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# Comparison of the Heat Generation of Light Curing Units

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## Abstract

**Aim:** The aim of this study was to evaluate the heat generation of three different types of light curing units.

**Methods and Materials:** Temperature increases were recorded from a distance of 1 mm from a thermocouple to the tip of three different types of light curing units including one quartz-tungsten halogen (QTH), one plasma arc (PAC), and one light emitting diode (LED) unit. An experimental model was designed to fix the 1 mm distance between the tip of the light curing units and the thermocouple wire. Temperature changes were recorded in 10 second intervals up to 40 seconds. (10, 20, 30, and 40 seconds). Temperature measurements were repeated three times for every light curing unit after a one hour standby period. Statistical analysis of the results was performed using the analysis of variance (ANOVA) and the Bonferroni Test.

**Results:** The highest temperature rises (54.4±1.65ºC) occurred during activation of a PAC light curing unit for every test period ($p<.05$). The least temperature increase (11.8±1.3ºC) occurred with a LED curing unit for each tested period except for the measurement of the temperature rise using the QTH curing unit at the tenth second interval ($p<.05$).

**Conclusion:** These results indicate the choice of light activation unit and curing time is important when polymerizing light activated resin based restorations to avoid any thermal damage to the pulp.

**Keywords:** Pulp damage, light curing units, heat generation

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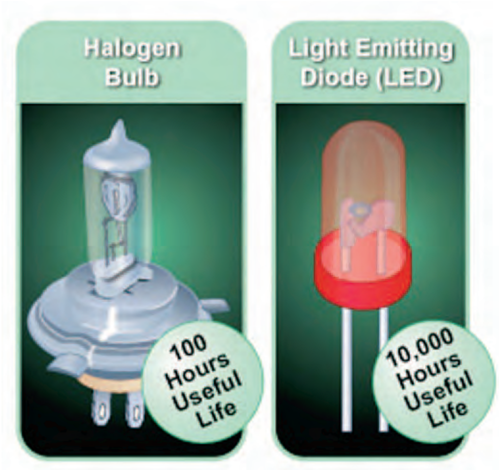
## Introduction

The detrimental effect of temperature increase on pulp tissue during restorative treatment has been of concern to clinicians.[1] External application of heat to a tooth can cause pulpal trauma if the magnitude and duration of the temperature increase reaches a critical level. Dental treatments often result in an increase of temperature at the tooth surface and ultimately in the dental pulp. The pulpal temperature increase may be a consequence of heat generated by rotating instrumentation during tooth preparation, ultrasonic instrumentation, laser treatment, electrothermal debonding of ceramic brackets, light-enhanced bleaching, polymerization of temporary crown and bridge materials, or the light curing of dental composites.[2,3] An increase of the intrapulpal temperature (exceeding 42.5°C) can result in irreversible damage to the pulp tissue.[4-6]

A temperature rise during curing of light activated restoratives relates to the exothermic reaction of the material during polymerization as well as to the heat output from the dental light curing unit.[1,7] Temperature rise induced by curing units may permanently damage the pulpal tissues.[8] Zach and Cohen[5] used a Macaca Rhesus monkey model to conclude a temperature rise of 5.5°C within the pulp chamber could lead to irreversible pulp damage. In another experiment[9] 15% of the pulps of 'small teeth' became necrotic following such a temperature rise, while 60% of the pulps failed to recover from an intrapulpal temperature rise of 11°C. Hussey et al.[10] have reported the dental pulp may be endangered by the temperature rise that occurs during light curing.[10]

The increased use of bonded composite resins in dentistry has stimulated the development of advanced technology designed to improve the resin polymerization process. Until recently, light emitted from a conventional quart-tungsten halogen light bulb (QTH) was used to cure composite resins and bonding agents. QTHs generate light when electrical energy heats a small tungsten filament to extremely high temperatures. This type of light source is usually operated at light intensities between 400 and 800 mW/cm$^2$ and polymerizes resin composite filling material to a depth of 2 mm within 40 seconds.[11,12] Most of the energy put into the halogen system is changed into heat but a small portion is emitted




as light.[13] Selective filters control the emission of other wavelengths so only blue light is emitted.[14,15] Wavelengths of 400-500 nm (blue light) emitted from these curing units activate camphorquinone-amine photoinitiation systems contained in most current composite resins. When these photoinitiator molecules are activated, they create free radicals that initiate the polymerization process.[15-18]

Despite common use in dentistry, QTH bulbs have several weaknesses.[19-21] The basic principle of light conversion in QTH bulbs has proven to be inefficient as the light power output is less than 1% of the consumed electrical power, and they have a limited effective useful life of approximately 100 hours due to degradation of bulb components caused by the high heat they generate.[22,23]

Current designs in light-curing units have concentrated on light emitting diodes (LEDs) in the blue light range. LEDs use junctions of doped semiconductors (p-n junctions) based on gallium nitride to produce blue light.[24] Earlier studies have shown LEDs to be more efficient than QTH lamps in converting energy to light and their light emission more closely matches the absorption spectrum of camphorquinone.[25]

As an alternative to the hot filaments used in QTH bulbs, LEDs use junctions of doped semiconductors for generating light.[26] LEDs have a useful life of more than 10,000 hours and undergo little degradation of output over this time.[27] LEDs do not require filters to produce blue light; they are resistant to shock and vibration and consume little power during operation. The newer gallium nitride LEDs produce a narrow spectrum of light (400–500 nm) that falls closely within the absorption range of camphorquinones that instigate the polymerization of resin monomers.[28] LEDs' longer life span and more consistent light output compared with QTH bulb technology appears promising for dental applications.[18,27]

To reduce clinical chair time required for curing, alternate light sources such as plasma arc (PAC) lights with intensities in excess of 2000 mW/cm$^2$ have been developed.[11] The PAC lamp has been introduced in restorative dentistry in order to reduce the needed time to cure composite resin filling materials from 30-40 seconds down to as little as one to three seconds.[28,29]

Curing lights emit continuous frequency bands which are much narrower than those emitted by QTH lights. In general, the spectral radiometric output is limited to the range between 440 and 490 nm and is suitable for activating the camphorquinone, photoinitiator (maximum absorption at 468 nm) found in most light-cured adhesives. Since PAC lights emit at higher intensities, they are supposed to reduce curing times.[30,31]

The purpose of this *in vitro* study was to monitor temperature rises on the exit window of the three different light guides every ten seconds during a 40 second period using three different types of light curing units. The hypothesis is the existence of a difference in temperature rise during the activation of three types of curing units due to the different levels of energy emitted by the units.

## Methods and Materials

This study evaluated the heat generation of three types of light curing units including the following: (Table 1):

1. One QTH halogen curing light at 500 mw/cm$^2$ (Hilux SmartLite, Benlioglu Dental, Turkey)
2. One PAC curing unit at over 1800 mw/cm$^2$ (Plasma Star SP2000, Monitex Co, Taiwan)
3. One LED curing unit at 600 mw/cm$^2$ (Ledmax 550, Benlioglu Dental, Turkey)

An experimental model was designed to fix the distance between the thermocouple and tip of the light curing unit (Figure 1).

A J-type 0.36-inch-diameter thermocouple wire (Omega Engineering Inc, Stamford, CT, USA) was used to measure the temperature of each light curing unit from a 1.0 mm distance during its operation. The temperature increases were evaluated every ten seconds during light curing for 40 seconds. Temperature measurements were repeated three times for every light curing unit after a one hour standby period. The light intensity of each curing unit was accepted as

**Table 1. Tested light curing units.**

| Brand | Unit Type | Output of Light Tip (mW/cm2) | Tip Diameter (mm) | Manufacturer |
|---|---|---|---|---|
| Hilux Smart Lite | Halogen | 500 | 11 | Benlioglu Dental, Turkey |
| Plasma Star SP2000 | PAC | 1800 | 7 | Monitex Co, Taiwan |
| Ledmax 550 | LED | 550-600 | 11 | Benlioglu Dental, Turkey |

**Table 2. Mean peak temperature rises (degrees Celsius) and standard deviations of the groups.**

| Time (Sec) | Plasma Star SP2000 (Monitex Co) T1-T2 | Hilux Ultra Fast Halogen Curing Light (Benlioglu Dental) T1-T2 | Ledmax 550 (Benlioglu Dental) T1-T2 |
|---|---|---|---|
| 10 | 18.4 ± 0.79°C (A , c) | 6.8 ± 0.3°C (A , a) | 11.8 ± 1.3°C (A , b) |
| 20 | 46.3 ± 5.15°C (B , c) | 18.9 ± 2.04°C (B , b) | 16.1 ± 0.95°C (B , a) |
| 30 | 49.8 ± 3.35°C (BC , c) | 20.4 ± 0.96°C (BC , b) | 17.9 ± 1.54°C (B , a) |
| 40 | 54.4 ± 1.65°C (C , b) | 21.6 ± 1.65°C (C , a) | 20.5 ± 2.25°C (C , a) |

**Note:** Big letters were used to identify the statistically differences between the different times of each light curing device; small letters were used to identify the statistically differences of light curing devices in each time period (p<.05).

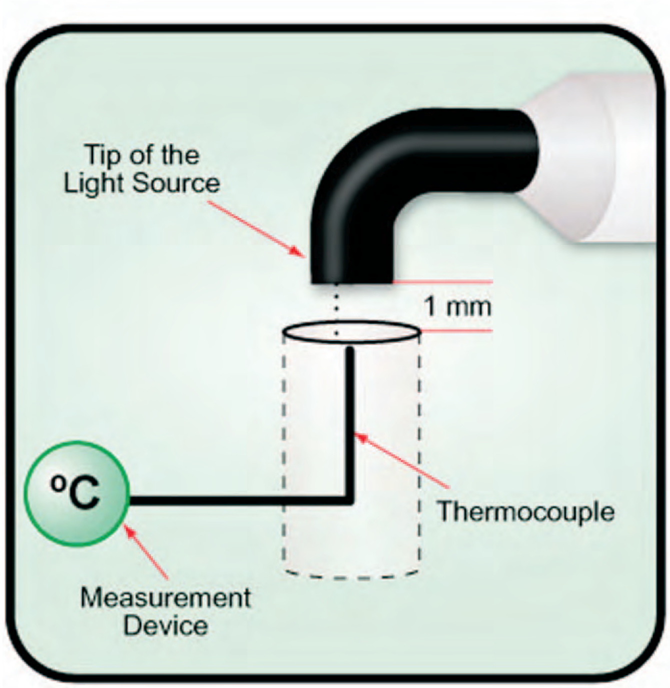



**Figure 1.** Schematic drawing of the configuration of the experiment.

the manufacturer's specification. Differences between the starting and highest temperature readings were taken, and the mean temperature increase was determined. All experimental trials were performed using the same procedure.

The results of the test were entered into Excel® spreadsheet software (Microsoft, Redmond, WA, USA) for calculation of the descriptive statistics. Statistical analysis was performed using one way analysis of variance (ANOVA) and the Bonferroni Test for comparisons among groups at the 0.05 level of significance.

## Results

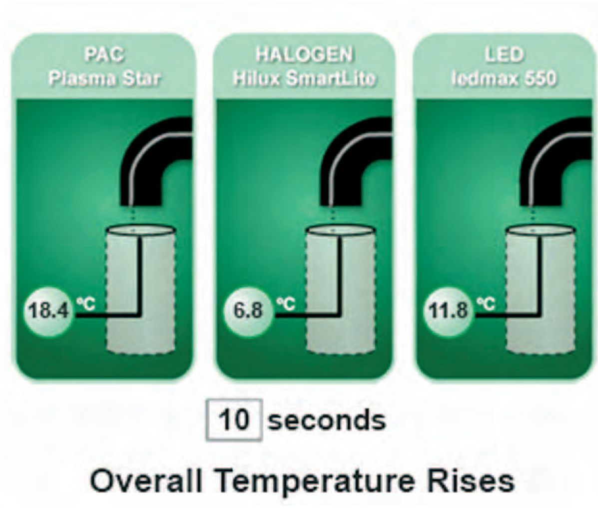
There were statistically significant differences between light curing units ($p<.05$). For all devices tested, an increase in irradiation time caused a proportionally elevation of the temperature. Temperature rises were (18.4±0.79°C), (46.3±5.15°C), (49.8±3.35°C), and (54.4±1.65°C) for each tested period at 10, 20, 30, and 40 seconds for the PAC curing unit. For the QTH curing unit, these values were (6.8±0.3°C), (18.9±2.04°C), (20.4±0.96°C), and (21.6±1.65°C). The LED curing unit showed temperature rises of (11.8±1.3°C), (16.1±0.95°C), (17.9±1.54°C), and (20.5±2.25°C) during the same tested intervals.

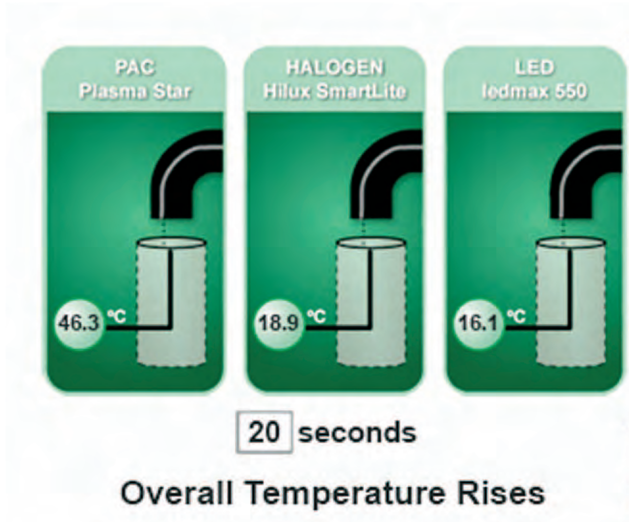
The least temperature increase was measured with the LED unit (11.8±1.3) for each tested period except for the measurement of the QTH curing unit (6.8±0.3) at the tenth second. The PAC curing unit induced significantly the highest temperature increase in all periods, and data was statistically different then the other tested groups ($p<.05$). The QTH (21.6±1.65°C) and LED (20.5±2.25°C) light curing units had similar temperature changes at the 40 second interval ($p>.05$). Output values of all tested devices showed a temperature rise of more than 5.5°C.

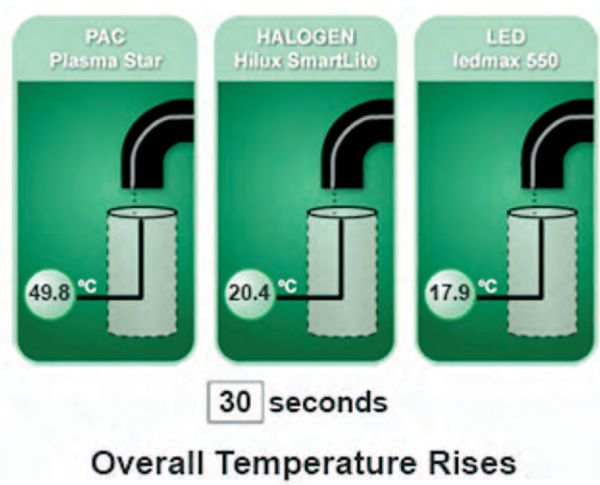
## Discussion

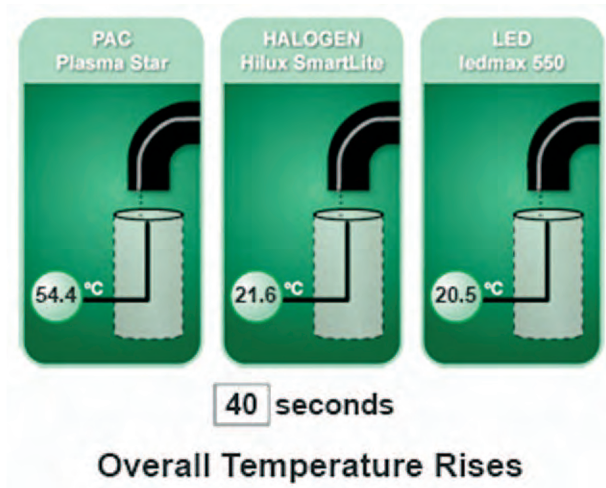
This *in vitro* study measured temperature changes from the heat generated by three commercially available light curing units. The results obtained support the hypothesis of the existence of a difference in temperature rise during the activation of three types of curing units due to the different levels of energy emitted by the units. For all curing units, increasing irradiation time caused a disproportionate elevation in temperature.

Previous studies have investigated the *in vitro* temperature rise during photopolymerization of resin composite materials using thermocouples,[31]




differential scanning calorimetry,[32] and differential thermal analysis.[33-35] In the current study a thermocouple wire was used to measure the temperature of the light curing units.

According to Strang et al.[36] the most significant source of heat during the polymerization of a light activated restorative is from the light activation unit and not the material itself. The energy absorbed during irradiation is the decisive factor for a temperature increase during the light-activated polymerization of composite resins.[37] During resin composite photopolymerization both the curing light and the exothermic polymerization reaction contribute to the temperature rise and must be differentiated.[1] For this reason, the current study attempted to quantify the temperature rise produced by the light source alone by monitoring the temperature rise on the exit window of the curing units.

Cacciafestaa et al.[38] irradiated samples at a distance of 2 and 9 mm away from the tip of the light guide and measured the Knoop hardness values. They found when the distance between the composite and the light guide was increased the effect on hardness of the composite was not the same for all light/tip combinations. Other studies[39,40] reported mean temperature rises from the light guide exit window along with a significant decline in temperature rise with an increase of the distance from the light guide. In the current study the distance of the curing tip was standardized for each light using an experimental model designed to fix the distance (1 mm) between the thermocouple and the tip of the light curing unit.

Bouillaguet et al.[8] found increasing the irradiation time for all curing units tested increases the external temperature of the tooth measured with thermocouples; they recorded mean peak temperature rises ranging from 10.5 to 23.2°C for a range of light-activation units using a 30 second irradiation time. In contrast, Shortall et al.[2] reported much greater temperature rises from a range of LED and QTH light units with peak temperature increases up to 46.4°C from the light guide exit window of a high intensity QTH light unit.[2] In the current study the temperature rise increased with an increase in irradiation time; for all devices, increasing the irradiation time caused a proportionally elevated temperature.

According to one recent study,[42] the polymerization of dental composites with powerful LED light curing units and QTH light curing units cannot be done without heating the tooth and creating the potential for harming the pulp. Nevertheless, LED light curing units represent a real alternative to QTH light curing units for the light polymerization of dental composites because of the considerably lower-temperature increase within the composite. The highest pulp chamber temperature rises were also recorded when using light curing units.[43]

In the current study the least temperature increase was measured with the LED light curing unit for each tested period except the measurement of QTH unit at the tenth second. This study also showed the most temperature increases were caused by the PAC light curing unit for every tested period. Output values of all tested devices showed a temperature rise more than 5.5°C.

There are other factors that can influence the temperature of the pulp during polymerization of a composite resin such as characteristics of the composite resin material used, the remaining thickness of the overlying dentin, and the status of the pulp's circulatory system. These factors along with the increase in temperature during light polymerization can be harmful to the pulp. Clinicians must exercise caution when increasing the output values of light curing devices in order to protect the delicate pulp tissue during the polymerization of composite resins.

## Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. The temperature increased with an increase in radiation time.
2. The least temperature increase was measured with the LED unit (11.8±1.3) for each tested period except the measurement of QTH curing unit (6.8±0.3) at the tenth second.
3. The PAC curing unit induced a significantly higher temperature increase in all periods, and data was statistically different then the other tested groups ($p<.05$).
4. Output values of all tested devices showed a temperature rise of more than 5.5°C.

## References


1. Hannig M, Bott B. *In vitro* pulp chamber temperature rise during composite resin polymerization with various light-curing sources. Dent Mater. 1999; 15:275-281.
2. Shortall AC, Harrington E. Temperature rise during polymerization of light-activated resin composites. J Oral Rehab. 1998; 25:908–913.
3. Uhl A, Mills RW, Jandt KD. Polymerization and light-induced heat of dental composites cured with LED and halogen technology. Biomater. 2003; 24:1809–1820.
4. Uhl A, Völpel A, Sigusch BW. Influence of heat from light curing units and dental composite polymerization on cells *in vitro*. J Dent. 2006 Apr;34(4):298-306.
5. Zach L, Cohen G. Thermogenesis in operative techniques, comparison of four methods. J Prosthet Dent. 1962; 12:977–984.
6. Photo M, Scheinin A. Microscopic observations on living dental pulp. Acta Odontol Scand. 1958; 16:303–327.
7. Lohbauer U, Rahiotis C, Krämer N, Petschelt A, Eliades A. The effect of different light-curing units on fatigue behavior and degree of conversion of a resin composite. Dent Mater. 2005; 21:608-615.
8. Bouillaguet S, Caillot C, Forchelet J, Cattani-Lorente M, Wataha JC, Krejc I. Thermal risks from LED- and high-intensity QTH-curing units during polymerization of dental resins. Biomed Res. 2005; 72:260-267.
9. Stewardson DA, Shortal AC, Lumley PJ. Thermal changes and cure depths associated with a high intensity light activation unit. J Dent. 2005; 32;643-651.
10. Hussey DL, Biagioni PA, Lamey PJ. Thermographic measurement of temperature change during resin composite polymerization *in vivo*. J Dent. 1995; 23:267-271.
11. Wataha JC, Lockwood E, Lewis J, Wesser LM. Biological effects of blue light from dental curing units. Dent Mater. 2004; 20:150-157.
12. Usumez A, Nilgün O. Temporary increase during resin cement polymerization under ceramic restoration: Effect type of curing unit. Int J Prosthodont. 2004; 17;200-204.
13. Althoff O, Hartung M. Advances in light curing. J Dent. 2000; 13:77–81.
14. Stahl F, Ashworth SH, Jandt KD, Mills RW. Light emitting diode (LED) polymerization of dental composites: flexural properties and polymerisation potential. Biomater. 2000; 21:1379–85.
15. Turkkahramanan H, Kucukesmen HC. Orthodontic Bracket Shear Bond Strengths Produced by Two High-power Light-emitting Diode Modes and Halogen Light. Angle Orthodont. 2005; 75:854–857.
16. Söderholm KJ. Chemistry of synthetic resins. In: Phillips' science of dental materials. 10th ed. Philadelphia: WB Saunders, 1996; 216.
17. Visible light-cured and activating units. Council on Dental Materials, Instruments, and Equipment. JADA. 1985; 110:100–23.
18. William J, Anneke C, Bush A. Comparison of polymerization by light-emitting diode and halogen-based light-curing units. Am J Dent Assoc. 2002; 133:335-341.
19. Eldeniz AU, Usumez A, Usumez S, Ozturk N. Pulpal temperature rise during light-activated bleaching. J Biomed Mater Res B Appl Biomater. 2005; 72;254-259.
20. Uzel A, Buyukyilmaz T, Kayalioglu M, Uzel I. Temperature Rise During Orthodontic Bonding With Various Light-curing Units—An Invitro study. Angle Orthodont. 2004; 76:330–334.
21. Mills RW, Jandt KD, Ashworth SH. Dental composite depth of cure with halogen and blue light emitting diode technology. Br Dent J. 1999; 186:388–91.
22. Jandt KD, Mills RW, Blackwell GB, Ashworth SH. Depth of cure and compressive strength of dental composites cured with blue light emitting diodes (LEDs). Dent Mater. 2000; 16(1):41–7.
23. Rueggeberg FA, Twiggs SW, Caughman WF, Khajotia S. Lifetime intensity profiles of light-curing units. J Dent Res. 1996; 75:380.
24. Whitters CJ, Girkin JM, Carey JJ. Curing of dental composites by use of InGaN light-emitting diodes. Opt Lett. 1999; 24:67-68.
25. Bennett AW, Watts DC. Performance of two blue light-emitting-diode dental light curing units with distance and irradiation-time. Dent Mater. 2004; 20:72-79.
26. Nakamura S, Mukai T, Senoh M. Candela-class high brightness InGaN/AlGaN double heterostructure blue-light-emitting diodes. Appl Phys Lett 1994; 64:1687–9.

27. Haitz RH, Craford MG, Wiessman RH. Handbook of optics. Vol. 2: Devices, measurements, and properties. New York: McGraw-Hill, 1995; 121–123.
28. Perimedde AP, Sheriffiss M, Irelands AJ. An *in vivo* study to compare a light and a conventional quartz halogen curing light in ortodontiv bonding. Eur J Orthod. 2004; 26:573-577.
29. Klocke A, Korbmacher HM, Lothar G. Huck, Kahl-Nieke B. Curing lights for orthodontic bonding. Am J Orthod Dentofacial Orthop. 2002; 122:643-8.
30. Sfondrini MF, Cacciafesta V, Pistorio A, Sfondrini G. Effects of conventional and high-intensity lightcuring on enamel shear bond strength of composite resin and resin-modified glass-ionomer. Am J Orthod Dentofacial Orthop. 2000; 119:30-5.
31. Peutzfeld A, Sahafi A, Asmussen F. Characterization of resin composites polymerized with curing units. Dent Mater. 2000; 16:330–336.
32. McCabe JF. Cure performance of light-activated composites by differential thermal analysis (DTA). Dent Mater. 1985; 1:231–234.
33. Goodis HE, White JM, Gamm B, Watanabe L. Pulp chamber temperature changes with visible-light-cured composites [in vitro]. Dent Mater. 1990; 6:99–102.
34. Vaidyanathan J, Vaidyanathan TK. Computer-controlled differential calorimetry of dental composites,.IEEE Trans Biomed Eng. 1991; 131:319–325.
35. Al-Qudah AA, Mitchell CA, Biagioni PA, Hussey PL. Thermographic investigation of contemporary resin-containing dental materials. J Dent. 2005; 33:593-602.
36. Strang R, Patterson CJW, McLundie AC, Cummings A, Smail SRJ. *In vitro* temperature rises produced by five polymerising light sources. Restorative Dent. 1988; 4:33–35.
37. McCabe JF, Wilson HF. The use of differential scanning calorimetry for the evaluation of dental materials. I. Cements, cavity lining materials and anterior restorative materials. J Oral Rehabil. 1980; 7:103–110.
38. Cacciafestaa V, Sfondrinib MF, Scribantec A, Boehmed A, Brinkmann PG. Effect of Light-tip Distance on the Shear Bond Strengths of Composite Resin. Angle Orthodont 2005; 75:386–391.
39. Price RB, Ehrnford L, Andreou P, Felix CA. Comparison of quartz-tungsten-halogen, light-emitting diode, and curing lights. J Adhes Dent. 2003; 5(3):193-207.
40. Cacciafesta V, Sfondrini MF, Barina E, Scribante A, Garino C, Klersye C. Effect of different light sources and guides on shear bond strength of brackets bonded with 2 adhesive systems. Am J Orthod Dentofacial Orthop. 2005; 128:99-102.
41. Yap UJ, Soh MS. Thermal emission by different light-curing units. Oper Dent. 2003; 28:260–266.
42. Uhl A, Robin W, Klaus D. Jandt Polymerization and light-induced heat of dental composites cured with LED and halogen technology. Biomater. 2003; 24:1809-1820.
43. Danesh G, Davids H, Duda S, Kaup M, Ott K, Schafer E. Temperature rise in the pulp chamber induced by a conventional halogen light-curing source and a lamp. Am J Dent. 2004; 17:203-8.

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