

Group	ARI 0 n (%)	1 n (%)	2 n (%)	3 n (%)	Total n (%)
G1 (xenon PAC – 6 s)	–	–	7 (35.0)	13 (65.0)	20 (100.0)
G2 (LED – 10 s)	–	–	8 (42.1)	11 (57.9)	19 (100.0)
G3 (halogen light – 40 s)	–	–	11 (61.1)	7 (38.9)	18 (100.0)
Total	–	–	26 (45.6)	31 (54.4)	57 (100.0)

χ^2 = 2.75; df = 2; p = 0.253; *The adhesive remnant index (ARI) scores: 0 = No adhesive remaining on tooth; 1 = less than half of enamel bonding site covered with adhesive; 2 = more than half of enamel bonding site covered with adhesive; 3 = enamel bonding site covered entirely with adhesive.

lower average than G3 (Table 3). The three light sources tested showed SBS values considered ‘clinically acceptable’ (27).

The chi-square test did not detect significant differences among the ARI scores obtained with the different light sources (Table 4). The majority of the adhesive remained on the teeth. Approximately half of all failures left the whole amount of adhesive on the teeth and the remaining half left more than 50% of the adhesive on the teeth. No fractures on enamel were observed in any of the specimens.

Discussion

Differences were observed among the three light sources used for lingual IDB. The xenon plasma arc used for 6 s produced lower SBS compared to the LED for 10 s and the halogen light for 40 s. Comparing our results to previous data in the literature is difficult due to the lack of studies evaluating the SBS of lingual brackets cured with plasma arc or LED. In labial brackets, however, no differences in SBS are seen when comparing plasma arc to LED using similar exposure times as those of the present study (8), disagreeing with our findings. In the same way, it has been shown that the plasma arc used from 6 to 9 s produces similar SBSs as those obtained with halogen light (14, 17, 19). This could be explained by the different methods used and more importantly, by the fact that the mechanical properties of composites may be compromised when short curing times are used. This can happen because the energy emitted by the plasma arc light during 6 s appears to be substantially smaller than that emitted with longer curing cycles with LEDs or halogen lights set to conventional exposure time (28). In addition, greater variability was observed with the plasma arc, suggesting a need for further investigations with this light source.

The high variability of the results could be explained by the degree of curing. Curing is directly related to the amount of energy absorbed by the composite, defined as the product of the power by the exposure time (21). Both the total energy and the power density, ratio between the power of the incident light and the unit area, are essential factors in the curing process (12). Besides, other factors can influence the absorbed energy, such as, the shape and size of the light tip, the distance from the light tip to composite surface, exposure time, light intensity, composite formulation and wavelength (29, 30). Altogether, they might have influenced the plasma arc curing due to the short exposure time associated with high-power-density light curing units.

The high power LED, used for 10 s, showed lower SBS than the halogen light used for 40 s. Previous studies with labial brackets, however, have showed similar SBS of brackets bonded with LED and halogen lights using the same exposure times as in our study (9, 11). As mentioned before, differences in the methodologies might explain these divergences. Besides, the lack of standardization in the experimental methodologies of studies evaluating bracket's SBS makes the comparison of any results found in this study to those of previous *in vitro* studies difficult (11). Along with the fact that the differences between our results and the labial studies may also be associated with the presence of intermediate resin layer in the IDB technique. Furthermore, several reports (8, 11, 31) did not check the power density of the tested light sources with a curing radiometer, considering only the values informed by the manufacturers in their analyses. In our study, for example, the power density of the LED checked with a curing radiometer was significantly smaller than that informed by the manufacturer (Table 2), what could cause alterations in the test results. Therefore, the methodology of studies evaluating light sources should always include the measurement of the power density of the devices, in order to avoid erroneous conclusions.

The three light sources tested showed higher SBS values than what is considered satisfactory for most clinical procedures, somewhere between 6 to 8 MPa (27). In orthodontics, the 'ideal' SBS is not simply the highest possible value, instead, it should be high enough to resist forces from mastication and mechanics, and low enough to allow bracket debonding without causing damage to the enamel (32). It is recommended that the SBS of orthodontic brackets should not exceed 14.5 MPa in order to avoid fractures on the tooth structure (8). Even with the high SBS found in this study, no damage to enamel was observed in any of the specimens. Therefore, both plasma arc and LED can be good alternatives to conventional halogen light, reducing considerably the working time and providing clinically acceptable bracket SBS.

No modifications were made in the IDB technique or on the lingual surface of the teeth. Some orthodontist believe that the current bonding techniques used in labial brackets should be the same for lingual bonding (33, 34), others authors, however, believe in some modifications, such as longer acid etching time and roughening of enamel surface (micro-etching with aluminum oxide) for a improved resistance in lingual brackets (35, 36). In our findings, high resistances were obtained without micro-etching the enamel in order to increase the resistance of the lingual brackets to the shearing forces, which suggest that such procedures might not be necessary.

No differences in the ARI scores were observed among the light sources. The debonding pattern of the brackets occurred predominantly between the adhesive and the composite base of the bracket, which is favorable, decreasing the risk of enamel damage during bracket removal. Although comparisons of these results to data published in the literature is not possible, there is controversy regarding the debonding interface resulting from curing of brackets with plasma arc compared to halogen light. Studies with labial brackets have reported a higher incidence of failure at the enamel/adhesive interface (7, 8, 37, 38), unlike ours and previous investigations' findings (9, 13, 20, 39). The variability of the results found in the literature may de due to differences in the methodologies, such as the properties of the materials used in the bonding technique, the shape of the bracket base and the method used for bracket debonding (40, 41). The lack of differences between the ARI scores obtained with the LED and halogen light is consistent with the literature (8, 9, 42). Likewise, no differences were found between the scores obtained with the LED and plasma arc, agreeing with one of the two studies on the subject (9), and disagreeing with the second (8), suggesting that more studies should be done in the subject. Notwithstanding, the analysis of ARI scores is subjective and the results should be interpreted with caution (43).

Conclusions

- Light-curing with xenon plasma arc light during 60% of the exposure time used for the LED and during 15% of the exposure time used for the halogen light produced lower SBS than those obtained with those light sources;
- Light-curing with LED during 25% of the exposure time used for the halogen light produced a lower SBS;

- The analysis of the ARI scores found no differences among the tested light sources regarding the debonding interface;
- Even though there were differences among times and light sources, all experimental groups' SBSs are considered clinically acceptable and may be used for lingual IDB techniques.

Clinical relevance

Chair time reduction employing lingual indirect bonding (IDB) techniques that use light curing could make this procedure more efficient. A shorter curing time for lingual brackets, without loss of shear bond resistance, would represent a remarkable improvement in lingual IDB. Thus, it is relevant to compare the differences of shear bond strength of lingual IDB brackets using different light curing devices with different curing times.

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