Critical Appraisal

LIGHT-EMITTING-DIODE CURING LIGHTS—REVISITED

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The Critical Appraisal of light-emitting-diode (LED) curing lights published in 2003 found that early first-generation LED curing lights did not meet manufacturers' claims and required exposure times twice as long as conventional quartz-tungsten-halogen (QTH) curing lights to adequately polymerize resin composites. This Critical Appraisal reviews a sample of the recently published research on the performance of the latest generation of LED curing lights.

TEMPERATURE RISE INDUCED BY SOME LIGHT EMITTING DIODE AND QUARTZ-TUNGSTEN-HALOGEN CURING UNITS

E. Asmussen, A. Peutzfeldt
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ABSTRACT

Objective: The purpose of this study was to measure the temperature rise caused by 10 light-emitting-diode (LED) and three quartz-tungsten-halogen (QTH) curing lights and to relate the measured temperature rise to the power density of the curing light. The authors hypothesized that the temperature rise induced by the LED curing lights would be smaller than that generated by the QTH curing lights operating at the same power density.

Materials and Methods: The curing lights evaluated in this study included a conventional QTH light (XL3000, 3M ESPE, St. Paul, MN, USA), two high-intensity QTH lights (Optilux 501, SDS/Kerr, Orange, CA, USA; Elipar Highlight, 3M ESPE), and 10 LED curing lights (Aqua Blue, Toesco, Kanagawa, Japan; CoolBlu, Dental-Systems, Tokyo, Japan; DioPower, CMS, Copenhagen, Denmark; Elipar Freelight, 3M ESPE; Elipar Freelight 2, 3M ESPE; L.E. Demetron 1, SDS/Kerr; Lux-O-Max, Akeda, Lystrup, Denmark; Lux-O-Max P1, Akeda; SmartLite, Dentsply, Konstanz, Germany; Ultra-Lume 2, Ultradent Products, South Jordan, UT, USA).

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The estimated relative heat generated by the curing lights was determined by measuring the temperature rise on the surface of a 4-mm × 4-mm cylinder of resin composite (Tetric Ceram; Ivoclar Vivadent, Schaan, Liechtenstein) using a thermocouple connected to a galvanometer (Radiometer, Copenhagen, Denmark). All measurements were made at the end of a 20-second exposure to the curing light. Power density was measured using a dental radiometer (Demetron Research, Danbury, CT, USA). The data were evaluated statistically by regression analysis and by the Neuman–Keuls multiple comparison test.

Results: Taking all curing lights into consideration, the coefficient of correlation between temperature rise and power density was very good and statistically significant at $r = 0.93$ ($p < 0.001$). The correlation coefficient for only the LED curing lights was even stronger, $r = 0.96$ ($p < 0.001$). This means, of course, that temperature rise increases with increased power density. On the plotted LED regression line, the temperature rise of two of the three QTH curing lights exceeded (by 2 and 2.3°C) the projected temperature rise of an LED curing light measured at the same power density (650 mW/cm^2). The measured temperature rise of the conventional QTH curing light operating at 360 mW/cm^2 was not significantly different from the predicted LED temperature rise regression line.

Conclusion: In general, the hypothesis that temperature rise caused by LED curing lights would be less than that generated by QTH curing lights operating at the same power density could not be confirmed. The data did not support earlier findings that LED curing units generated smaller temperature rises than QTH curing lights. The authors concluded that the main reason for earlier findings was that first-generation LED curing lights had lower power densities than present-day lights.

COMMENTARY

This simple, straightforward study confirms what should be intuitive, ie, that increased energy output results in increased temperature rise. The study does not attempt to measure the temperature rise inside the dental pulp or use sophisticated power density measurement techniques. It simply compares the relationship of power density to temperature rise. Early reports of decreased temperature rise with LED curing lights were the result of the first-generation LED curing lights' insufficient power density. Current-generation LED curing lights have power densities comparable to those of high-intensity QTH curing lights and, as a result, generate comparable temperature rise values. The filters used in QTH curing lights effectively reduce the heat-generating longer wavelengths exiting the curing light to levels comparable to those seen in the LED curing light's spectral emission.

SUGGESTED READING

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Schneider LF, Consani S, Correr-Sobrinho L, et al. Halogen and LED light curing of composite: temperature increase and Knoop hardness. Clin Oral Investig 2006;10:66–7.

EFFECT OF LIGHT DISPERSION OF LED CURING LIGHTS ON RESIN COMPOSITE POLYMERIZATION

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ABSTRACT

Objective: To evaluate the effect of light dispersion of QTH and LED curing lights on resin composite polymerization.

Materials and Methods: One QTH (Optilux 501, SDS/Kerr) and five LED curing lights (SmartLite iQ, Dentsply Caulk, Milford, DE, USA; L.E. Demetron 1, SDS/Kerr; FLASHlite 1001, Discus Dental, Culver City, CA, USA; Ultra-Lume LED 5, Ultradent Products; Allegro, Den-Mat, Santa Maria, CA, USA) were used in the study.

Degree of conversion (DC) at the bottom surface of 2-mm-thick highly filled (Z100, 3M ESPE) and microfill (A110, 3M ESPE) resin composite specimens was evaluated using micro-Fourier transform infrared (FTIR) spectroscopy. Five specimens of each composite type were polymerized by each curing light for 5 seconds at a distance of 1 and 5 mm. The short exposure time was used to prevent specimens from maximal polymerization and to allow relative comparisons of curing effectiveness between the various lights. The DC at the bottom surface was compared with the maximum DC of each type of resin composite. The maximum DC was determined by irradiating five specimens of both resin composites for 40 seconds on each side using an Optilux 501 curing light. The specimens were then evaluated with micro-FTIR and a mean maximum DC was determined. Percent mean DC ratios and standard deviations were calculated for each curing light under each testing condition. Data were analyzed by a three-way analysis of variance (ANOVA) and Tukey's test ($\alpha = 0.5$) to evaluate the effect of composite type, tip-to-target distance, and curing light type on DC ratios.

A beam analyzer (LBA-700, Spiricon, Logan, UT, USA) was used to image the emitted light from each curing light at 0 and 5 mm. The power for each light at each distance was measured using a power meter (PowerMax 5200 and PM 10 probe, Molectron, Portland, OR, USA). The two-dimensional image was encircled, and the total area was assigned the corresponding power value. From this data, the equipment software calculated the irradiance (mW/cm^2) across the image. A Top Hat factor (a measure of beam homogeneity) was determined and used to compare the quality of the emitted beam profile. The divergence angles of the light projections from 0 to 5 mm off of vertical were recorded in the x- and y-axis. The data were analyzed using a two-way ANOVA and Tukey's Test ($\alpha = 0.5$) to evaluate the effects of target distance and curing light on the mean Top Hat factor, and of the axis and curing light on the mean divergence angle. Irradiance over distances from 0 to 20 mm was measured for each light using a power meter (PowerMax 5200 and PM probe). Light diffusion images for each curing light were captured by projecting the emitted light from each curing light parallel across the surface of flat black paper and photographed.

Results: Significant differences in DC ratios were found based on composite, distance, and curing light. At 1 mm, the Optilux 501 and FLASHlite 1001 produced significantly higher DC ratios with the heavily filled resin composite. No significant differences were found between lights at 1 mm with the microfill resin composite. At 5 mm, the SmartLite IQ, FLASHlite 1001, L.E. Demetron 1, and Ultra-Lume LED 5 produced significantly higher DC ratios with the heavily filled composite, but only the L.E. Demetron 1 and SmartLite iQ produced significantly higher DC ratios with the microfill resin composite. The Ultra-Lume LED 5, Allegro, and Optilux 501 demonstrated significantly lower DC ratios between 1 and 5 mm with both resin composites. Significant differences were found in the Top Hat factor based on distance and curing light. Significant differences in divergence angle were found based on curing light. No significant difference was found in the divergence angle based on axis. The SmartLite iQ had the highest overall Top Hat factor and the lowest divergence angle of the tested curing lights. A linear regression relating pooled DC ratios with pooled Top Hat factors and divergence angles found a very good correlation ($r^2 = 0.86$). The SmartLite iQ maintained its irradiance well from 0 to 20 mm, whereas the irradiance of the Allegro dropped dramatically over distance.

Conclusions:

1. Overall, the latest generation of LED curing lights provided similar or better DC ratios than the QTH curing light at 5 mm.

2. Dispersion of light plays a significant role in DC of resin composite.
3. The SmartLite iQ had the most uniform distribution and the lowest divergence angle of light.

COMMENTARY

This extremely well-done research article underscores the fact that the polymerization of resin composite is a complex phenomenon. Previous studies have suggested that degree of cure is directly related to energy density (power density × exposure duration). These studies typically measured power density at 0 or 1 mm. Clinically, limited access makes positioning the curing tip at 0 mm difficult except in anterior Class III, IV, and V restorations. Class II and deep Class I restorations necessitate the curing tip be positioned more distantly. The distance from the cusp tip to the floor of a Class II preparation is approximately 5 mm.

This research study found that other factors such as Top Hat factor (homogeneity of light) and divergence angle are major factors in the efficacy of curing lights. Two of the least powerful lights in terms of power density at the exit window (0 mm), the SmartLite iQ and L.E. Demetron 1, demonstrated the highest DC at 5 mm. This is directly related to their superior Top Hat factor and lower divergence angle. Measurement of DC can be made directly using laser Ramen spectroscopy and infrared spectroscopy or indirectly with surface hardness, scraping, and optical methods. Direct methods such as those used in this study are the most sensitive for measuring depth of cure. In addition, this study used sophisticated analytic methods to evaluate beam homogeneity and divergence, both of which were found to be significant factors affecting curing light performance. Future evaluations of curing lights will be less than ideal if done without evaluating these parameters.

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LIGHT-EMITTING DIODE CURING LIGHT IRRADIANCE AND POLYMERIZATION OF RESIN-BASED COMPOSITE

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ABSTRACT

Objective: To characterize commercially available LED curing lights and compare their performance with a commonly used QTH curing light.

Materials and Methods: Seven LED curing lights: Cool Blu (Dental Systems International, Ormond Beach, FL, USA), E-Light (GC America, Alsip, IL, USA), Elipar Freelight (3M ESPE), Flashlite (Discus Dental), Hilux LED MAX 1 (First Medica, Greensboro, NC, USA), L.E. Demetron 1 (SDS/Kerr), Ultra-Lume 2 (Ultradent Products), and one QTH curing light, the Optilux 400 (SDS/Kerr), were used in the study.

The evaluation of each light included curing light intensity and temperature rise, and depth of cure, surface hardness, and double-bond conversion of resin-based composites. Curing light intensity was measured using a laboratory-grade power meter with band-pass filters to limit the measured intensity to wavelengths between 400 and 535 nm. Intensity also was measured using two commercially available radiometers (Optilux Model 100, SDS/Kerr; Cure Rite Visible Light Curing light meter no.

644726, Dentsply Caulk). Depth of cure (DOC) was evaluated using the 2000 ISO Standard 4049 scrape test method. Three shades (A1, A3, A4) of a hybrid composite (TPH Spectrum, Dentsply Caulk), two shades (A1, A4) of a microfill composite (Heliomolar, Ivoclar Vivadent, Amherst, NY, USA), and one shade (A3) of a heavily filled composite (Z100, 3M ESPE) were used in the evaluation. Length of curing time was as recommended by the resin-composite manufacturer. Surface hardness was measured on the same resin composites and shades, as was DOC. Barcol hardness was measured on the top and bottom surfaces of 2-mm resin composite specimens. For the Z100 resin composite, 2.5-mm specimens were used because the manufacturer claimed a 2.5-mm DOC at its recommended curing time. A bottom-to-top ratio of at least 80% was considered evidence of acceptable polymerization. Degrees of double-bond conversion of Heliomolar shades A1 and A4 at depths of 0.5, 2.0, and 3.5 mm were measured using a near-infrared (NIR) spectroscopic technique. Temperature rise for each evaluated curing light was measured using a type K thermocouple inserted 1 mm into a 3-mm high × 4.7-mm diameter Heliomolar specimen (shade A1). Temperature rise was the difference between the temperature measured at baseline and the temperature measured after 40 seconds of curing.

Results: Except for the L.E. Demetron 1, the intensities measured for the LED curing lights were lower than the intensity of the QTH curing light. The DOC for all tested resin composite/shade combinations cured with the L.E. Demetron 1 were significantly greater than the QTH curing light DOCs. The majority of the other LED lights, however, produced DOCs significantly lower than the QTH curing light. To achieve the same depth of cure as the QTH curing light, additional irradiation times ranging from 10 to 70 seconds were required for two of the LED curing lights (E-Light and Hilux LED MAX 1).

Measurement of bottom-to-top surface hardness ratios determined that out of a total of 49 curing light/resin composite/shade combinations, three were significantly higher for the LEDs than for the QTH curing light, and 16 combinations for the LEDs were significantly lower. Testing of the Hilux LED MAX 1 curing light consistently resulted in lower hardness ratios for all resin composite/shade combinations. The degrees of double-bond conversion for specimens of Heliomolar shade A4 at 0.5 and 2 mm were not statistically different when cured with the LED curing lights than when cured with the QTH light. For Heliomolar shade A1, three of the seven LED curing lights gave statistically lower double-bond conversion compared with the QTH curing light at both 2 and 3.5 mm. At irradiation times required to achieve a DOC equivalent to that obtained with the QTH curing light, five of seven LED curing lights demonstrated significantly lower temperature rise values.

Conclusions: In general, six of the seven LED curing lights were similar in performance to the QTH curing light. For the tested parameters, there were only slight differences between lights with the exception of the Hilux LED MAX 1 curing light, which generally performed poorly.

COMMENTARY

The Division of Science of the American Dental Association conducted this comprehensive study. It evaluated the curing lights using established methodology, including comparisons of irradiance, DOC, degree of double-bond conversion, and temperature rise. From this study, the reader should conclude that the majority of the tested LED curing lights, with the exception of the Hilux LED MAX 1, performed similarly to a medium-intensity QTH curing light. It is logical to conclude that had the LED curing lights been compared with a high-intensity QTH curing light, they may not have compared as favorably. In fairness, however, the LED curing lights used in the study were early second-generation or late first-generation LED lights. All of these lights have been replaced by newer, improved, higher-intensity models. This study found that five of the seven LED curing lights generated statistically lower temperature rise than did the QTH curing light. This supports the claims made by the manufacturers of first-generation LED lights. It also suggests, however, that lower temperature rise was due to the lower intensity of the lights. The best-performing LED curing light in the study (L.E. Demetron 1), which outperformed the QTH curing light, had the greatest temperature rise of all the evaluated curing lights.

SUGGESTED READING

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THE BOTTOM LINE

LED dental curing lights were first introduced in the late 1990s. Compared to QTH lights, their purported advantages were more efficient curing, decreased heat from the light tip, portability because they were powered by rechargeable batteries, and significantly longer service life of the LED compared to the QTH bulb. However, the first-generation LED curing lights were found to be woefully underpowered. Despite a more efficient spectral emission that closely mirrored the peak absorption of camphorquinone, they required longer curing times than conventional QTH curing lights to adequately polymerize resin composites. Since then, manufacturers have released second-generation LED lights with increased power density. So-called third-generation LED curing lights have increased power density and dual-peak spectral emission patterns to adequately polymerize resin composite that use other initiators (eg, phenyl-propanedione, Lucirn TPO) that the narrow spectral emission did not activate. There are very few resin composites that use these photoinitiators and, unless specifically required, second-generation LED curing lights are usually adequate.

The increased power density of the second-generation LED curing lights did not come without a cost. Decreased curing tip temperature is no longer an advantage. Research has determined that the temperature rise of second-generation LED curing lights is equivalent to that of high-intensity QTH curing lights. However, with a history of over 25 years of clinical use of QTH curing lights without deleterious effects on pulp vitality, this does not appear to represent a serious concern. Although the LED curing light does not require a fan to cool a QTH bulb, the LED chip itself must be protected from overheating and subsequent failure because of its greater output. For this reason, second-generation curing lights now have cooling fans that shorten the battery charge or have incorporated weighty "heat sinks" that draw heat away from the chip. One unit, the L.E. Demetron II, incorporates both a pulsed output technology and a cooling fan to improve output and protect the LED chip from overheating and failure.

Vandewalle and colleagues demonstrated in their article that power density is not the only determinant in optimizing resin composite polymerization. Top Hat factor (beam homogeneity) and collimation (decreased divergence angle) of the curing light beam have been shown to be important, especially when curing resin composites in the depth of Class II preparations or when obstructed by cusp tips, etc. Shining the curing light beam parallel to a common index card will give a very good approximation of the curing light's divergence angle.

The bottom line is that second-generation LED curing lights are now similar in output and performance to high-intensity QTH curing lights and are actually superior to standard QTH curing lights. From all indications, LED curing lights are the wave of the future in visible light curing. If you are considering purchase of a "second-generation" LED curing light to replace your existing light, you should take into account several factors before you decide on a specific product. For example, you should assess how well your current light (whether it is a high-intensity or a standard QTH) has performed for you. Also, the relative importance of portability and the cost of maintenance should be considered. Maintenance costs can vary quite a bit. For LED lights, the battery will need to be replaced every 2 to 3 years at $75 to $125 per battery. With QTH lights, the bulb will need to be replaced every 40 hours of use at a cost of $35 to $75. Finally, the nature of your practice and the various ways you use a curing light should be considered. It is important to know that LED curing lights with heat sinks will overheat and shut off to protect the LED chip when used for extended periods. Several minutes of cool-down time are required before they become operable again. This can be very inconvenient if you frequently treat multiple teeth at one time. On the other hand, LED curing lights with cooling fans operate without overheating, but the fan operation shortens the battery charge time. Because of the need to more frequently recharge these lights, you might want to buy more than one unit of this type, or purchase a model with an additional battery to always have a charged battery. LED curing lights differ in quality and performance. With a multitude of different models available and new ones being introduced all the time, you must be careful in selecting the "right" one to buy.

Editor's Note: We welcome readers' suggestions for topics and contributors to Critical Appraisal. Please address your suggestions to the section editor:

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