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ORIGINAL ARTICLE

Temperature increase during orthodontic bonding with different curing units using an infrared camera

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Abstract

Aim. To evaluate the effects of different curing units and light-tip tooth surface distances on the temperature increase generated during orthodontic bonding, using an infrared camera (IR) and artificial neural networks (ANN). ***Materials and methods.*** Fifty-two freshly extracted human premolar teeth were used. Metallic orthodontic brackets were bonded to the buccal surfaces of the teeth and thermal records were taken using an IR camera and ANN. Brackets were cured with a light-emitting diode (LED) and high intensity halogen (HQTH). Teeth were divided into four groups according to the curing units (LED and HQTH) and curing distances (from tooth surface and 10 mm away from tooth surface). The results were analyzed with analysis of variance (ANOVA) and the Tukey HSD test. ***Results.*** The ANOVA and Tukey HSD tests revealed that temperature changes were influenced by the type of light source and exposure times. All groups revealed significant differences between each other ($p < 0.001$). The highest surface temperature increase was gained from curing with a LED unit from the tooth surface (11.35°C ± 0.91°C). The lowest surface temperature increase was gained from curing with a HQTH unit 10 mm away from the tooth surface (2.57°C ± 0.6°C). ***Conclusion.*** The LED unit induced significantly higher temperature changes than did the HQTH. The temperature increase during orthodontic bonding was increased with long exposure time. A shorter light-tip tooth surface distance leads to greater increases in temperature.

Key Words: *temperature, image processing, thermography, bonding, infrared*

Introduction

Light-cured composite materials are now popular among orthodontists as the excess adhesive around the bracket could be easily removed and the bracket could be accurately positioned [1]. Many factors may affect the polymerization of light-cured bonding materials, such as light intensity, curing times [2] and distance from the light guide to the adhesive [3]. Higher bond strengths were demonstrated with the increasing polymerization times [4,5]. This result was attributed to the higher conversation rate of monomer to polymer at increased polymerization times [4].

Light emitting diode (LED), argon-laser, high intensity, low intensity and plasma arc light curing units have become commercially available in recent years [6]. These curing units are recommended for the polymerization of adhesives and resin composites. Quartz-tungsten-halogen (QTH) and LED units are widely used light sources for photo-activation and QTH lights with higher light intensities (HQTH) have important potential for usage in dentistry. However, due to higher energy output, these new curing lights may cause excessive heat generation in the pulp [7]. Temperature rise occurs as a result of heat output of the curing unit and the exothermic reaction of the material during polymerization [8,9]. Hussey et al. [10] indicated that the dental pulp may be endangered by the temperature rise that occurs during light curing. Zach and Cohen [11] reported that a temperature rise of 5.5°C within the pulp chamber could lead to irreversible pulp damage. In another study following such a temperature rise, 15% of the pulps of small teeth become necrotic, when the intra-pulpal temperature rise was 11°C, in 60% of the teeth the pulps did not recover [12]. Even a small increase in pulp temperature seems to produce evidence of pulpitis of varying severity in animals [7]. So, a temperature rise during bonding can cause detrimental effects to patients.

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The factors effecting the heat generation during polymerization are; (1) the type of light source, (2) exposure time, (3) composite resin thickness and (4) distance between light source and the pulp [5,13–15]. Hannig and Bott [8] reported that high intensity light curing units lead to a greater intra-pulpal temperature rise compared with halogen light sources. On the other hand, lower temperature rises were reported when LEDs and plasma arc light (PAC) were used instead of halogen lights because of their short exposure times [16]. Uzel et al. [17] reported greater temperature increases with halogen lights and closer light-tip distances. According to Malkoc et al. [18], high- and low-intensity halogen lights results in higher temperature rises compared to LEDs and PACs. Goodis et al. [5] found greater increase in temperature with extended curing times. Oesterle et al. [19] suggested using xenon plasma arc light with short exposure times, especially on teeth with thin enamel.

In all these abovementioned studies thermocouples were used and thermocouples have been the traditional gold standard of temperature measurement [20]. They have been shown to have an accuracy of within 0.5% [21]. The limitation of thermocouples is measuring the temperature at only the point on a surface that it is contacting. The contact between the thermocouples and the surface must be optimal to ensure accurate recordings [21]. The thermocouple tips are also prone to easy separation from the object during the operational steps [22]. Infrared thermography using artificial neural networks has many applications in dentistry [23]. Its principal advantage over thermocouple analysis lies in its ability to measure temperatures over a large surface area, and dedicated software packages allow the investigation and identification of points of temperature extremes. Modern equipment is sensitive enough to record changes of 0.1°C. The method has been used previously to study temperature changes on the root surface during root canal obturation [24] and in post space preparations [25]. McCullagh et al. [24] also showed lower temperature values with thermocouples compared to infrared thermal imaging systems.

Detrimental effects of the light sources may be eliminated by short curing times and using high intensity lights. Uzel et al. [17] showed higher temperature rises with closer light-tip distances. Thus, the aims of this study was to evaluate the increase in surface temperature when different curing units and light tip distances were used and to present the effectiveness of a new measuring system about temperature increases because of limitations or disadvantages of the thermocouple system.

Materials and methods

A power analysis established by G*Power Ver. 3.0.10. (Franz Faul, Universität Kiel, Germany) software, based on a 1:1 ratio between groups, showed a sample size of 10 teeth in each group would give more than 60% power to detect significant differences with a 0.25 effect size and $\alpha = 0.05$ significance level.

Table I. Groups of the study.

Group	Details
LED1	LED curing from tooth surface
LED2	LED curing from 10 mm distance
HQTH1	HQTH curing from tooth surface
HQTH2	HQTH curing from 10 mm distance

In this study, 52 intact human first premolar teeth freshly extracted for orthodontic reasons were used. Exclusion criteria were presence of cracks, hypoplastic areas, irregularities of the enamel structure and pre-treatment with a chemical agent such as alcohol, formalin or hydrogen peroxide. Teeth were stored in 0.1% thymol solution for no more than 1 month. Teeth were molded in acrylic blocks and stored in artificial saliva. Crowns were cleaned to remove callus and debris and polished with fluoride-free pumice and rubber cup. The buccal enamel of the teeth was etched for 30 s with 37% orthophosphoric acid (3M Dental Products, St Paul, MN), rinsed with water from a 3-in-1 syringe for 30 s, and dried with an oil-free source for 20 s. Metallic orthodontic brackets (Dentaurum, Ultra-minitrim, Ispringen, Germany) were bonded using Transbond XT (3M Unitek, Monrovia, CA) adhesive, excess composite was gently removed with a scaler before curing. All brackets were bonded by the same operator (A.D.). The light intensity of the halogen-curing unit was checked before each testing procedure with a curing radiometer (Demetron Kerr, Danbury, CT) and that of the LED with a LED curing radiometer (Hilux Ledmax, Benlioglu Dental Inc., Ankara, Turkey). There was no measurable reduction in intensity for light during the research. The teeth were separated randomly into two groups of 26 teeth each according to the light curing unit type and then these two groups were divided into two sub-groups of 13 teeth each. In the first sub-groups, the light tip was adjusted at the buccal enamel surface; and 10 mm away in the second sub-groups (Table I) .

The light curing units and technical details including exposure times are shown in Table II. For the curing units, high intensity quartz-tungsten-halogen (HQTH) and light-emitting diode (LED) units were selected. HQTH unit (Optilux 501, Kerr) and LED unit (Elipar Freelight, 3M ESPE, St Paul, MN) were used to bond brackets. The thermal images (TI) taken from the tooth surface during the curing was recorded via a special image card using an infrared (IR) camera (FLIR ThermaCAM® E45, Niceville, FL) and transferred to the image processing software developed in a MATLAB environment. The camera was mounted on a tripod 5 cm away from the vestibular surface of the teeth (Figure 1) . Images were recorded at 10-s

Table II. Curing units used in this study.

	Manufacturer	Diameter of tip (mm)	Power intensity (mW/cm^2)	Exposure time (s)
Optilux 501	Kerr, Danbury, CN	8	850	20
Elipar Freelight	3M ESPE, St Paul, MN	8	400	20

time interval time points including all exposure times (before curing, at 10th and at 20th s). Then, the thermal images were processed using artificial neural networks (ANN) and the temperatures of enamel beside the bracket on the specimen surface were obtained (Figure 2) .

Obtaining temperature values using an infrared camera and artificial neural networks

Thermal video images taken from FLIR E45 IR camera are recorded via a special image card and transferred to the image processing software developed in a MATLAB environment. Figure 2 shows the TI and the characteristic spot temperatures (the hottest, coldest and medium heat spot temperatures) obtained from the TI. The highest, lowest and middle spot temperatures are determined by using ANN in order to obtain the characteristic spot temperatures of each TI.

From a number of measurements performed, it was seen that the relationship between the temperature of the spot in the TIs and the gray level was a second-degree function. In order to show the temperature distribution on the whole of each TI, the curve fitting process signifying this relationship is performed and the temperature distribution on the whole of the TI is obtained. This curve, which is based on the temperatures and gray levels of the characteristic spots obtained from the TI, is presented as a second degree function in equation (1) given below.

$$T(x) = ax^2 + bx + c$$

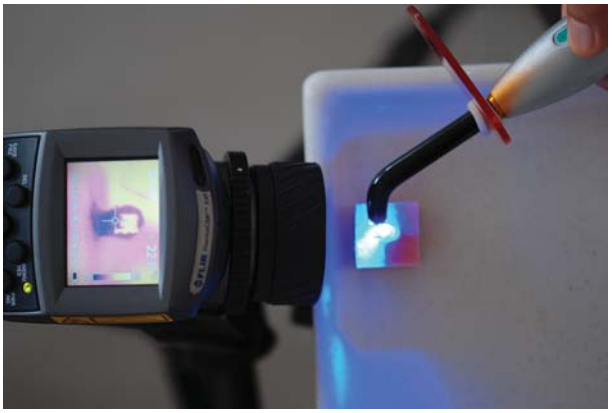

Figure 1. Infrared camera recording process during orthodontic bonding.

where, x is the gray level of a pixel on the TI; $T(x)$ is the temperature of the spot signified by this pixel; and a, b, c are coefficients that vary with respect to TI, thus needing to be determined according to each TI [26].

As the result of these procedures, characteristic spot temperatures, which we define as the hottest, coldest and medium heat spot temperatures of each TI, are obtained through the ANN in a reliable way. These values, which are a part of the thermal-analog video image, are obtained as a numerical value through the ANN and used as coefficients a, b and c in the second-degree function given in equation (1). This signifies the relationship between the temperatures and gray levels of the characteristic spots, in order to discover the temperature distribution on the whole of each TI [26].

Statistical analysis

All statistical analyses were performed with Statistical Package for Social Sciences (SPSS), 15.0 software for Windows (SPSS Inc, Chicago, IL). Arithmetic means and standard deviations were calculated for each measurement. The normality test of Shapiro–Wilks and Levene's variance homogeneity test were applied to the data. The data was normally distributed and there was homogeneity of variance between the groups. Thus, the statistical evaluation of the data was performed using parametric tests.

Descriptive statistics were calculated for each of the four groups. Analysis of variance (ANOVA) and the Tukey honestly significant difference (HSD) tests were used to analyze temperature changes between the groups at significance level of $p \leq 0.05$.

Results

Descriptive statistics of the data are shown in Table III. ANOVA and the post-hoc tests revealed that temperature changes were influenced by the type of light sources and exposure distances.

The highest temperature increases were observed during photo-activation of composite resin with the LED1 group (11.35°C ± 0.91°C), followed by the HQTH1 group (8.17°C ± 0.8°C) and the LED2 group (3.55°C ± 0.46°C). The lowest temperature increase was with the HQTH2 group (2.57°C ± 0.6°C).

The results of ANOVA and the Tukey HSD tests revealed significant changes in temperature rises between the groups tested ($p < 0.001$). A graphic presentation of the results is shown in Figure 3.

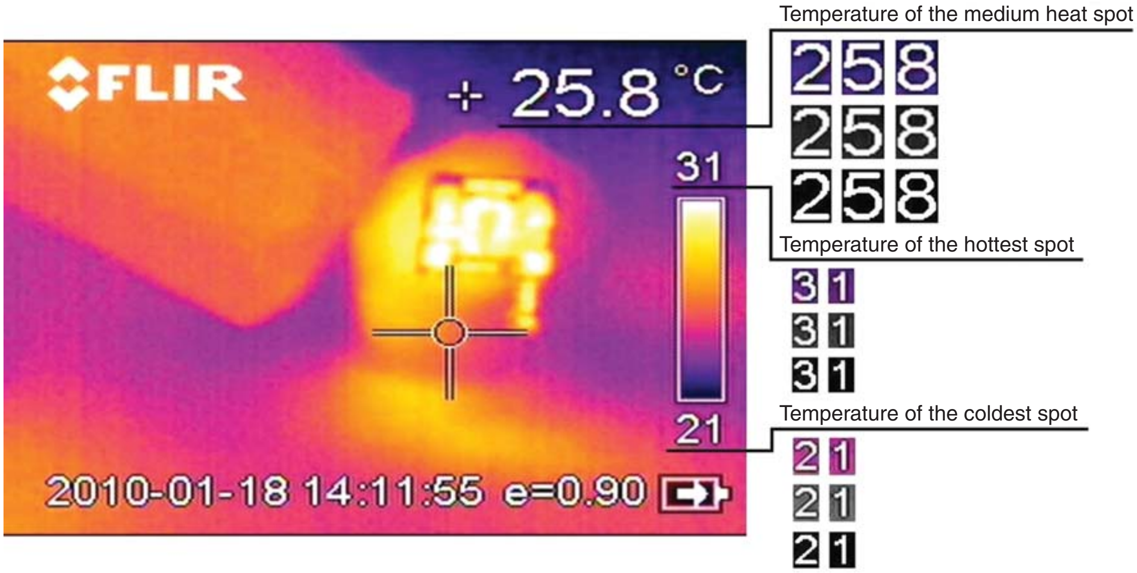

Figure 2. TI and the characteristic spot temperatures of TI.

Discussion

In the present study, temperature increase during the orthodontic bonding procedure was assessed with an IR camera and ANN. To the best of our knowledge, this was the first study using IR thermal images and recordings in orthodontic bonding. There are two experimental techniques *in vitro* used for the evaluation of tooth surface temperature. They are thermocouple and IR thermographic techniques [20,26–28]. Thermocouples used for the detection of temperature rise during cavity preparation by lasers [29,30] or diamond instruments [31] and during light activated polymerization of composite materials [8,18,19,32,33]. Although thermocouples were extensively used for many years, this technique has some disadvantages [20,22,34]. Thermocouples only measure the temperature values at the surface locations where they are attached. The thermocouple tips are also easily separate from the object during the operational steps [22]. With the use of IR thermal cameras, more detailed assessment of curing units and composite materials would be achieved and would be applicable in *in vitro* as well as *in vivo* conditions [35]. The IR thermal camera and thermocouple measurements correlated reasonably well with each other [35]. According to the results of recent studies, temperature measurements with thermocouples were found to be lower than IR camera measurements [25,33] and it was concluded that thermocouples may under-estimate the temperature increases much of the time [35]. Therefore it may be thought that higher temperature increases occur during light polymerization than reported in previous studies in which thermocouples were used.

Based on the results of the current study, the temperature increase detected from the tooth surface increases with long exposure time and short light-tip distance. The present findings are in accordance with Uzel et al. [17]. They reported temperature increases as 1.35°C when the LED light-tip distance was zero and 0.52°C when this distance was 10 mm. In the current study, after 20 s of curing time at the tooth surface and 10 mm light tip distances, these values were 11.62°C and 3.78°C, respectively. Similarly, Malkoc et al. [18] reported 2.95°C and Ulusoy et al. [32] reported 0.52°C temperature increases, with 20 s of curing with LEDs. Greater temperature increases recorded in our study may depend on the method used to assess the temperature changes. In all the above-mentioned studies thermocouples were used. Bouillaguet et al. [36] performed two different temperature measurements at the internal and external surfaces. The reported temperature increases of 7.80°C with thermocouple measurement and 2.63°C with IR cameras. In

Table III. Temperature rises (°C) during polymerisation.

Group	*n*	Mean	SD	Minimum	Maximum	Tukey HSD
LED1	13	11.35	0.91	10.45	13.07	A
LED2	13	3.55	0.46	3	4.38	B
HQTH1	13	8.17	0.8	6.9	9.49	C
HQTH2	13	2.57	0.6	1.8	3.7	D

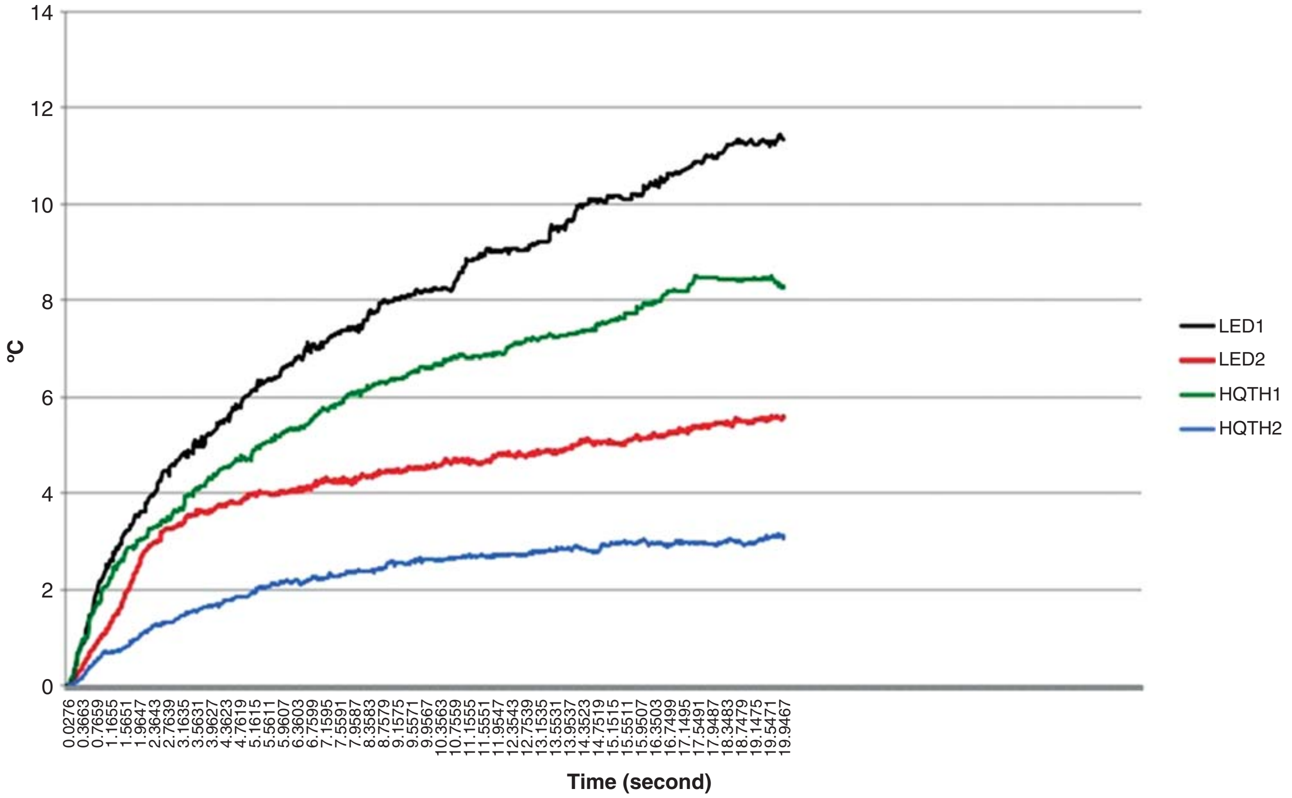

Figure 3. Graphic representation for temperature increases with two light sources at two distances.

the literature, lower thermal changes were reported with thermocouple measurements compared to IR cameras [25,33].

Light curing the adhesive while holding the light-tip away from the tooth surface and shortening the exposure time may be logical in order to decrease the heat generated during curing. This may be advantageous when the detrimental effect of the heat taken into account, but another important aspect is the degree of conversion of the composite. Cacciafesta et al. [37] performed a study on light-tip distance and shear bond strength (SBS). They showed significantly lower SBS with a greater light-tip distance and this finding was attributed to the decreased power output. Additionally, in our study, both HQTH and LED were applied for 20 s and resulted in significantly higher temperature increases. This result can be explained by the different specifications of the light sources and temperature measurement systems.

The results of this study should be interpreted cautiously. Firstly, a 5.5°C temperature increase was accepted as a critical increase based on a study performed on primate monkeys [11]. The temperature change that affects the vitality of the tooth may be different for humans. For this reason, any significant temperature change should attract our attention. Moreover, the laboratory findings should not be extrapolated to the clinical situation. Although the laboratory studies are valuable, the clinical situations are quite different. So, in the future, after presenting these *in-vitro* studies in dental literature, our further study about *in-vivo* temperature increases during orthodontic bonding can be performed with an infrared camera and ANN system.

Conclusions

Based on the results of this study;

- Temperature increase during orthodontic bonding is increased with long exposure times.
- Shorter light-tip tooth surface distance leads to greater increases in temperature.
- LED curing units reveal more temperature increase than HQTH units.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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