

## Comparison of Light-Emitting Diode-Curing Unit and Halogen-Based Light-Curing Unit for the Polymerization of Orthodontic Resins: An *In vitro* Study

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ABSTRACT

**Aims and Objectives:** Conventionally, composites are cured using halogen-based light-curing units (LCUs). However, recently, light-emitting diode (LED) LCUs have been introduced commercially, claiming many advantages, yet producing comparable bond strength even when cured with single LED LCUs. This present study was undertaken to compare the shear bond strength of orthodontic brackets bonded to teeth with conventional halogen LCU (3M ESPE Elipar 2500) and LED LCU (3M ESPE Elipar FreeLight 2) and to determine the site of bond failure.

**Materials and Methods:** Fifty extracted human bicuspid teeth were randomly divided into two groups of 25 each. All the teeth were etched and primed. Then, orthodontic brackets were bonded onto the teeth with the light-cured adhesive (Transbond XT, 3M Unitek), and the adhesive was cured with halogen LCU and LED LCU for Group I and Group II, respectively. The brackets were then subjected to shear stress using a Hounsfield universal testing machine at a crosshead speed of 1 mm/min. The force was recorded in Kgf and converted to MPa. The residual adhesive was scored based on the modified adhesive remnant index (ARI) using an optical stereomicroscope. The data were analyzed using the Student's *t*-test and the Mann-Whitney test at a significance level of 0.05.

**Results:** The results have shown that there is no significant difference between the shear bond strengths and the ARI scores of both the groups.

**Conclusion:** From this study, it can be concluded that (1) LED LCUs containing even only a single LED can cure the composite as well as a halogen-based LCU; (2) there is no statistically significant difference in the shear bond strengths of the two groups; and (3) the ARI scores show no significant difference.

**KEYWORDS:** Adhesive remnant index scores, halogen-based light-curing unit, light-emitting diode light-curing unit, shear bond strength

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### INTRODUCTION

The development of firm attachment of brackets to the teeth is one of the prominent milestones in the orthodontic field as it enables efficient movement of the teeth. Firm attachment was initially achieved by cementing bands on all the teeth.

Since Buonocore in 1955<sup>[1]</sup> demonstrated that bond strength of dental resin to enamel could be increased by etching the enamel surface and Newman introduced the bonding of orthodontic attachments to the enamel surface

as an alternative to banding in 1965, the advances in bonding have made the use of bands on anterior teeth nearly obsolete.

Bonded brackets are more advantageous compared to the orthodontic bands because they are easier to place and

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remove, separation of teeth not required, more esthetic, hygienic, and less irritating to the gingiva. However, the frequency of bond failure during treatment has prompted manufacturers to improve on bonding material and curing technique.

Since the introduction of light cure systems in the 1970s,<sup>[2]</sup> they have become an important part of modern adhesive dentistry. They are used to cure resin-based composite restorative materials, resin-modified glass ionomer cement, preventive pit and fissure sealants, etc., and most important to the orthodontist, to bond orthodontic brackets to the teeth.<sup>[2,3]</sup>

In the field of orthodontics, light-activated bonding system is popular because the extended working time allows for precise bracket placement and ease of manipulation. As soon as the bracket is placed at the desired site, rapid set is accomplished through photoactivation.

At present, there are four different technologies available for curing of dental composites by light.

- Halogen lamps
- Plasma arc lamps
- Lasers
- Light-emitting diode (LED).

Rather than a hot filament as used in halogen bulbs, LEDs used the junctions of doped semiconductors (p-n junctions) for the generation of light. Under proper forward biased conditions, electrons and holes recombine at the LED's p-n junction leading, in the case of gallium nitride LEDs, to the emission of blue light.<sup>[4,5]</sup> A small polymer lens in front of the p-n junction partially collimates the light. The gallium nitride blue LED falls conveniently within the absorption spectrum of camphorquinone photo-initiator (400–500 nm) present in the light-activated dental materials so that no filters are required in the LED LCUs. Furthermore, LEDs have an expected lifetime of several 1000 h without significant degradation of light flux over time. Several studies have shown the potential of LED technology for light-activated materials.

Hence, the aim of this study is to compare the shear bond strength of orthodontic brackets bonded to teeth with conventional halogen light-curing units (LCUs) and commercial LED LCU.

### OBJECTIVES

1. To compare the shear bond strength of orthodontic brackets bonded to teeth with conventional halogen LCU and commercial LED LCU
2. To determine the site of bond failure.

### MATERIALS AND METHODS

Before beginning the study, ethical clearance was obtained from the Institutional Review Board of

College of Dental Sciences with ethical approval letter no. 04\_ D031\_22905, Davangere. The study was carried out for a period of 90 days from January to March 2004.

### MATERIALS

1. Fifty extracted human bicuspid teeth
2. Distilled water
3. Pumice and rubber prophylactic cups
4. Orthodontic metal brackets
5. LED-curing unit (3M ESPE Elipar FreeLight 2)
6. Halogen-based LCU (3M ESPE Elipar 2500)
7. Transbond XT light cure adhesive (3M Unitek)
8. Mounting Jig
9. Self-cure acrylic
10. Universal testing machine connected with a computer.

### METHODS

#### Teeth

A total of 50 human bicuspid teeth were extracted in the Department of Oral Surgery, College of Dental Sciences, Davangere, for orthodontic purposes during December 2003 were collected and stored in distilled water.

The sample size was determined using the following formula:

$$n = \frac{Z^2 \times SD^2}{L^2}$$

where

$$Z = 1 - \alpha = 1.96$$

SD = Pooled standard deviation = 0.36 (based on pilot study)

L = Allowable error = 10%

N = Sample size

Level of significance = 10%

Power of the study (1- β) = 90%.

Substituting the values in the formula, the sample size was calculated as follows:

$$N = \frac{(1.96)^2 \times (0.36)^2}{(0.1)^2}$$

$$= 49.78$$

Thus, the sample size was 50.

The criteria for tooth selection included as follows:

- Intact buccal enamel
- Not subjected to any pretreatment chemical agent
- No caries
- No cracks caused by the pressure of extraction forceps.

The teeth thus collected were randomly divided into two groups of 25 each and embedded in yellow and blue self-curing acrylic up to the level of the cemento-enamel junction. The labial surfaces of the teeth were kept perpendicular to the bottom surface of the mold.

#### Cleaning and etching

The teeth were cleaned and polished with pumice and rubber prophylactic cups. The buccal surface of each tooth was etched for 30 s with 37% phosphoric acid gel.<sup>[6]</sup> Each tooth was then rinsed with a water spray for 20 s and dried with oil-free air for 10 s.<sup>[6]</sup> The buccal enamel surface of the etched teeth appeared chalky white.

A light-cured adhesive primer (Transbond XT, 3M Unitek) was placed on the etched enamel surface, lightly air thinned, and polymerized for 10 s as recommended by the manufacturer.<sup>[6]</sup>

#### Brackets

Premolar brackets of 0.022" slot MBT prescription (3M Unitek, Gemini series) were used. The surface area of the bracket base was 10.61 mm<sup>2</sup> as described by the manufacturer.

#### Bonding procedure

The two groups were bonded in the same manner except the light source.

- Group 1 (color code: yellow): 25 teeth were bonded using conventional halogen-based LCU (3M-ESPE Elipar 2500) [Figure 1].
- Group 2 (color code: blue): 25 teeth were bonded using LED LCU (3M-ESPE Elipar FreeLight 2) [Figure 2].

The bracket-adhesive interface was cured for 20 s on the mesial side of the bracket and for 20 s on the distal side, for a total cure time of 40 s.<sup>[3]</sup>



Figure 1: Group I cured with halogen-curing light

#### Technical details

The 3M ESPE Elipar 2500 halogen-curing light produces high-intensity visible blue light in the 400–500 nm wavelength [Figure 3].

The Elipar 2500 light has an optical filter which reduces radiation above 520 nm. A 75 W bulb is supplied in the unit and has a minimum average life of 4000 cycles at 20 s each cycle.

Two optical filters, a blue pass filter and a heat filter, are included in the light path to substantially block unwanted nonvisible radiation and visible light other than that in the range of 400–500 nm.

A high-intensity LED generates light in the Elipar FreeLight 2 LED-curing light. In contrast to conventional LEDs, high-intensity LEDs use a larger semiconductor crystal which increases both the illuminated area and intensity [Figure 4]. Dissipation of heat generated by the LEDs during operation is crucial for durability of LED-based systems. The Elipar FreeLight 2 LED-curing light produces 95% less heat than the halogen lamp. Ninety percent of the photons emitted by blue LEDs occur between 440 and 500 nm, while the maximum emission of the blue LEDs used in the Elipar FreeLight 2 LED-curing light is approximately 465 nm, almost identical to the absorption peak of camphorquinone.

#### Shear bond strength testing procedure

All the bonded test samples were stored in distilled water at room temperature for 24 h before testing. Shear bond strength testing was done in the Department of Textiles, Bapuji Institute of Engineering and Technology, Davangere, using a Hounsfield universal testing machine, which was connected to a digital meter, and the debonding force was recorded automatically in Kgf. The test samples were stressed for debonding at a crosshead speed of 1 mm/min until the bracket debonded [Figures 5 and 6].

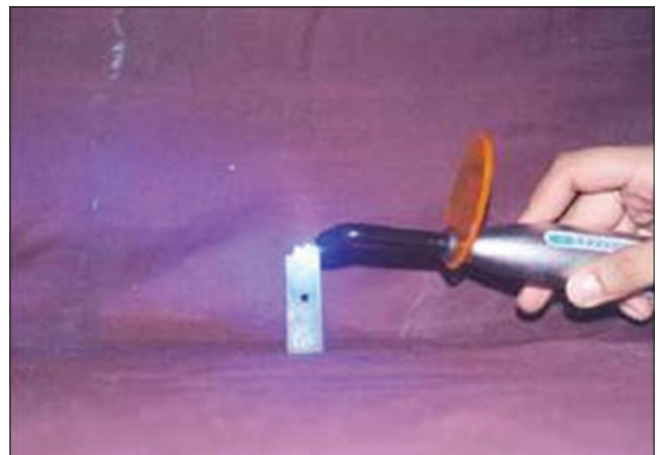
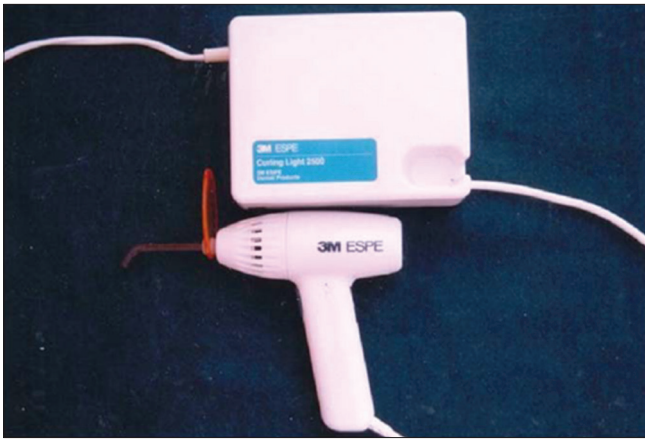


Figure 2: Group II cured with light-emitting diode-curing light

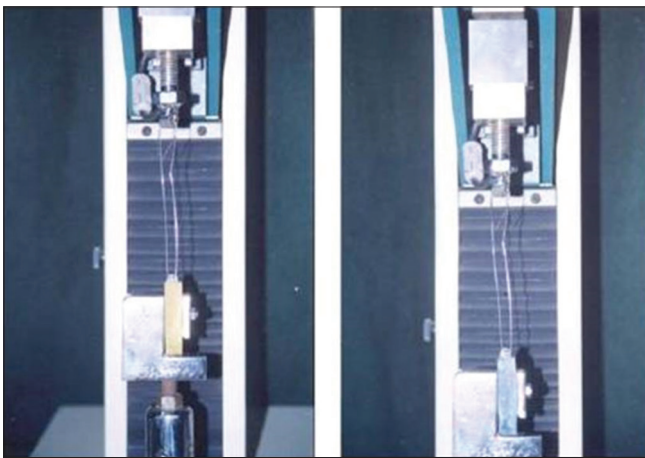




**Figure 3:** Halogen light-curing unit (3M ESPE Elipar 2500)



**Figure 4:** Light-emitting diode light-curing unit (3M ESP Elipar FreeLight2)



**Figure 5:** Shear bond strength testing of Group I and Group II

The force required for debonding was recorded in Kgf and converted to MPa using the formula:

$$\text{MPa} = \frac{\text{Force in Kgf}}{\text{Surface area of the bracket base in mm}^2} \times 9.81$$

#### Adhesive remnant score

The amount of adhesive remaining on the tooth was evaluated using a stereomicroscope (Olympus SZX12). The amount of adhesive remaining was scored on the basis of a modified adhesive remnant index (ARI).

- 5 = No composite remained on the enamel
- 4 = Less than 10% of composite remained on the enamel
- 3 = Greater than 10% and less than 90% of composite remained on the enamel
- 2 = Greater than 90% of composite remained on the enamel
- 1 = All of the composite with the impression of the bracket base remained on the enamel.

#### STATISTICAL ANALYSIS

The mean and standard deviations were calculated for the shear bond strengths of the two groups. Student's *t*-test



**Figure 6:** Stereomicroscope picture of tooth surface to determine adhesive remnant index

was used to compare the shear bond strength of the two groups, and the Mann–Whitney test was performed to compare the ARI scores of both the groups. A  $P < 0.05$  was considered for statistical significance.

#### RESULTS

The present study aims to assess and compare shear bond strength and site of bond failure between enamel, adhesive, and bracket base of brackets bonded with conventional halogen LCUs and LED LCUs under the following groups.

- Group I: Brackets bonded onto the teeth with halogen-based LCU (3M ESPE)
- Group II: Brackets bonded on to the teeth with LED LCU (3M ESPE Elipar FreeLight 2).

The samples in each group were tested for shear bond strengths using the universal testing machine. The shear bond strengths were recorded in Kgf and converted in MPa.

The results obtained were tabulated, and in each group, mean and standard deviations were calculated [Graph 1]. The differences in bond strength

between the groups were assessed by Student's *t*-test as illustrated in Table 1.

The Student's *t*-test revealed that Group I – halogen-based LCU – (mean  $8.89 \pm 2.46$ ) and Group II – LED LCU – (mean  $8.30 \pm 1.51$ ) exhibited almost the same bond strengths, and the difference between the two groups is not significant ( $P > 0.05$ ) [Table 1].

### ADHESIVE REMNANT INDEX SCORES

After debonding, enamel surfaces were observed under the optical stereomicroscope at  $\times 10$  magnification to determine the amount of composite remaining on the tooth surface [Graph 2]. The Mann–Whitney test was used to compare the pattern of ARI scores between the two groups. It was found that there were no significant differences in the debonding characteristics of the two groups, with the majority of the bond failures occurring within the adhesive [Table 2].

### DISCUSSION

In orthodontics, treatment time can be greatly influenced by the number and frequency of debonded brackets. This can lead to a lack of progress in the treatment and in some cases even relapse.

Therefore, the strength of the bond between the bracket and enamel has become an important issue in research.

Bond strength is influenced by many factors such as tooth conditioning, adhesive systems used, design of the bracket base, and the mode of cure.

The most important of these factors is whether the adhesive composite has reached a level of polymerization that will adequately retain the bracket to the tooth when orthodontic forces are applied. With light-cure systems

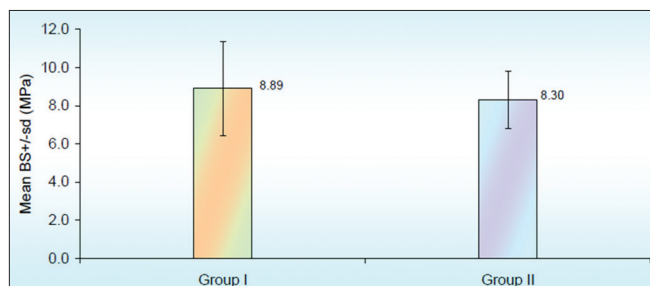
in vogue, their ability to adequately polymerize the adhesive is crucial.

The first light-cure unit had ultraviolet (UV) light which had the disadvantage that 1 min was required per millimeter of thickness. Because of the safety concerns of the long-term use of UV light, visible light curing was introduced around 1980.<sup>[7]</sup>

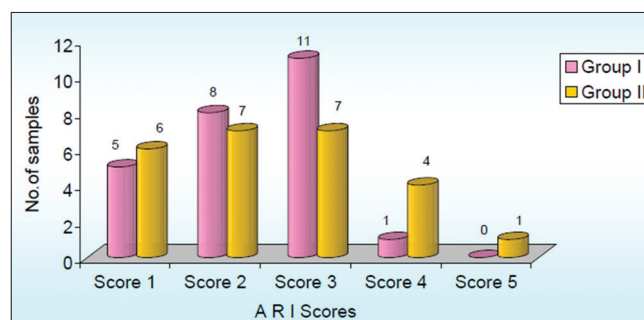
Most dental photo-initiator systems use camphorquinone as the diketone absorber, with the absorption maximum in the blue region of the visible light spectrum at a wavelength of 470 nm.<sup>[2,6]</sup>

Halogen bulbs generate light when electric energy heats a small tungsten filament to high temperatures. Most of the energy put into the halogen system is changed into heat, but a small portion is given off as light. Selective filters screen the wavelength so that only blue light is emitted. Despite their popularity, halogen bulbs have several shortcomings. Halogen bulbs have an effective lifetime of approximately 100 h. High heat is generated degrading the components of the halogen bulb over time.<sup>[6]</sup> The lamp reflector may lose its properties because of loss of its reflective material or may be due to deposition of surface impurities.

The argon lasers introduced in the late 1980s and early 1990s are capable of curing in only 10 s for filled resins and 5 s for unfilled resins, at a wavelength of 488 nm. More recently, xenon arc light units have been introduced for rapid light curing in restorative dentistry. Plasma arc lamps work by application of high voltage current across two closely placed electrodes, resulting in a light arc between the electrodes. The plasma



Graph 1: Shear bond strength



Graph 2: Adhesive remnant index scores

Table 1: Descriptive statistics and comparison of bond strength between two study groups

	Number of samples	Bond strength (MPa)					
		Range	Mean	SD	Difference Between Groups		
					Mean Diff	<i>t</i> *	<i>P</i>
Group I	25	4.53-13.39	8.89	2.46	0.59	1.02	0.31
Group II	25	4.60-10.67	8.30	1.51			

\*Student *t*-test [The difference between the two groups are not significant ( $P > 0.05$ )]

**Table 2: Frequency distribution and comparison of ari scores between two study groups**

Groups	No. of samples	A.R.I SCORES				
		1	2	3	4	5
Group I	25	5 (20)	8 (32)	11 (44)	11 (44)	0
Group II	25	6 (24)	7 (28)	7 (28)	7 (28)	1 (4)

$P=0.72$ , N.S, Mann-Whitney Test : (Two Sample Rank Test)

arc-curing system emits a continuous spectrum of light and has filters that narrow the spectrum of visible light to a band centered over the 470 nm wavelength for activation of the camphorquinone. Hence, their operating temperatures increase in proportion to the amount of blue light produced. The curing time with plasma arc-curing lights is as short as those with argon lasers.<sup>[7]</sup> These curing units are not commonly used, as they are very expensive, with very low efficiency and high-temperature development.

Jandt *et al.* in 1995<sup>[6-8]</sup> proposed solid-state LED technology for the polymerization of light-activated dental materials.

LEDs produce visible light by quantum mechanical effects. LEDs comprise a combination of two different semiconductors, the “n-doped” and the “p-doped” type. n-doped semiconductors have an excess of electrons, while p-doped semiconductors require electrons, resulting in electron “holes.” When these two types of semiconductors are combined and a voltage is applied, electrons from the n-doped type connect with holes from the p-doped type.

The color of an LED light, its most important characteristic, is determined by the chemical composition of the semiconductor combination. When electrons in the semiconductor combination move from higher to lower energy levels, the energy difference of the band gap is released in the form of a photon of light.

The primary difference between light produced by LEDs and other light sources is that LEDs produce light with a narrow spectral distribution as lights of selected wavelengths can be preferentially produced using LEDs with appropriate band gap energies. Previous research has shown that LED LCUs can cure composite as well as halogen-based lights, but these studies used experimental lights with considerably more LEDs in the light tip than are commercially available today.

The present study was undertaken to compare the shear bond strength of brackets cured by halogen LCU (3M, ESPE Elipar 2500) and LED LCU (3M, ESPE Elipar FreeLight 2).

The LED light used in this study (3M ESPE Elipar, FreeLight 2) has a single high-intensity LED, which

uses a substantially larger semiconductor crystal, which increases both the illuminated area and the light intensity.

In this study, it was found that the shear bond strength of the bracket bonded by the LED LCU containing a single LED was comparable to the shear bond strength of brackets bonded with halogen LCUs ( $8.30 \pm 1.51$  and  $8.89 \pm 2.46$ , respectively). It has been suggested that bond strengths between 8 and 9 MPa are sufficient to withstand normal orthodontic forces. In fact, the highest bond strength might not be the most desirable characteristic because brackets must eventually be removed and clinical problems with enamel damage could occur during debonding if bond strengths are excessive. Jandt *et al.*<sup>[8]</sup> and Mills *et al.*,<sup>[9]</sup> Dunn and Bush,<sup>[10]</sup> and Leonard *et al.*<sup>[2]</sup> compared that the depth of cure and hardness of composite cured with halogen LCU are LED LCUs and found that the performance of LED LCU was lower or equivalent to that of halogen LCUs.

bani *et al.*<sup>[5]</sup> using GC E-Light (64 LEDs) found that it can cure more rapidly than halogen without a significant reduction in bond strength.

Dunn and Taloumis<sup>[3]</sup> using LED units containing seven LEDs found no difference in the shear bond strength or in the ARI scores which concurs with the present study even though the LED LCU used in the present study contains only a single LED.

Similar studies by Bishara *et al.*,<sup>[11]</sup> Swanson *et al.*,<sup>[12]</sup> and Uşümez *et al.*<sup>[13]</sup> comparing the shear bond strengths of brackets bonded with conventional halogen LCUs and LED LCUs found comparable shear bond strengths, which again concurs with the result of the present study.

The present study brings into significance the fact that even though it has been previously stated by Mizrahi E *et al.*<sup>[14]</sup> that as the number of LEDs in the LCU will decrease, the performance will be lower, the single LED LCU used in the present study has given comparable bond strengths.

In this study, comparable shear bond strength of the LED LCUs with the halogen LCUs was observed, but the LEDs have certain advantages over halogen LCUs.

They are cordless, smaller, and lighter with estimated lifetime of over 10,000 h.

In addition, they have low maintenance costs and half the heat production of halogen lights.

## CONCLUSION

Based on the recorded data and the statistical analysis, the following conclusions were drawn:



1. There is no statistically significant difference in the shear bond strength of the two groups.
2. As the LED LCU used in this study contained only a single LED, it is a technological advancement over the previous LED.
3. In LCUs containing multiple LEDs, the comparable bond strengths becomes significant.
4. The ARI scores showed no significant difference and the LEDs have the advantage of being cordless, smaller, lighter with estimated lifetime of over 10,000 h with lower maintenance costs as well as far lower heat production.

#### LIMITATIONS AND RECOMMENDATIONS

The present study has the limitations of being *in vitro* and a full clinical trial is needed to compare the shear bond strength of orthodontic brackets bonded to teeth with conventional halogen LCUs and commercial LED LCU.

As this study was carried out among fewer subjects and results are not statistically significant, further studies should be carried out in other parts of the world with larger sample to validate the results.

#### STRENGTH OF THE STUDY

Strict protocol and procedure were followed during the study to eliminate the procedural error.

This study is unique and known to be first of its kind in Davangere, Karnataka, India.

#### FINANCIAL SUPPORT AND SPONSORSHIP

Nil.

#### CONFLICTS OF INTEREST

There are no conflicts of interest.

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