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Effect of DPSS laser on the shear bond strength of orthodontic brackets

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Abstract

Purpose—To test the bonding of orthodontic brackets to teeth using a diode-pumped solid state (DPSS) laser.

Methods—A total of 60 extracted human teeth were divided randomly into four groups: Group 1 (control) - the brackets were bonded to teeth using the quartz-tungsten-halogen (QTH) light (800 mW/cm^2) for 40 seconds; Groups 2–4 - the brackets were bonded to teeth using the DPSS laser (500 mW/cm^2) for 40 seconds, 20 seconds, and 10 seconds, respectively. The teeth were debonded using shear force in a universal testing machine, and the amount of residual adhesive remaining on each tooth was evaluated. Statistical analysis was carried out for the shear bond strength (SBS) and Adhesive Remnant Index (ART).

Results—The brackets bonded using the DPSS laser for 40 seconds showed the highest mean SBS (13.1±1.2 MPa) among the groups. Furthermore, the DPSS laser with 10 seconds light-curing could achieve 83% of the mean SBS obtained using the QTH light for 40 seconds. The ARI scores showed no differences among all four groups suggesting a similar failure mode.

Introduction

The direct bonding of orthodontic brackets to the teeth is one of the most important advancements in modern dentistry. Three factors affecting the success of bonding are the tooth surface, the design of attachment base, and the bonding material itself. The single-paste light-cured adhesive has become the routine process in orthodontic treatments. The major advantage of light-cure materials is its ease of clinical use. The polymerization process in these materials is very slow prior to the light activation, which provides sufficient working time for bracket positioning. Traditionally, a relatively long curing time (approximately 40 seconds per bracket) is required using QTH (quartz-tungsten-halogen) light. This causes prolonged chair time, creating an inconvenience for both the clinician and the patient.

The light-cured adhesives using the camphorquinone (CQ), photoinitiator, which is activated by blue light, have been developed. Several light systems have been introduced to cure the

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CQ-containing adhesives. These systems include the conventional QTH light-curing unit, the light-emitting diode (LED) unit, the plasma arc unit, and the argon laser. The LED unit emits light with a narrow bandwidth, which matches closely to the absorption peak of CQ.[1–5] The emission spectrum of the plasma arc light is similar to that of the QTH light. The manufacturers suggest a 3 or 5 seconds light-curing time because the light intensity of the plasma arc light is much higher than that of the QTH light. However, incomplete curing/setting of the dental materials has frequently been reported due to the short light-curing time.[6–10] The advantage of an argon laser is its excellent match with the absorption peak of the photoinitiator. Furthermore, because lasers have extremely high monochromaticity and coherence nature (waves in phase), the argon laser can achieve high bond strength compared with the QTH light even with a much shorter light-curing time (5–10 seconds).[11–15] However, due to the high price, the argon lasers are not as popular for light-curing as the QTH light.

To date, diode-pumped solid state (DPSS) lasers are widely used as laser pointers, a light source for the excitation of phycoerythrins (PE), and for the low-level laser light (LLLT) treatments.[16–20] The advantage of DPSS lasers are the compactness, economy, and efficiency over other types of lasers. Nevertheless, DPSS lasers have few applications in dentistry in their recent introduction.[21] The present study examined the effectiveness of the blue DPSS laser as a light-curing source for the direct bonding of orthodontic brackets to the teeth. Its effectiveness was determined by evaluating the shear bond strength (SBS) and compared with that obtained by the conventional QTH light.

Materials and Methods

A total of 60 caries-free human lower premolars were collected and stored in a solution of 0.2% thymol for no more than 3 months. After the detachment of one-quarter of the root and eliminating all soft tissues, the teeth were cleaned and pumiced with a polishing paste for 10 seconds. Each tooth was then rinsed with tap water for 20 seconds.

Two different light sources were used for the investigation: QTH light-curing unit and DPSS laser. For the control, a QTH light-curing unit (Optilux 501[a]) with an intensity of 800 mW/cm^2 was used. For comparison, a DPSS laser[b] with a 500 mW/cm^2 intensity (wavelength: 473 nm; spot size: 6 mm; power: 140 mW) was used for polymerization of the resin adhesive. The emission spectrum of the light sources was measured using a photodetector (M1420[c]) connected to a spectrometer (SpectroPro-500[d]).

The teeth were divided randomly into four groups containing 15 teeth each. The brackets[e] (for upper centrals) were bonded to the teeth according to the manufacturers' instructions as follows. For Group 1 (control), the enamel surfaces were etched for 15 seconds using 37% phosphoric acid (Gel Etch[f]), rinsed with tap water for 15 seconds, dried with air for 15 seconds, followed by the application of the primer (Transbond XT[f]). The resin adhesive in the same product was applied to the bracket base. The bracket was placed onto the enamel surface and then firmly pressed. Any excess adhesive was removed carefully. Light-curing using the QTH light-curing unit was applied for 20 seconds both on the mesial and distal sides (40 seconds in total). For Group 2, the same process used for Group 1 was performed using the DPSS laser instead of the QTH light-curing unit. Light-curing was applied for 20

[a]Kerr, Dansbury, CT, USA.
[b]LVI Technology, Seoul, Korea.
[c]EG&G PARC, Princeton, NJ, USA.
[d]Acton Research, Acton, MA, USA.
[e]Tomy, Tokyo, Japan.
[f]3M Unitek, Monrovia, CA, USA.

seconds both on the mesial and distal sides (40 seconds in total). For Group 3, the same process used for Group 1 was performed using the DPSS laser. Light-curing was applied for 10 seconds both on the mesial and distal sides (20 seconds in total). Group 4. The same process used for Group 1 was performed using the DPSS laser. Light-curing was applied for 5 seconds both on the mesial and distal sides (10 seconds in total). Through the preparation, the end of the light guide and the laser beam was made, facing the bracket at an angle of 90°. In addition, the end of the light guide was positioned as closely as possible to the bracket.

After bonding, the specimens were mounted in acrylic resin and stored in distilled water at 37°C for 24 hours. After storage, the shear bond strength (SBS) of each group was determined using a universal testing machine[g] with a crosshead speed of 1 mm/minute. A steel rod with a flattened end was attached to the crosshead of the test machine. A shear force was then applied parallel to the long axis of the tooth. At this time, the base of the bracket was placed as close as possible to the steel rod. The maximum load to debond the bracket was recorded.

After debonding, the enamel surface of each tooth was examined under an optical microscope to determine the amount of residual adhesive remaining on each tooth. The adhesive remnant index (ARI) was determined as follows (1) all the adhesive remaining on the tooth; (2) > 90% of the adhesive remaining on the tooth; (3) between 10–90% of the adhesive remaining on the tooth; (4) < 10% of the adhesive remaining on the tooth; and (5) there was no adhesive remaining on the tooth.[22]

ANOVA and Tukey's *post hoc* test were used to determine if there was a significant difference in the shear bond strength between the groups. A nonparametric Kruskal-Wallis test was used to test for significant differences in the ARI scores between the groups. A $P < 0.05$ was considered significant.

Results

The Figure shows the emission spectrum of the light sources and the absorption peak of CQ. The QTH light matches broadly with the whole absorption spectrum of CQ but the DPSS laser matches the absorption peak of CQ at the tail part.

Table 1 shows the mean SBS values for the different light-curing conditions. Among the groups, the brackets bonded using the DPSS laser for 40 seconds (total) showed the greatest SBS value (13.1 ± 1.2 MPa). The brackets bonded using the QTH light-curing unit for 40 seconds (total) showed a slightly lower SBS value (12.1 ± 1.2 MPa; control group) than that with the DPSS laser. These two SBS values were not significantly different. The mean SBS value increased with increasing curing time in case of the brackets bonded using the DPSS laser. Within 10 seconds (total) of curing, the DPSS laser could achieve 83% of the mean SBS value of the control group.

Table 2 shows the failure modes of the groups for the ARI tests. According to the statistical analysis (Kruskal-Wallis test), each group showed similar ARI scores indicating similar bracket failure modes ($P > 0.05$). Regardless of the test groups, most of the bond failure was the cohesive type within the adhesive.

[g]Instron Corporation, Canton, MA, USA.

Discussion

Newer curing lights have been introduced offering narrow spectral bandwidth, higher power output and potentially shorter curing times with high polymerization conversion. One light-curing unit used in this study was a QTH lamp-based unit. The blue light emitted from this unit broadly matches the absorption band of CQ, which is the photoinitiator in light-cured dental composites. Tailored light wave 400–500 nm from white light is delivered through a fiber optic light guide with a diameter of 7 mm or more. Delivery of the light using a fiber optic poses two problems: a decrease in light intensity with an increasing distance between the surface of the material and the end of the light-guide. Since light diverges while transmitting, there would be unequal irradiation of light depending on the geometry of the tooth structure.

The other light-curing unit was a DPSS laser. The laser used in this study has a much narrower emission bandwidth and a much lower light intensity than that of the QTH light. However, despite the much lower light intensity or much shorter light-curing time, the DPSS laser achieved similar SBS values. This is attributed to the characteristics of the laser such as coherence (in phase), directionality, and monochromaticity. Since all the photons emitted from the DPSS laser have the same wavelength, the conversion efficiency of the DPSS laser by activating the photoinitiators would be much greater than that of the QTH lamp-based unit. In addition, since the laser has directionality, it may have less light attenuation and divergence within the composite substrate. The similar SBS value from the DPSS laser-treated groups may be due to these reasons. The short light-curing time will benefit both the practitioner and patients by reducing chair time. In a forthcoming test, the possibility of further reducing the light-curing time with a much higher light intensity will be tested to determine if it is possible to obtain clinically acceptable SBS.

The ARI scores in this study were consistent regardless of the difference in the curing light used. According to the observation, all the debonded teeth had adhesive on their surfaces. In a clinical aspect, the remaining adhesive may require considerable chair time to remove. However, the possibility of tooth damage can be reduced by leaving some adhesive on the enamel surface.[23,24] The similar ARI scores among Groups 2–4 may indicate consistent curing effects within the adhesive regardless of the difference in total light-curing time. The low standard deviation (STD) values of the SBS from the DPSS laser-treated brackets may indicate the consistency of light-curing, and such consistency was maintained even after only 10 seconds light-curing.

In conclusion, despite the much lower light intensity of the DPSS laser, the brackets bonded using the DPSS laser for 40 seconds had a slightly higher SBS than that obtained using the QTH lamp-based unit. After only 10 seconds light-curing, the DPSS laser achieved 83% final SBS of the control group. The ARI scores were similar regardless of the different light-curing conditions used. These results suggest that the DPSS laser is effective for the bonding of orthodontic brackets as a light-curing source.

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Clinical significance

Within the limits of the present study, the shear bond strength was higher by the DPSS laser than the conventional QTH light. The DPSS laser can provide fast and high bond strength for bonding brackets to teeth.

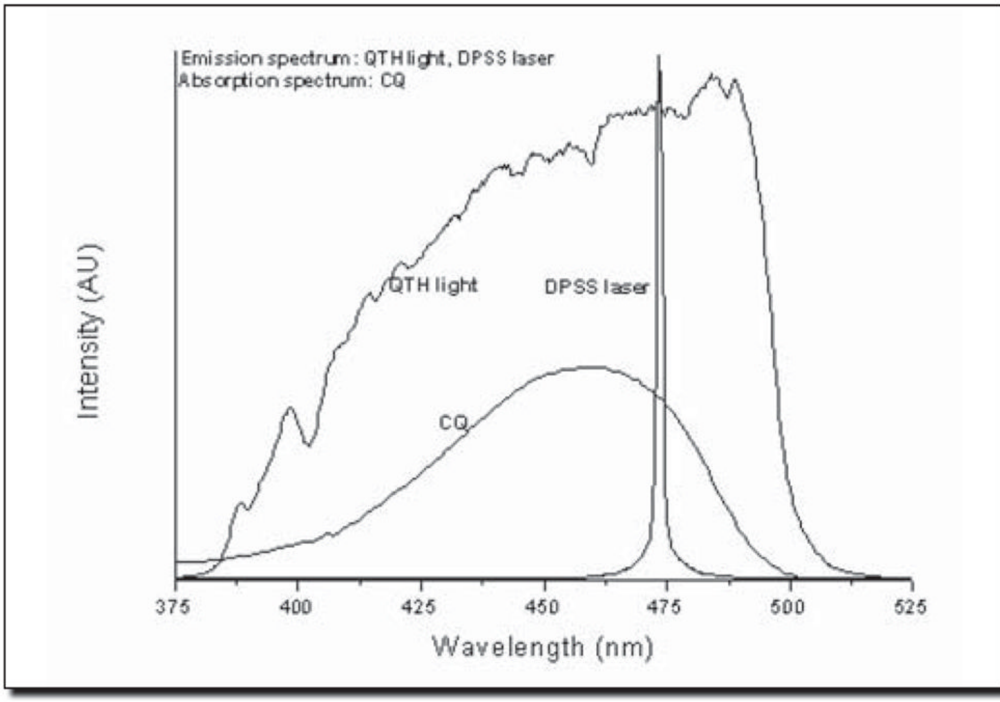

Figure.

The emission spectra of the used lights and the absorption spectrum of caphorquinone(CQ).

Table 1

Shear bond strength by group with different light-curing conditions.

Group	Light-curing condition	SBS (MPa)
C20[ABC]	QTH light; distal 20 seconds/mesial 20 seconds: (QTH 20/20)	12.1 ±1.2
L20[B]	DPSS Laser distal 20 seconds/mesial 20 seconds: (DPSS 20/20)	13.1 ±1.2
L10[CD]	DPSS Laser distal 10 seconds/mesial 10 seconds: (DPSS 10/10)	11.0 ± 1.0
L5[D]	DPSS Laser distal 5 seconds/mesial 5 seconds: (DPSS 5/5)	10.0 ±1.1

*Statistically significant difference of group is shown by superscript letters[A,B]. Same letters are not significantly different ($P < 0.05$).

Table 2

Adhesive Remnant Index (ARI) scores by group with different light-curing conditions.

Group	Light-curing condition	ARI scores*				
		1	2	3	4	5
C20	QTH 20/20	1	4	10	0	0
L20	DPSS 20/20	1	5	9	0	0
L10	DPSS 10/10	1	4	10	0	0
L5	DPSS 5/5	1	3	11	0	0

*There was no significant difference among the groups.

Score 1: All adhesive remaining on the tooth; Score 2: More than 90% of the adhesive remaining on the tooth; Score 3: 10% – 90% of the adhesive remaining on the tooth; Score 4: Less than 10% of the adhesive remaining on the tooth; Score 5: No adhesive remaining on the tooth.