European Journal of Orthodontics 30 (2008) 413–417
doi:10.1093/ejo/cjn013
Advance Access publication 16 July 2008

Temperature rise and shear bond strength of bondable buccal tubes bonded by various light sources

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SUMMARY The objective of the present investigation was to determine the intrapulpal temperature changes and to compare the shear bond strength (SBS) of bondable buccal tubes bonded by high-intensity light sources.

Ninety caries-free human first molar teeth extracted for periodontal reasons were used. For the temperature measurement test, 30 teeth were randomly divided into three groups ($n=10$) whereas 60 teeth were used in three groups ($n = 20$) for SBS testing. Three light sources, high-intensity halogen, blue light-emitting diode (LED), and xenon plasma arc (PAC), were used for polymerization of Transbond XT. Temperature variations (ΔT) were recorded by a K-type thermocouple wire connected to a data logger. For SBS testing, a universal testing machine was used at a crosshead speed of 1 mm/minute until buccal tube bonding failure occurred. Data were analyzed using the Kruskal–Wallis test.

The high-intensity halogen light resulted in significantly ($P < 0.01$) higher intrapulpal temperature changes than the LED or PAC. The results of the shear bond test revealed significant ($P < 0.05$) differences only between the halogen and LED groups.

The findings of the present investigation showed that high-intensity curing devices can safely be used in bonding buccal tubes to molar teeth without causing a deleterious effect on the dental pulp.

Introduction

Light-initiated resin adhesives have become popular in orthodontic bonding because they offer a reduced contamination risk, faster and comfortable fixation of brackets, and bondable buccal tubes (Graber and Vanarsdall, 2000; Sfondrini *et al.*, 2001; Dunn and Taloumis, 2002; Evans *et al.*, 2002; Oesterle *et al.*, 2002; Attilio *et al.*, 2005; Tecco *et al.*, 2005; Vicente *et al.*, 2005).

The clinical performance of visible light-cured adhesives is greatly influenced by the quality of polymerization (Rueggeberg *et al.*, 1994). Light curing units that utilize a higher intensity than conventional halogen units, such as high-intensity halogen, light-emitting diode (LED), and xenon plasma arc (PAC), are recommended for the polymerization of adhesives and resin composites (Read, 1984; Sfondrini *et al.*, 2001; Dunn and Taloumis, 2002; Oesterle *et al.*, 2002; Cacciafesta *et al.*, 2005). However, due to a higher energy output, these new curing lights may cause excessive heat generation in the pulp.

The effect of excessive heat on dental pulpal tissue has been reported to cause pulp injury (Zach and Cohen, 1965; Ulusoy *et al.*, 1991; Silva *et al.*, 2005; Uysal *et al.*, 2005; Uzel *et al.*, 2006). A pulp temperature rise of 5.5°C in Rhesus macaca monkeys had deleterious pulpal effects, whereas an intrapulpal rise of 16.6°C resulted in pulpal necrosis (Zach and Cohen, 1965). A temperature of 5.5°C has been considered as a reference value for possible pulp injury *in vitro* (Ulusoy *et al.*, 1991; Silva *et al.*, 2005; Uysal *et al.*, 2005; Uzel *et al.*, 2006). Goodis *et al.* (1989) measured the increase in temperature when six visible-light curing lamps were tested with exposure times of 20 and 60 seconds and showed that the lamps caused a higher temperature rise within the pulp chamber when the exposure time was extended. Hannig and Bott (1999) found that intrapulpal temperature rise during composite resin polymerization in Class II cavities is increased with high-intensity light sources compared with halogen light sources. Tarle *et al.* (2002) showed that temperature rise was significantly lower when blue LEDs and plasma light were used; plasma light caused minimal temperature rise because of its short exposure time.

Although pulp temperature change during bracket bonding and the shear bond strength (SBS) of bonded brackets have been investigated for incisor and premolar teeth (Silva *et al.*, 2005), there are no scientific reports concerning pulp chamber temperature changes and SBS of orthodontic buccal tubes bonded to molar teeth.

The purpose of the present investigation was to determine the intrapulpal temperature changes during the bonding of orthodontic buccal tubes using different light sources including high-intensity halogen, LED and PAC, and to compare the SBS of orthodontic buccal tubes bonded by these high-intensity light sources.

Materials and methods

In this *in vitro* study, a total of 90 human first molar permanent teeth freshly extracted for periodontal reasons were collected and stored in distilled water for 2 weeks at room temperature with thymol crystals (0.1%) added to inhibit bacterial growth. The teeth were cleaned and polished with fluoride-free pumice slurry and examined to ensure the absence of caries and cracks on the labial surface.

The buccal enamel was etched with 37 per cent orthophosphoric acid (3M Espe, St Paul, Minnesota, USA) for 30 seconds, rinsed with water for 15 seconds, and air dried with oil-free compressed air. Each bondable tube (Platina bondable buccal tubes, GAC International Inc., New York, USA) was bonded using Transbond XT primer and adhesive paste (3M Unitek, Monrovia, California, USA) but separately polymerized by one of the three light sources—group 1 (control): high-intensity halogen; group 2: blue LED using ortho mode; group 3: PAC. The light units and technical details are shown in Table 1.

All molar tubes were bonded by the same operator (ÇU). Half of the exposure time was applied from the occlusal and the other half from the gingival surfaces of the bondable tubes.

The light intensity of the halogen curing unit was checked before each testing procedure with a curing radiometer (Demetron Kerr, Danbury, Connecticut, USA) and that of the LED with an LED curing radiometer (Hilux Ledmax). There was no measurable reduction in intensity for any light during the experiment. The light intensity of the PAC was taken to be that stated by the manufacturer.

For the temperature measurement test, 30 teeth were randomly divided into three groups (n = 10). Before acid etching and bonding, an opening was made in the pulp chamber of each tooth at the bifurcation. After the pulp remnants were removed, the pulp chamber was then filled with dry aluminium powder (Ulusoy *et al.*, 1991) and the roots of the teeth were embedded in silicon putty (Optosil, Heraeus Kulzer, Hanau, Germany). Temperature variations (ΔT°C) were recorded by a K-type thermocouple wire (Testo, Testo AG, Lenzkirch, Germany) which was placed in the pulp chamber (Figure 1). The bifurcation opening was then secured with Cavit G (3M Espe AG, Seefeld, Germany). The thermocouple wire was connected to a data logger (Data Logger Testo 175-T3 V01.10, Testo AG) and the collected data were transferred to a computer during the bonding procedure. The data were available in both tabular and graphic forms. Intrapulpal temperature changes were recorded every 2 seconds.

For the SBS test, the remaining 60 teeth were divided into three groups (n = 20) and the roots of the teeth embedded in standardized 16 × 20 mm acrylic blocks. After bonding was complete, the teeth were immersed in sealed containers of distilled water and kept at 37°C for 72 hours to permit adequate water sorption. A universal testing machine (Instron Corp., Canton, Massachusetts, USA) was used at a crosshead speed of 1 mm/minute. Each bonded buccal tube was positioned in the testing machine parallel to the direction of load application. Force was directly applied to the bondable buccal tube–tooth interface until failure occured. The load at failure was recorded on a personal computer connected to the testing machine. The load at failure was recorded in Newtons (N), and the stress calculated in megapascals (1 MPa = 1 N/mm^2) by dividing the force in N by the area of the buccal tube base. Measurement of the area of the molar tube base, carried out with digital callipers an accurace to 0.01 mm, was 23.88 mm^2.

Data were analyzed using the Kruskal–Wallis test with a significance level of 0.01.

Results

The mean values, standard deviations, and statistical significances of the temperature increases and SBS for the three light curing units are shown in Tables 2 and 3, respectively. The Kruskal–Wallis test revealed that pulp chamber temperature changes were influenced by the light source type ($P < 0.01$). Significantly different bond strength results were found between the halogen and LED groups ($P < 0.05$).

Table 1 Light sources and light intensity output used in the study.

Light source	Light intensity	Tip diameter (mm)	Curing time (s)	Model	Manufacturer	Serial number
Halogen*	700 mW/cm^2	11	20	Hilux Ultra Plus Halogen Curing Light	Benlioğlu Dental Inc., Ankara, Turkey	5111069
Light-emitting diode†	700 mW/cm^2 (Ortho mode)	11	20	Hilux LED Curing Light	Benlioğlu Dental Inc.,	5111072
Xenon plasma arc‡	1850 mW/cm^2	8	6	Remecure Plasma Arc Curing and Whitening Device CL-15E	Remedent NV, Deurle, Belgium	D5054

*Light intensity was measured using a curing radiometer (Model 100, Kerr, USA, serial number 132580).
†Light intensity was measured using a curing radiometer (Hilux Ledmax Dental Curing Light Meter, Benlioğlu Dental Inc., Demetron serial number 4063127).
‡Light intensity was accepted as that stated by the manufacturer.

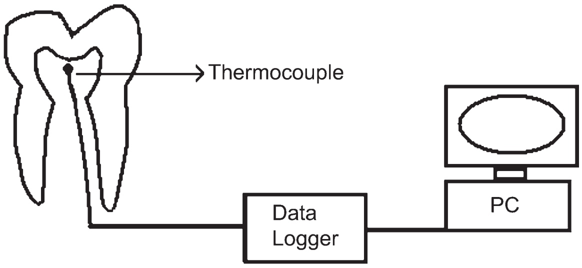

Figure 1 Schematic drawing of the test apparatus.

Table 2 Descriptive statistics of temperature variations (°C) in the pulp chamber during the application of high-intensity light sources.

Group	*N*	Mean	Standard deviation	Minimum	Maximum
Halogen[a]	10	1.44	0.417	0.9	2.1
Light-emitting diode[b]	10	0.52	0.2044	0.2	0.7
Xenon arc light[c]	10	0.30	0.2261	0.1	0.6

Different letters indicate statistically significant differences between the groups.

Table 3 Descriptive statistics for shear bond strength of bondable buccal tubes bonded by high-intensity light sources.

Group	*N*	Mean	Standard deviation	Minimum	Maximum
Halogen[a]	20	8.35	4.24	4.14	18.00
Light-emitting diode[b]	20	5.832	2.341	2.98	11.22
Xenon arc light[ab]	20	6.526	2.266	3.57	10.47

The same letters indicate groups with no significant difference.

Bonding of orthodontic buccal tubes to molar teeth with different light curing sources was below the critical 5.5°C value for pulpal health.

Discussion

The use of direct bonding has reduced and simplified chair time, resulted in less discomfort for the patient, and eliminated caries risk under loose bands (Graber and Vanarsdall, 2000). The bonding of metal orthodontic attachments is primarily through mechanical retention between the bracket base and adhesive interface.

There are many studies on the effects of light sources (Read, 1984; Ulusoy *et al.*, 1991; Rueggeberg *et al.*, 1994; Hannig and Bott, 1999; Harari *et al.*, 2000; Sfondrini *et al.*, 2001; Dunn and Taloumis, 2002; Oesterle *et al.*, 2002; Attilio *et al.*, 2005; Cacciafesta *et al.*, 2005; Nalcacı *et al.*, 2005; Tecco *et al.*, 2005), but little information about intrapulpal temperature rise during orthodontic bonding procedures (Goodis *et al.*, 1989; Tarle *et al.*, 2002; Silva *et al.*, 2005; Uysal *et al.*, 2005; Uzel *et al.*, 2006). Previous research has shown that conventional halogen light sources induce a higher temperature in the pulp chamber as a result of the longer exposure time (Tarle *et al.*, 2002; Uzel *et al.*, 2006). Uzel *et al.* (2006) found that halogen, LED, and PAC light curing lights produced significantly greater heat changes in the incisor than in the premolar teeth, and the temperature increase was significantly higher at closer distances. This increase has been ascribed to the longer exposure time (Tarle *et al.*, 2002). Another study revealed that curing with PAC for 10 seconds resulted in higher intrapulpal temperature than conventional halogen units at 40 seconds (Oesterle *et al.*, 2001).

The use of high-intensity light sources in this study did not cause an intrapulpal temperature change that exceeded the reference values of 5.5°C reported for pulpal injury. The results showed statistically significant differences among the three high-intensity light sources tested (Table 2). Halogen resulted in significantly higher intrapulpal temperature changes than the LED or PAC. Both the halogen and LED were applied for 20 seconds and resulted in significantly different intrapulpal temperatures. This result may be explained by the different properties of these two light sources. In halogen units, only 1 per cent of the total energy input is converted into light with the remaining energy generated as heat. The short life of halogen bulbs and the noisy cooling fan are other disadvantages (Yoon *et al.*, 2002; Turkkahraman and Kucukesmen, 2005). On the contrary, LED units generate minimal heat and have a lifetime of more than 10000 hours, do not need a cooling fan, and are silent (Turkkahraman and Kucukesmen, 2005).

PAC had the shortest exposure time in the present investigation and demonstroted the least temperature change. This result is in agreement with Tarle *et al.* (2002), but in conflict with Hannig and Bott (1999).

Uzel *et al.* (2006) examined possible increases in intrapulpal temperature using high-energy curing lights for orthodontic bonding of human lower incisors. The present results are contrary to their findings because the effects of high-energy curing units on molar teeth were examined. This conflict may be due to the variations in the enamel and dentine of lower incisors and molar teeth. Lower incisors have thinner enamel and dentine on the labial surface than the molars (Jost-Brinkmann *et al.*, 1992; Uzel *et al.*, 2006).

Hannig and Bott (1999) studied the increase in intrapulpal temperature induced during composite resin polymerization applied to Class II restorative preparations on molar teeth, leaving a dentine layer 1 mm thick between the pulp chamber and proximal cavity wall. They reported that PAC resulted in a higher intrapulpal temperature rise at 10 seconds compared with the halogen unit at 40 seconds. In restorative dentistry, composites are bonded to enamel and dentine, different from orthodontic bonding (Uzel *et al.*, 2006). The findings in the present study compared with those of Hannig and Bott (1999) may be explained by the differences in restorative and orthodontic bonding techniques. In the present study, the bondable buccal tubes were applied on enamel and had no connection with dentine, and in addition a thinner adhesive layer was applied between the tube and the tooth. The bondable buccal tube may also be a factor that inhibits the flow of heat.

However, as it is difficult to duplicate *in vivo* conditions *in vitro*, the low temperature rise recorded in this study may not reflect the temperature changes *in vivo*. The effect of blood circulation, dentinal fluid flow, and surrounding periodontal tissues may change the heat transfer to the pulp. On the other hand, actual temperature increases might be higher in younger teeth. For this reason, additional studies are necessary to determine the parameters of light curing that can be safely used in bonding of brackets and tubes during orthodontic treatment of permanent teeth.

Although many studies have evaluated the bond strength of various types of brackets to tooth enamel (Harari *et al.*, 2000; Oesterle *et al.*, 2001; Sfondrini *et al.*, 2001; Evans *et al.*, 2002; Oesterle *et al.*, 2002; Tarle *et al.*, 2002; Attilio *et al.*, 2005; Cacciafesta *et al.*, 2005; Tecco *et al.*, 2005; Turkkahraman and Kucukesmen, 2005; Vicente *et al.*, 2005; Cozza *et al.*, 2006), there is no information about the SBS of bondable buccal tubes in the literature. Reynolds (1975) reported that a bond strength of 5.8–7.8 MPa is more than sufficient for successful orthodontic bonding. The bond strengths of the orthodontic buccal tubes bonded by high-intensity light sources in the present study were at the limit or greater than the clinically acceptable bond strength levels. The bond strength provided by halogen and LED light sources was significantly different in the present study.

Oesterle *et al.* (2001) compared the SBS of brackets exposed to a tungsten–quartz halogen light for 40 seconds with those exposed to a PAC curing light for 3, 6, or 9 seconds but found no statistically significant difference between the curing lights. However, they stated that PAC curing light exposures of 6 or 9 seconds were required to create bond strengths equal to those produced by the tungsten–quartz halogen light. The results of the present study are in agreement with Oesterle *et al.* (2001). Dunn and Taloumis (2002) showed that LED curing units bonded brackets to etched tooth enamel as well as halogen-based light curing units. On the other hand, the present results showed that the high-intensity halogen produced a greater increase in bond strength (8.35 MPa) than the LED (5.832 MPa).

The strength of the bond between the enamel and orthodontic appliance depends on the type of enamel conditioner, acid concentration, etching time, composition of the adhesive, sufficient polymerization of the adhesive, the distance between the light source and the teeth, bracket base design, bracket material, oral environment, and the skill of the clinician (Bishara *et al.*, 2007). The fact that SBS in this investigation was studied *in vitro* and does not simulate the mastication forces and oral conditions that may result in adhesive material failure could be seen as limiting the validity of the results. However, *in vitro* shear bond tests are acceptable in determining the retention capacity without considering *in vivo* conditions.

The results of the present investigation showed that high-intensity curing devices can be safely used in bonding buccal tubes to molar teeth without causing a deleterious effect on the dental pulp. Of primary concern to the clinician is to be able to perform faster and easier bonding procedures. Within the limitations of this study, the PAC system seems to be more advantageous light source because it has a shorter clinical time of operation, causes the lowest temperature change in the pulp chamber of molar teeth, and has an acceptable SBS. Clinicians should consider all the advantages and disadvantages of the curing lights available on the market and be aware of how these lights perform for different teeth.

Conclusions

Intrapulpal temperature changes of molar teeth during bonding of buccal tubes with high-intensity light sources were recorded *in vitro*. The following conclusions were drawn: (1) The use of high-intensity light sources did not cause an intrapulpal temperature change which would exceed the reference values of 5.5°C reported for pulpal injury. (2) Statistically significant differences were found among the three high-intensity light sources tested. Halogen induced significantly higher intrapulpal temperature changes than the LED or PAC. (3) The results of the present investigation showed that high-intensity curing devices can be safely used in bonding buccal tubes to molar teeth without causing a deleterious effect to the dental pulp. (4) The bond strength provided by halogen and LED light sources was significantly different. (5) Within the limitations of this study, the PAC system seems to be an advantageous light source because it has a shorter clinical time of operation, causes the lowest temperature change in the pulp of molar teeth, and has an acceptable SBS.

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