Original Article

Shear Bond Strength and Temperature Rise of Orthodontic Brackets Bonding by Using a New 3-Second LED Mode

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ABSTRACT

Objective: The aim of this study was to evaluate the effects of different curing times of a light-emitting diode (LED) on the bond strength of stainless steel brackets and to evaluate the temperature changes in the pulp chamber during curing of the composite.
Materials and Method: Caries-free human first premolar and maxillary central incisor teeth extracted for orthodontic and periodontal reasons were used. For the temperature-measurement test, 60 incisor teeth were randomly divided into 3 groups (n=20), and 60 premolar teeth were used in 3 groups (n=20) for shear bond strength (SBS) testing. Three light sources—quartz tungsten halogen, LED, and LED in Xtra Power Quadrant mode—were used for polymerization of Transbond XT. Temperature variations were recorded by J-type thermocouple. For SBS testing, a universal testing machine was used. Statistical analyses were performed by χ^2, ANOVA, and Holm-Sidak tests at $p < 0.05$ level.
Results: The results of the SBS test revealed no statistically significant (p=0.305) differences between the halogen and LED groups. The conventional halogen light resulted in significantly ($p<0.01$) higher intrapulpal temperature changes.
Conclusions: This study showed that high-intensity curing devices (3-seconds mode) can safely be used in bonding orthodontic brackets to teeth without causing a harmful effect on the dental pulp. (*Turkish J Orthod* 2013;26:45–50)

KEY WORDS: Bond strength, LED, Temperature rise

INTRODUCTION

Light-polymerized orthodontic composites allow for ease of bracket placement and removal of excess resin.[1,2] Bonding with light-cured adhesives has become popular among orthodontists due to the ease of use and the time allowed for exact bracket positioning.[2,3]

Most dental photo initiator 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.[4] This is the region of the visible light spectrum, which includes the quartz tungsten halogen light (QTH), light-emitting diodes (LED), the argon laser, and the xenon plasma arc light (PAC). Although halogen bulbs have numerous disadvantages, QTH light was commonly used in dentistry for nearly four decades. The basic principle of light conversion by this technique is ineffective because the light power output is less than 1% of the consumed electrical power, and QTH bulbs have a limited effective lifetime of about 100 hours because of the degradation of the bulb's components by the high heat generated.[4–6] The PAC and laser have a reduced polymerization time; on the other hand, their equipment cost remains high.

LED systems were proposed as an alternative curing system in 1994.[7] They are now well known by orthodontists and have a cost comparable with that of other light curing units. There are numerous advantages to using LEDs: they have a lifetime of over 10,000 hours with relatively little degradation, they require little power to operate, they are resistant to shock and vibration, and they require no filters to produce blue light.[8,9] Undoubtedly, LED systems are excellent systems for curing orthodontic composites.

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Recently, a high-intensity LED unit (Valo Ortho) has been introduced onto the market. The manufacturer claims that this unit combines all the advantages of its predecessors and provides a significant reduction in the exposure time needed to bond orthodontic attachments in Xtra Power Quadrant mode (3200 mW/cm^2), which uses only a 3-second burst of energy. A reduced curing time means reduced chair time, thereby improving patient comfort during the orthodontic bonding process. Reducing the amount of curing time is a great advantage to both the orthodontist and the patient. However, there is as yet no available information on the *in vitro* or *in vivo* behavior of the Valo Ortho for this curing time. No research has been published in the literature that has evaluated and compared the shear bond strength (SBS) values and adhesive remnant index (ARI) scores of orthodontic brackets bonded with Xtra Power Quadrant mode.

Zach and Cohen[10] showed that, with their chosen experimental technique, a rise of 5.5°C in pulp caused considerable damage, resulting in a loss of nearly 15% of pulp vitality. They also reported that an increase of $\geq 11°C$ incessantly resulted in necrosis. Even a small rise in pulpal temperature, irrespective of its cause, seems to produce histological evidence of pulpitis of variable severity in animal studies.[11]

The aim of this study was to evaluate the effects of different curing times of an LED on the bond strength of stainless-steel brackets and to evaluate the temperature changes in the pulp chamber during bracket bonding. The null hypotheses to be tested were that there are no statistical significances in (1) the bond strength and (2) the failure site location of Xtra Power Quadrant Mode (3200 mW/cm^2) in 3 seconds.

MATERIALS AND METHOD

Shear Bonding Testing

Sixty noncarious human upper premolars extracted for orthodontic indications were used in this study. Teeth with cracks, hypoplastic areas, or gross abnormalities 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 3 groups of 20 teeth each. Each tooth was embedded vertically in a self-cure acrylic so that the crown was exposed. The buccal enamel surfaces of the teeth were cleaned then polished with nonfluoridated pumice (Pressage; Shofu, Inc, Kyoto, Japan) in a low-speed handpiece and rubber prophylactic cups for 15 seconds and then washed and dried before the bonding process. A 37% phosphoric acid gel (Scothbond Etchant; 3M ESPE, London, ON, Canada) was used to etch premolars for 40 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 was observed on the etched enamel premolar buccal surface.

Sixty stainless-steel upper premolar brackets (American Orthodontics, Sheboygan, WI, USA) with a mesh base surface area of 12.6 mm^2 were used for this research. After surface preparation, the brackets were bonded to upper premolars with Transbond XT (3M Unitek, Monrovia, CA, USA) according to the manufacturer's recommendations. All bonding procedures were performed by the same operator (S.K.B.), who used a pair of pliers (Dentaurum Group, Ispringen, Germany), and the excess material was removed with a scaler (Dentaurum Group). A conventional halogen light source (Hilux 350; Express Dental Products, Toronto, ON, Canada) 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 and 3, a high-intensity LED unit (Valo Ortho, Opal Orthodontics, South Jordan, UT, US) was used for curing for 20 and 3 seconds, respectively. In group 3, exposure time was determined in Xtra Power Quadrant Mode (3200 mW/cm^2). The light intensity of the LED unit was at its maximum before each exposure. After photo activation, the samples were stored in distilled water at 37°C for 24 hours for short-term storage.

Before debonding procedure, the embedded specimens were secured in a jig attached to the base plate of an Instron testing machine (Instron Corp, Canton, MA, USA). A chisel-edge plunger was mounted in the movable crosshead of the testing machine and positioned such that the leading edge aimed at the enamel-adhesive interface before being brought into contact at a crosshead speed of 0.5 mm/min. Where possible, testing was carried out following the recommendations of Fox *et al*.[12]

After debonding, all teeth and brackets were examined under a stereomicroscope (SZ 40; Olympus, Tokyo, Japan) at ×10 magnification. The amount of adhesive remaining on the enamel surface was coded using the criteria proposed in the ARI of Artun and Bergland.[13]

Table 1. Descriptive statistics and results of ANOVA test comparing the shear bond strength of 3 groups tested (n=20)

Groups Tested[a]	Mean, MPa	SD	Minimum	Maximum	ANOVA Comparisons (Significance)
Group 1	15.232	4.370	9.726	21.431	
Group 2	13.288	4.418	6.476	21.373	$p = 0.305$
Group 3	13.089	4.262	5.868	20.693	

[a] Group 1, quartz tungsten halogen 40 seconds; Group 2, light-emitting diode (LED) 20 seconds; Group 3, LED in Xtra Power Quadrant mode 3 seconds.

Thermocouple Testing

Sixty maxillary central incisors extracted for periodontal reasons were used for this evaluation. Pulp chamber locations were evaluated with periapical radiographic films by using calibrated calipers. Periapical radiographs for all teeth were made with the same X-ray unit (60 kV, 10 mA; Siemens, Munich, Germany). After radiographic evaluation, teeth with atypically large or small pulp chambers were excluded from the study.

The maxillary central incisors were divided into 3 groups of 20 teeth each. The root portions were sectioned about 2 mm below the cement-enamel junction perpendicular to the long axis of the teeth. The opening was made in the pulp chamber of each tooth at the bifurcation as needed to insert the thermocouple wire.

A 37% phosphoric acid gel (3M Dental Products, St Paul, MN, USA) was applied to teeth for 30 seconds, then the teeth were rinsed with water for 30 seconds and dried with an oil-free source for an additional 30 seconds. Metallic orthodontic brackets (American Orthodontics) were bonded by using Transbond XT adhesive, excess composite was amenably removed before curing, and light curing was performed with 3 light modes. The light curing was done in a manner similar to that of the shear bond testing groups: group 1, QTH (Hilux 350) for 40 seconds; group 2, LED light (Valo Ortho) for 20 seconds; and group 3, LED light (Valo Ortho) for 3 seconds in Xtra Power Quadrant Mode (3200 mW/cm^2).

A J-type thermocouple wire of 0.36-in diameter (Omega Engineering, Stamford, CT, USA) was placed in the pulp chamber during the light-curing processes, and a data logger (XR440-M Pocket Logger; Pace Scientific, Mooresville, NC, USA) was used to transfer data to the computer during the bonding procedure. The thermocouple wire was put into the pulp chamber by touching the center region of the roof.

For each group, temperature variation was determined as the change from reference point temperature to the highest or lowest temperature recorded after the various light-curing procedures. A positive temperature variation value indicated an increase in pulp temperature, whereas a negative temperature variation value indicated a decrease in pulp temperature. A temperature increase of 5.5°C was established as the reference point value, above which Zach and Cohen[10] reported pulpal damage.

Statistical Analysis

All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS for Windows 13.0; SPSS, Chicago, IL, USA). When the p value was less than 0.05, the statistical test was determined as significant.

Descriptive statistics, including the mean, SD, and minimum and maximum values, were calculated for the 3 groups of teeth tested. The Shapiro-Wilks normality test and the Levene variance homogeneity test were applied to the SBS data. The data showed normal distribution, and there was homogeneity of variances among the groups. Comparisons of the means of the SBS values were made with ANOVA. Fracture modes were analyzed using a Pearson χ^2 test. Descriptive statistics, one-way analysis of variance (ANOVA) and Holm-Sidak tests were used to determine statistically significant differences in temperature rise in pulp chamber for different curing units.

RESULTS

Descriptive statistics for SBS values, including the mean, SD, and minimum and maximum values for each of the 3 groups, are presented in Table 1. The results demonstrated that group 1 (15.232 ± 4.370 MPa) had higher SBS values than group 2 (13.288 ± 4.418 MPa) and group 3 (13.089 ± 4.262 MPa; p=0.305). No statistically significant differences were found between any of the 3 groups

Table 2.   Frequency of distribution of adhesive remnant index (ARI) scores (%)

Group Tested[a]	n	ARI Score[b]				Pearson χ^2
		0	1	2	3	
Group 1	20	3 (15%)	13 (65%)	2 (10%)	2 (10%)	Not significant (p=0.276)
Group 2	20	5 (25%)	8 (40%)	2 (10%)	5 (25%)	
Group 3	20	9 (45%)	7 (35%)	2 (10%)	2 (10%)	

[a] Group 1, quartz tungsten halogen 40 seconds; Group 2, light-emitting diode (LED) 20 seconds; Group 3, LED in Xtra Power Quadrant mode 3 seconds.
[b] ARI scores: score 0, no adhesive left on the tooth; score 1, less than half of the adhesive left on the tooth; score 2, more than half of the adhesive left on the tooth; and score 3, all adhesive left on the tooth, with a distinct impression of the bracket mesh.

(p=0.305). Thus, the first null hypothesis of this study cannot be rejected.

The ARI scores for the various groups tested are listed in Table 2. The results of the χ^2 comparisons indicate that there were no statistically significant differences between any of the 3 groups (p=0.276). Therefore, the second null hypothesis was accepted.

The results of the ANOVA test and the Holm-Sidak method showed statistically significant differences in temperature rise between the various groups tested (p<0.001; Table 3). The greatest temperature rises were observed during photo activation of orthodontic composite resin with QTH curing (4.84°C ± 0.89°C), followed by LED curing in 20 seconds (3.68°C ± 1.14°C); the lowest temperature rise was with LED curing in Xtra Power Quadrant mode (2.06°C ± 0.82°C).

DISCUSSION

In the bonding procedure for orthodontic brackets, the most crucial factor is whether the adhesive composite has reached a level of polymerization that will sufficiently keep the brackets secured to the teeth when orthodontic forces are applied. Direct bonding in orthodontics using halogen light sources is a common procedure in the routine of orthodon-

tists, but the use of other light sources, like LED units, has also come to be a standard and usual practice for bracket bonding. Taking in view some advantages and differences among halogen light- and diode-curing units, the present *in vitro* study compared the SBS of brackets bonded with different curing times, such as the extra-short time of 3 seconds. QTH was used as the positive control material, with an exposure time of 40 seconds, in order to compare the new curing time in an LED device with one of the most powerful conventional halogen-based devices.

The factors that affect curing light power are power density, beam collimation and uniformity, optical waveguides, light rate equations, and diffusion through composite. The Hilux 350 halogen light, with an 11-mm curing guide, produced a power density of 350 mW/cm^2, whereas Valo Ortho LED unit, without a light guide, produced a power density of 1200 mW/cm^2 in standard power mode and produced a power density of 3200 mW/cm^2 in Xtra Power Quadrant mode. All of these factors lead to greater effectiveness and shorter curing times for the LED units.

The aim of orthodontics is not only to develop a perfect occlusion, but also to maintain the normal function of the temporomandibular joint. Many

Table 3.   Descriptive statistic of temperature rise in pulp chamber during polymerization by different curing units and results of ANOVA and Holm-Sidak tests

Groups Tested[a]	n	Mean, MPa	SD	ANOVA	Holm-Sidak Method (Critical Level)		
					Group 1	Group 2	Group 3
Group 1	20	4.84	0.89	****		0.050	0.017
Group 2	20	3.68	1.14		0.050		0.025
Group 3	20	2.06	0.82		0.017	0.025	

[a] Group 1, quartz tungsten halogen 40 seconds; Group 2, light-emitting diode (LED) 20 seconds; Group 3, LED in Xtra Power Quadrant mode 3 seconds.
*** p < 0.001.

theories related to the etiology of temporomandibular joint disorders have been presented. Any active force that imposes extreme tension on temporomandibular ligaments may produce permanent stretching of the ligaments, with a resulting wearing down of the condyles.[14] One of the related etiologic factors is prolonged mouth opening during dental appointments[15]; if the mouth is kept open for a long time, it can cause temporomandibular problems. The 3-second curing time reduces chair time, thereby improving patient comfort during the orthodontic bonding process.

The results of the present study suggest that the new Xtra Power Quadrant mode may reduce the time necessary for bonding orthodontic brackets. An exposure time of 3 seconds resulted in SBS values that, *in vitro*, were comparable with those obtained using a high-power halogen lamp for 40 seconds. Previous studies[9,16,17] have demonstrated that LED devices provided equivalent or even superior performance compared to halogen light devices given a 40-second composite curing time.

Clinically, bonded brackets should be able to resist forces generated by treatment mechanics and occlusion and yet allow easy debonding without damage to the teeth.[18,19] A tensile bond strength value of 6–8 MPa would be adequate to resist treatment forces.[20] In this study, the SBS values achieved with the QTH and LED devices at different curing times were above this clinically admissible level.

There was no significant difference in ARI scores among the groups. Besides, the predominant score was 2 (46.6%). This result showed that the majority of failures after debonding occurred at the bracket-adhesive interface, with material remaining adhered to the surface; consequently, enamel was preserved despite the possible trauma.[21–23]

Some concerns have been presented about the use of high-intensity lights. Intense light produces heat on the surface of the teeth during curing. Therefore, this light may cause pulp temperature increases of various degrees. Zach and Cohen[10] found that an intrapulpal temperature increase above the threshold of 16°C leads to pulp necrosis. Furthermore, Hibst and Keller[24] reported that a temperature increase in the pulp chamber of 5.5°C for 1 minute caused irreversible pulpal damage. In orthodontic bonding, the distance from the pulp chamber to the light source is greater. Also enamel and dentin isolate heat and protect the pulp tissue. The current study shows that using the Xtra Power

Quadrant mode for orthodontic bonding appears to be safe from the aspect of increasing pulpal temperatures. At 3 seconds of curing time, *in vitro* pulp chamber temperature increases from LED units in Xtra Power Quadrant Mode were significantly lower than those of the LED (20 seconds) and QTH (40 seconds) lights. The long duration of light increased the heat generated in pulp. Therefore, especially for teeth that have thin enamel and dentin, the short exposure times should be preferred.

The results of the present study showed that LED in Xtra Power Quadrant mode in 3 seconds can be used safely in bracket bonding with reduced light-curing time without affecting the SBS of the brackets and dental enamel. Dall'Igna *et al.*[25] stated that reduction of the curing time is beneficial due to the shorter chair time.

CONCLUSIONS

The results of the present *in vitro* research show that:

- Therewere no statistically significant differences between the SBS values produced with the use of QTH and LED photoactivation during bonding.
- Theuse of LED in Xtra Power Quadrant mode (3200 mW/cm^2) results in a decrease in light-curing time of the composite resin to 3 seconds, with bond strength values clinically acceptable for orthodontic treatment.
- Moreover,no significant differences in debond locations were found among the groups.
- Theintrapulpal temperature changes induced by various light sources were as follows in descending order: QTH, LED (20 seconds), and LED (3 seconds in Xtra Power Quadrant mode).
- Intrapulpaltemperature generated by only light emitted from the Xtra Power Quadrant mode unit during a 3-second composite exposure (2.06°C ± 0.82°C) is significantly less than that of major competitor QTH (4.84°C ± 0.89°C).

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