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TABLE OF CONTENTS

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Effect of Light-Emitting Diode on Bond Strength of Orthodontic Brackets

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ABSTRACT

The aim of this study was to evaluate the effect of light-emitting diode (LED) light curing on shear bond strength (SBS) of orthodontic brackets bonded to teeth. Light exposure of 40 seconds from a conventional halogen-based light-curing unit was used as a control. Eighty human premolars were divided into four groups of 20 each. Brackets were bonded to acid-etched teeth with Transbond XT light-cured adhesive. In the first group, the adhesive was light cured for 40 seconds with a conventional halogen unit (XL3000, 3M). In the other three groups, adhesive was cured with a commercial LED unit (Elipar FreeLight, 3M ESPE) for 10, 20, or 40 seconds. SBS of brackets was measured on a universal testing machine and recorded in megapascals. Adhesive remnant index (ARI) scores were determined after failure of brackets. Data were analyzed using analysis of variance and chi-square tests. No statistically significant differences were found among the SBS values of halogen-based light-cured (13.1 ± 3.1 MPa) and 20- and 40-second LED-cured (13.9 ± 4.8 MPa and 12.7 ± 5.1 MPa) specimens ($P > .05$). However, 10 seconds of LED curing yielded significantly lower SBS ($P < .05$). No statistically significant differences were found between the ARI scores among groups. The results of this study are promising for the orthodontic application of LED-curing units, but further compatibility and physical characteristic studies of various orthodontic adhesives and clinical trials should be performed before validation.

KEY WORDS: LED, Bond strength, Bracket bonding.

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INTRODUCTION Return to TOC

The desire to cure on demand is driving an increasing number of orthodontic practices to use light-cure adhesives instead of the more traditional two-paste adhesives that require in-office mixing. In light-cure adhesives, the curing process begins when a photoinitiator is activated. The first products were cured with ultraviolet light and the later versions with visible light, which has a wavelength between 400 and 500 nm. An advantage of visible light is the greater depth of polymerization achieved in shorter periods.[1]

Most dental photoinitiator systems use camphoroquinone as the diketone absorber, with the absorption maximum in the blue region of the visible light spectrum at a wavelength of 470 nm.[2] Currently, the most popular method of delivering blue light is the use of halogen-based light-curing units.[3] Halogen bulbs produce light when electric energy heats a small tungsten filament to high temperatures.[4] Despite their common use in dentistry, halogen bulbs have several disadvantages. The basic principle of light conversion by this technique is inefficient because the light power output is less than 1% of the consumed electrical power and because they have a limited effective lifetime of approximately 100 hours due to the degradation of the bulb's components by the high heat generated.[3,5–7]

In 1995, Mills et al[3] proposed solid-state light-emitting diode (LED) technology for the polymerization of light-activated dental materials to overcome the shortcomings of halogen visible light–curing units. LEDs use junctions of doped semiconductors to generate light instead of the hot filaments used in halogen bulbs.[8] LEDs have a lifetime of over 10,000 hours and undergo little degradation of output over this time.[9] LEDs require no filters to produce blue light, are resistant to shock and vibration, and take little power to operate.[3] LEDs' longer lifespan and more consistent light output compared with halogen bulb technology show promise for dental applications.[4]

Previous research[3,10,11] on the dental application of LEDs compared with halogen-based light-curing units demonstrated that, at the same irradiance, LEDs perform as well as or better than halogen lights. A recent study by Dunn and Taloumis[4] demonstrated that the two different commercial LED light–curing units provided a power density of 150 mW/cm^2 bonded brackets to etched tooth enamel as well as halogen-based light-curing units. However, Dunn and Taloumis suggested that additional clinical studies should be performed before routine use of commercial LED light–curing units can be recommended for orthodontic bonding. There is a lack of information about the compatibility of LEDs with orthodontic adhesives and the optimum curing time required. Moreover, a review of the literature revealed no studies about effect of LED curing on orthodontic adhesives with various exposures times.

The aim of this study was to evaluate the effect of 10, 20, and 40 seconds of LED light curing from a commercial curing unit, which operates at a power density of 400 mW/cm^2, on the shear bond strength (SBS) of orthodontic brackets bonded to teeth. Light exposure of 40 seconds from a conventional halogen-based light-curing unit was used as a control.

MATERIALS AND METHODS Return to TOC

Eighty noncarious human premolars extracted for orthodontic indications were used in this study. Teeth with hypoplastic areas, cracks, or gross irregularities of the enamel structure were excluded from the study. The teeth were stored in distilled water after extraction. The water was changed weekly to avoid bacterial growth. The sample was randomly divided into four groups of 20 teeth each. Each tooth was mounted vertically in a self-cure acrylic so that the crown was exposed. The buccal enamel surfaces of the teeth were polished with nonfluoridated pumice and rubber prophylactic cups and then washed and dried before the bonding procedure. A 37% phosphoric acid gel (Email Preparator, Vivadent, Liechtenstein) was used to etch premolars for 30 seconds. The teeth were then rinsed with water for 30 seconds and dried with an oil-free air source for 20 seconds. In all cases that were etched, the frosty white appearance of etched enamel was noticed.

Bonding

Eighty stainless steel premolar brackets (Generous, GAC, York, Pa) with a mesh base surface area of 12.6 mm^2 were used for this study. After surface preparation, the brackets were bonded on premolars with Transbond XT (3M Unitek, Monrovia, Calif), and any excess resin was removed with an explorer before the resin was polymerized.

A conventional halogen light source (XL3000, 3M Dental Products, St Paul, Minn) was used for curing for a total of 40 seconds (20 seconds from the mesial and the distal side each) in group 1. In groups 2, 3, and 4 a commercial LED curing light (Elipar FreeLight, 3M ESPE, Seefeld, Germany) was used for 10, 20, and 40 seconds, respectively (total curing time was halved for equal curing times from the mesial and the distal side each). Both units had built-in radiometers for testing the adequacy of light intensity emitted. In the XL3000 unit, intensity was confirmed by blinking its green LED before each exposure. The FreeLight unit has a five-stage LED indicator, indicating the level of intensity of light emitted, with all five LEDs being on when the intensity is at a maximum. The light intensity of the LED unit was at its maximum before each exposure. Descriptive information about the light sources and their respective technical information are given in Table 1. After complete sample preparation, all samples were kept in distilled water at 37°C for 24 hours for short-term storage.[12]

Testing

Before debonding, the embedded specimens were secured in a jig attached to the base plate of a universal testing machine (Model 500, Testometric, Lancashire, UK). A chisel-edge plunger was mounted in the movable crosshead of the testing machine and positioned such that the leading edge aimed the enamel-adhesive interface before being brought into contact at a crosshead speed of 0.5 mm/min. The force required to dislodge the brackets was measured in Newtons, and the SBS (1 MPa = 1 N/mm^2) was calculated by dividing the force values by the bracket base area (12.6 mm^2).

After being debonded, the teeth and brackets were examined under 10× magnification. Any adhesive that remained after bracket removal was assessed and scored according to the modified adhesive remnant index (ARI).[13]

Statistical analysis

Descriptive statistics that included the mean and standard deviation values were calculated for the test groups. A one-way analysis of variance (ANOVA) and Duncan tests were used to determine whether significant differences in the bond strengths were present among the groups. The chi-square test was used to determine significant differences in the ARI scores among groups. Significance for all statistical tests was predetermined at a probability value of .05 or less.

RESULTS Return to TOC

Shear bond strength comparisons

Table 2 shows the descriptive statistics for the SBSs of the four groups tested. ANOVA revealed statistically significant differences among the groups tested. Furthermore, Duncan tests revealed that the bond strength values produced by the conventional halogen (13.1 ± 3.1 MPa), 20-second LED (13.9 ± 4.8 MPa), and 40-second LED (12.7 ± 5.1 MPa) groups were not statistically different. However, SBS values of the 10-second LED group (9.1 ± 3.1 MPa) were significantly lower than those of the other test groups ($P < .05$).

The survival graph (Figure 1) indicates that half the brackets remain bonded at 13 MPa in the conventional halogen and 20-second LED groups, at 11.5 MPa in the 40-second LED group and at nine MPa in the 10-second LED group.

ARI comparisons

The results of the chi-square comparisons indicated that there were no significant differences between the four groups tested (Table 3) ($P = .750$). There was a greater frequency of ARI scores of 1 (all adhesive remained on tooth) in all groups, which indicated that failures were mainly in the adhesive-bracket interface.

DISCUSSION Return to TOC

LEDs are being aggressively marketed; however, independent research has not yet verified the potential of this technology to replace halogen visible light–curing units.[4] Optimal cure times for LEDs and their ability to cure all resins are still unknown.[14] A number of studies have confirmed the potential of LED technology for the light activation of dental materials. Fujibayashi et al[10,11] detected no differences in composite hardness and depth of cure between the LED and a halogen unit and obtained a deeper cure with the LED of 470-nm wavelength than with the halogen light at 10, 20, 40, and 60 seconds. Mills et al[3] compared a light source containing 25 LEDs with a halogen unit adjusted to an irradiance of 300 mW/cm^2. The LED unit cured composite specimens to a significantly greater depth than did the halogen unit when tested at 40 and 60 seconds.[3] The LED unit used in this study had 19 LEDs placed in three respective planes.

Mean power densities of the light-curing units used in this study are presented in Table 1. The halogen-based light-curing unit had a higher mean power density than the LED-curing unit. However, SBS values achieved with the same (40 seconds) or lower (20 seconds) LED exposures were not statistically different from halogen-based curing light. Fujibayashi et al[11] demonstrated that the quality of light polymerization is not exclusively due to the light intensity. The narrow absorption peak of the initiator system must also be taken into account. This makes the emitted spectrum an important determinant of a curing light's performance. The absorption curve of camphoroquinine extends between 360 and 520 nm, with its maximum at 465 nm. It has been shown that within this range, the optimal emission bandwidth of the light source lies between 450 and 490 nm.[15] With conventional curing devices, a major portion of the photons is emitted outside the optimal spectrum range for light curing. These photons cannot, or can only with reduced probability, be absorbed by camphoroquinine. In contrast, 95% of the emission spectrum of blue LEDs is situated between 440 and 500 nm. Furthermore, the emission maximum of the blue LEDs used in this study is approximately 465 nm, which is almost identical to the absorption peak of camphoroquinine. These factors may explain the similar SBS values obtained by LED with shorter exposure.

At clinically realistic irradiances, a modestly greater depth of cure was found when composites were polymerized with an LED lamp in comparison with a halogen lamp, despite the former having a measured output approximately 70% of the latter (276 vs 388 mW/cm^2 when measured between 410 and 500 nm).[3] Knezevic et al[16] demonstrated only a minor increase in conversion degree values when 66× stronger halogen-curing units were compared with an LED with a minimal intensity of 12 mW/cm^2. This finding also supports the importance of considering the emission spectra of curing lamps relative to the absorption spectrum of camphoroquinine when assessing the quality of light polymerization.

The ARI scores indicated that, regardless of light-curing type, most of the composite remained on the tooth after bracket debonding. This type of failure suggests that the weak link in the adhesive chain was between the bracket base and the composite. This implies that resin penetrated into the undercuts of the bracket base and was unable to resist the shear stresses when not fully cured. However, this situation does not bias the data because the same adhesive was used for all test groups, and the research parameter is the ability of different light source–curing time combinations to polymerize this adhesive. Regarding statistically significant differences between short and long curing times, it is clear that the adherence of composite to the bracket base was related to the cure of the resin. The bond between etched enamel and composite was generally adequate with any of the light-curing units evaluated.

According to the results of previous research, commercial LED-curing units do not polymerize any faster than halogen-based lights.[4] However, the present study suggests that 20 seconds of LED exposure may yield SBS values comparable with those obtained by halogen-based units in 40 seconds. On the other hand, when these results are compared with those of previous research, this commercial LED does not polymerize faster than xenon plasma lamps.[17] Xenon plasma arc lights have demonstrated markedly reduced curing times: exposures of six to nine seconds produce SBSs and surface hardness values equal to those produced with 40-second exposures to a conventional tungsten-quartz halogen light.[17,18]

The LEDs, however, have certain advantages over both halogen- and plasma arc–curing lights. They are cordless, smaller, and lighter, with estimated lifetimes of over 10,000 hours, and they do not require a noisy cooling fan.[9] Moreover, LED technology is still developing, and high-intensity LED-curing lights are being introduced to the market. According to Dunn and Taloumis,[4] halogen-based light-curing units may be replaced by LEDs as semiconductor technology improves. Consequently, laboratory studies involving LED technology will increase. The laboratory assessment of bond strength cannot predict clinical performance, but it is a valuable screening tool.[12] The results of this study are promising for the orthodontic application of LED-curing units, but further compatibility and physical characteristic studies of various orthodontic adhesives and clinical trials should be performed before validation. Studies are under way in our clinic to test the compatibility of different adhesives with LEDs under clinical conditions.

CONCLUSIONS Return to TOC

This study investigated the effect of 10, 20, and 40 seconds of LED exposure on the SBS of orthodontic brackets and used 40 seconds of halogen-based light exposure as control. Within the limitations of this study, the results suggest that LED curing of 20 and 40 seconds yields SBS values that are statistically similar to those of 40 seconds of halogen-based curing in vitro. However, 10 seconds of LED curing resulted in significantly decreased SBS values. There were no significant differences in the ARI scores of any of the light-curing units tested. Most of the remnant composite adhesive remained on the etched enamel surface.

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TABLES Return to TOC

TABLE 1. Light-Curing Units Tested

Light	Type	Tip (mm)	Energy Consumption	Power Density (mW/cm²)[a]	Serial No.
XL 3000	Halogen	13	75 W	550	120277
Elipar FreeLight	Light-emitting diode	8	0.75 W in standby mode	400	939.800.008.375

[a] Power densities are manufacturer information (3M Espe).

TABLE 2. Descriptive Statistics and the Results of the Duncan's Multiple Range Test Comparing the Shear Bond Strengths (in MPa) of the Four Groups Tested

Groups Tested	Mean (MPa)	SD[a]	Range (MPa)	Test*
XL 3000, 40 s	13.1	3.1	8.2–20.4	A
FreeLight, 10 s	9.1	3.1	4.1–14.6	B
FreeLight, 20 s	13.9	4.8	7.3–22.0	A
FreeLight, 40 s	12.7	5.1	6.5–23.2	A

[a] SD = standard deviation.

* Groups with different letters are statistically significantly different.

TABLE 3. Frequency Distribution of the Adhesive Remnant Index (ARI) Scores and the Chi-Square Comparison of the Four Groups Tested

	ARI Scores						
Groups Tested	1	2	3	4	5	*n*	Test*
XL 3000, 40 s	17	2	—	1	—	20	Not significant
FreeLight, 10 s	10	5	1	2	2	20	
FreeLight, 20 s	11	4	1	2	2	20	
FreeLight, 40 s	11	4	2	1	2	20	

ARI scores: 1 = all of the composite, with an impression of the bracket base, remained on the tooth; 2 = more than 90% of the composite remained; 3 = more than 10% but less than 90% of the composite remained on the tooth; 4 = less than 10% of composite remained on the tooth surface; 5 = no composite remained on the enamel.

FIGURES Return to TOC

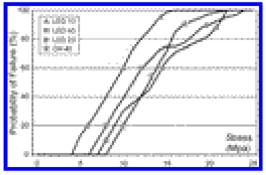

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FIGURE 1. Probability of failure of different curing methods at particular shear stress values

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