Critical Appraisal

QUARTZ-TUNGSTEN-HALOGEN AND LIGHT-EMITTING DIODE CURING LIGHTS

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Curing lights are an integral part of the daily practice of restorative dentistry. Quartz-tungsten-halogen (QTH), plasma-arc (PAC), argon laser, and light-emitting diode (LED) curing lights are currently commercially available. The QTH curing light has a long, established history as a workhorse for composite resin polymerization in dental practices and remains the most common type of light in use today. Its relatively broad emission spectrum allows the QTH curing light to predictably initiate polymerization of all known photo-activated resin-based dental materials. However, the principal output from these lamps is infrared energy, with the generation of high heat. Filters are used to reduce the emitted heat energy and provide further restriction of visible light to correlate better with the narrower absorbance spectrum of photo-initiators. The relatively inefficient emission typically requires corded handpieces with noisy fans. PAC lights generate a high voltage pulse that creates hot plasma between two electrodes in a xenon-filled bulb. The irradiance of PAC lights is much higher than the typical QTH curing light, but PAC lights are more expensive and generate very high heat with an inefficient emission spectrum similar to that of QTH bulbs. Light emitted from an argon laser is very different from that emitted from the halogen or PAC lights. The photons produced are coherent and do not diverge; therefore, lasers concentrate more photons of specific frequency into a tiny area. With very little infrared output, unwanted heat is minimized. However, argon lasers are very expensive and inefficient due to a small curing tip. LED curing lights have been introduced to the market with the promise of more efficient polymerization, consistent output over time without degradation, and less heat emission in a quiet, compact, portable device. This review evaluates some of the published research on LED and QTH curing lights.

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THERMAL RISKS FROM LED- AND HIGH-INTENSITY QTH-CURING UNITS DURING POLYMERIZATION OF DENTAL RESINS

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ABSTRACT

Objective: The purpose of this study was to test the ability of an infrared (IR) camera to assess temperature changes and distributions in teeth during photopolymerization of resin-based dental restorative materials.

Materials and Methods: Class II slot preparations were made in six extracted human third molars. The roots were sectioned at the cemento-enamel junction, the pulp was extirpated and the tooth was mounted on Plexiglas. Polyethylene tubing was used to perfuse the pulp with a solution of sodium chloride and to insert a K-type thermocouple (TCA, Themocoax, Suresnes, France). A second thermocouple was secured on the external enamel surface. The tooth was placed over a thermally regulated water bath (Bioblock Scientific, AM3001K, Illkirch, France). Composite resin (Tetric Ceram A2, Ivoclar Vivadent, St. Jorioz, France) was placed into the preparation without an adhesive to allow for easier removal. Two quartz-tungsten-halogen (QTH) and one light-emitting diode (LED) curing light (Astralis 10, Ivoclar Vivadent, Schaan, Liechtenstein; Swiss Master Light, EMS, Nyon, Switzerland; FreeLight 2, 3M ESPE, Seefeld, Germany) were used at three different curing times at a distance of 1 mm from the specimen. External and internal temperatures were recorded continuously over 360 seconds (Fluke Hydra 2620A and Hydra Logger, Fluke Corp., Everett, WA, USA). Teeth were sectioned in half and positioned 1 mm above the water bath. A thermographic camera (TST-2000ST, Avio Tech, Japan) was placed perpendicular to the cross-section of the tooth. The composite resin was again inserted into the tooth and irradiated as before. The resulting thermal image represented the temperature distribution on the specimen surface. Thermal images were obtained at different time intervals (5, 10, 20, 40, and 60 seconds). Mean maximum temperature values and standard deviations were calculated for each condition ($N = 6$) and analyzed using one-way analysis of variance (ANOVA) and Fisher's least significant difference ($\alpha = 0.05$).

Results: For all curing units, increasing the irradiation time always increased the external and internal temperature of the tooth, as measured with thermocouples and IR images. IR images also showed that external temperatures were consistently lower than temperatures recorded inside the composite material and that heat was able to propagate toward the internal aspects of the tooth into the pulp chamber.

Conclusions: The QTH curing lights, with higher irradiance, caused higher tooth temperatures than the LED source, and increased light exposure increased the temperature of the tooth. IR images revealed more detailed information than thermocouples about temperature distribution and temperature changes within the restoration.

COMMENTARY

Studies have suggested that the thermal increase to tooth structure produced by light-curing units can cause pulpal damage. However, it is very difficult to predict the temperature rise in any particular tooth resulting from multiple variables such as preparation depth, remaining dentin thickness, output intensity of the curing light, and exposure time. Previous studies have shown that intrapulpal temperature rise during light-curing is low because dentin is an excellent thermal insulator. Understandably, the increased irradiance of the latest generation of curing lights has renewed concerns. Although the actual critical temperature necessary to cause pulpal damage is controversial, pulpal temperature changes should be kept as minimal as possible.

The lower heat emission of LED curing lights has been promoted commercially as a distinct advantage over other types of curing lights. Early studies suggested that LED curing lights, with their narrow spectral emission, generate significantly less heat from the light guide than QTH lights. However, the first generation of LED curing lights had low irradiances. The latest generation of LED lights has much higher irradiances and, therefore, potentially much higher thermal emissions. Although this study found that the LED curing light produced the lowest temperature rise in teeth, it had the lowest irradiance of the tested lights. The data appeared to show a correlation between irradiance and temperature rise. A recent study evaluating 10 LED and 3 QTH curing lights found that temperature rise in composite resin increased with irradiance. The authors concluded that, in general, the belief that LED curing units produce less temperature rise than QTH units does not hold true.

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THE EFFECT OF DISTANCE FROM LIGHT SOURCE ON LIGHT INTENSITY FROM CURING LIGHTS

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ABSTRACT

Objective: The purpose of this study was to investigate how light intensity changes with distance from the tip of the light guide.

Materials and Methods: Ten different curing light (ie, QTH, LED, plasma arc) and light-guide combinations (ie, standard and turbo fiberoptic) were used to investigate how light intensity varies with distance through air. The light irradiance was measured at 0, 3, 6, and 10 mm from the tip of the light guide using a radiometer (Cure Rite, Dentsply Caulk, Milford, DE, USA). Measurements were repeated in five separate trials and the mean irradiance and standard deviation were calculated. Repeated measures ANOVA was used to test for significant differences in the rate and extent of change in irradiance with increasing distance from the tip of the light guide. The irradiance produced by each curing light was ranked at each distance with Tukey's Studentized Range test ($\alpha = 0.05$). The number of fibers per square millimeter of the entrance and exit ports of the light guides was measured for the light guides using a photomacrographic camera (Zeiss, Oberkochen, Germany).

Results: As the distance increased, the irradiance decreased more rapidly from the turbo than from standard light guides. Turbo light guides delivered higher irradiance at distances of 0 and 3 mm, but at distances of 6 and 10 mm, the standard light guides delivered higher irradiance. The cross-sectional area of the entrance fibers was larger than that of the exit fibers for the turbo light guides. Not all light guides are assembled in the same manner, with some containing regular fibers and others containing irregular fibers.

Conclusions: This study showed that the light irradiance over distance is dependent on the type of light guide. Although turbo light guides may successfully boost the irradiance of a curing light, that advantage might be quickly lost at greater curing distances.

COMMENTARY

Manufacturers often promote the irradiance of their curing lights, typically with irradiance measurements recorded near the tip of the light guide. Although it is recognized that irradiance will naturally decrease with distance, it can—as was found with this well-done study—decrease more rapidly with turbo light guides. A light marketed as "the most powerful curing light on the planet" may not have the highest irradiance at greater curing distances if the dispersion of its light is high. This is clinically relevant because most often the light guide cannot be positioned immediately adjacent to the photo-initiated material, especially in deeper proximal areas of a preparation. One study found that beyond 5 mm, a standard fiber-optic light guide delivered greater irradiance than a turbo light guide using the same curing light. In addition to standard and turbo fiber-optic light guides, some curing lights may use solid acrylic and simple aperture openings (ie, no light guide), producing highly variable light dispersion.

The authors used a Cure Rite radiometer to measure irradiance in this study. Several reports have determined that handheld dental radiometers can provide an accurate means of correlating irradiance and visible-light curing-unit performance. However, the accuracy of handheld dental radiometers is sensitive to the light-guide exit diameter. Radiometers that have a fixed aperture are calibrated to determine irradiance based on the area of their fixed aperture independent of the light-guide exit diameter. Accordingly, light-guide exit diameters of less than the standard 7.5-mm diameter can underestimate irradiance while larger tips tended to overestimate curing unit performance.

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POLYMERIZATION EFFICIENCY OF CURING LAMPS: A UNIVERSAL ENERGY CONVERSION RELATIONSHIP PREDICTIVE OF CONVERSION OF RESIN-BASED COMPOSITE

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ABSTRACT

Objective: The purpose of this study was to describe a universal energy-conversion relationship (ECR_u) predictive of conversion of a composite resin polymerized using any light source and to predict scrape-back lengths of composite resins polymerized with both QTH and LED curing lights.

Materials and Methods: A universal energy-conversion relationship predictive of conversion of a composite resin polymerized with any light source was derived from an ECR for a composite resin (Z100, shade A3.5, 3M ESPE, St. Paul, MN, USA) polymerized with a QTH curing light (XL 3000, 3M ESPE) and the light's efficiency relative to a hypothetical lamp. The composite resin was packed into a split stainless-steel mold (6 × 16 mm). The specimen was exposed for 60 seconds from the QTH curing light. The output from the QTH light was adjusted, using a variable transformer, to match the irradiance of an LED light (FreeLight, 3M ESPE).

At 24 hours, the specimen was split and analyzed along its entire length using transmission FTIR microscopy (Nic-Plan Microscope, Magna-IR 750, Nicolet, Madison, WI, USA). Three cylinders were prepared and analyzed for each group with three to five specimens measured at each depth to determine degree of conversion. Transmittance was determined by placing the polymerized specimens on the detector of a power meter (351 Power Meter, UDT Instruments, Baltimore, MD, USA). A minimum of three replications was completed for each condition and a mean value was determined. Transmission as a function of thickness was determined by regression analysis of data. The energy exposure at various depths was determined from the incident energy and the transmittance. The relative efficiencies of the QTH and LED curing lights were expressed relative to a hypothetical standard light source. This output was multiplied by the camphorquinone (CQ) spectral absorbance, defining a standard relative energy absorption.

The spectral emission curves of the QTH and LED curing lights were also obtained using a spectroradiometer (Model S2000, Ocean Optics, Dunedin, FL, USA) and multiplied by the normalized CQ curve, yielding areas when divided by the standard area, gave the relative curing light efficiencies. An ECR_u was obtained by multiplying the previous scale by the efficiency factor of the QTH curing light. Conversion throughout the cylinder of the composite resin polymerized with the LED curing light was then predicted from the relative efficiency factor of the LED and the ECR_u.

The critical scrape-back energy related to the LED curing light was used to predict scrape-back lengths for the composite resin at various energy densities. The composite resin was packed into the cylindrical molds once again and exposed to the LED curing light at various energy densities to experimentally verify the predicted scrape-back lengths. After 24 hours, the poorly polymerized material was gently scraped off and the resulting cylinder length was measured. Three replicates were prepared and measured to the nearest 0.01 mm.

Results: An ECR_u was described, and was predictive of conversion of a composite resin polymerized with any light source by means of an efficiency factor for that light source. The universal scale was predictive of scrape-back lengths for the composite resin when polymerized from any light source. The predictions rely on characterization of light efficiency in comparison to the described hypothetical light source. From the relative efficiencies of the curing lights, it was predicted and experimentally verified that the LED curing light would cure the composite resin to greater depths than the QTH curing lights with an equivalent energy density.

Conclusions: Despite a 31% greater relative efficiency of the LED, scrape-back lengths from the composite resin polymerized using the LED curing light were predicted and experimentally verified to be only 6% greater than those polymerized with the QTH curing light on an equal energy density basis. Because of the exponential decay of light through the composite resin, a proportional increase in cure depth was not found.

COMMENTARY

The first generation of LED curing lights had relatively low irradiances, resulting in reduced depth of cure compared with QTH curing lights. However, some manufacturers made claims initially that the increased curing efficiency of the LED would compensate for the lower irradiance levels. This laboratory study by Halvorson and colleagues demonstrated an increase in depth of cure of a composite resin by the LED curing light compared with the QTH curing light at equal energy densities; however, the differences were minor and might not be clinically significant. The latest generation of LED lights generally has much higher irradiance values than the earlier LED lights and depth of cure similar to popular QTH curing lights. Instead of an array of very low-intensity LEDs, newer LED curing lights use a single LED with a larger semiconductor crystal that generates much greater light intensity.

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THE BOTTOM LINE

LED curing lights were introduced to the dental profession in the fall of 2001. LEDs, or light-emitting diodes, are special semiconductors that produce electroluminescence of light in a manner completely unlike the hot filament found in QTH lights. This difference reportedly provides a longer life span, more consistent output, lower power consumption, and reduced induced heat. The decreased power demand of LEDs allows the use of battery-powered units. However, in spite of marketing claims, the actual heat emitted from the tip of the light guide of LED curing lights has been found in recent laboratory studies to be similar to that of QTH curing lights at similar energy densities. Recent studies also suggest that, in general, the irradiance and depth of cure of the latest generation of LED curing lights are similar to those of popular QTH curing lights.

The energy from the LED is clearly defined by the semiconductor and most of the emitted light is concentrated in a narrow band around 470 nanometers, which is ideally suited for composite resins that use the photo-initiator CQ. However, the emission spectra from most LED curing lights are so narrow that they may not be absorbed by alternative photoinitiators (eg, phenylpropanedione). These photoinitiators, which are incorporated into a few photo-initiated dental materials, absorb light energy in lower regions of the visible light spectrum. In response, some dual-spectrum LED curing lights have been introduced. These have additional diodes that produce a bimodal emission spectrum, reportedly curing all photo-initiated dental materials. Fortunately, very few dental materials use the alternative photo-initiators exclusively and concern over the use of LED curing lights may be exaggerated.

When comparing curing lights, keep in mind that irradiance is only one factor in curing potential. The dispersion of light from the light guide can have a significant impact on the composite resin polymerization. Curing lights that display lower irradiances up close might perform better than higher-powered units that have greater light dispersion.

Another variable feature of LED curing lights is its cooling mechanism. Many LED curing lights do not incorporate a fan, allowing a smaller handpiece design and easier infection control. The use of a fan allows sufficient cooling to provide continuous operation. An LED curing light without a fan typically relies on a heat sink for heat dissipation and may power down for several minutes after a few minutes of continuous use. Although this may not be clinically significant during routine operation, the curing of multiple restorations, such as in a complex veneer case, may cause a disruption in treatment.

Dental LED light-curing technology is still in its early development and the popularity of LED curing lights is expected to increase with continuing improvements in design and function. As with most new technology, it takes several years of published research to determine the actual advantages and disadvantages of the resultant products.

DISCLOSURE

The views expressed in this article are those of the authors and do not reflect the official policy of the Department of Defense or other departments of the US government. The authors have no financial interest in any of the companies whose products are included in this article.

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