Effect of Light Dispersion of LED Curing Lights on Resin Composite Polymerization

KRAIG S. VANDEWALLE, DDS, MS*
HOWARD W. ROBERTS, DDS†
JEFFREY L. ANDRUS, DDS‡
WILLIAM J. DUNN, DDS§

ABSTRACT

Purpose: This study evaluated the effect of light dispersion of halogen and LED curing lights on resin composite polymerization.

Materials and Methods: One halogen (Optilux 501, SDS/Kerr, Orange, CA, USA) and five light-emitting diode (LED) curing lights (SmartLite iQ, Dentsply Caulk, Milford, DE, USA; LEDemetron 1, SDS/Kerr; FLASHlite 1001, Discus Dental, Culver City, CA, USA; UltraLume LED 5, Ultradent Products, South Jordan, UT, USA; Allegro, Den-Mat, Santa Maria, CA, USA) were used in this study. Specimens (8 mm diameter by 2 mm thick) were made in polytetrafluoroethylene molds using hybrid (Z100, 3M ESPE, St. Paul, MN, USA) and microfill (A110, 3M ESPE) composite resins. The top surface was polymerized for 5 seconds with the curing light guide tip positioned at a distance of 1 and 5 mm. Degree of conversion (DC) of the composite specimens was analyzed on the bottom surface using micro-Fourier Transform Infrared (FTIR) spectroscopy (Perkin-Elmer FTIR Spectrometer, Wellesley, PA, USA) 10 minutes after light activation. DC at the bottom of the 2 mm specimen was expressed as a percentage of the mean maximum DC. Five specimens were created per curing light and composite type ($n = 5$). Percent mean DC ratios and SDs were calculated for each light under each testing condition. Data were analyzed by analysis of variance (ANOVA)/Tukey's test ($\alpha = .05$). A beam analyzer (LBA-700, Spiricon, Logan, UT, USA) was used to record the emitted light from the curing lights at 0 and 5 mm distances ($n = 5$). A Top Hat factor was used to compare the quality of the emitted beam profile (LBA/PC, Spiricon). The divergence angle from vertical was also determined in the x- and y-axes (LBA/PC). Mean values and SDs were calculated for each light under each testing condition (0 and 5 mm, x- and y-axes) and analyzed by a two-way ANOVA/Tukey's test ($\alpha = .05$).

Results: For DC ratios, significant differences were found based on curing light and curing distance ($p < .05$). At 1 mm, Optilux 501 and FLASHlite 1001 produced significantly higher DC ratios with the hybrid resin composite. No differences were found among lights with the microfill at 1 mm. At 5 mm, SmartLite iQ, FLASHlite 1001, LEDemetron 1, and UltraLume LED 5 produced significantly higher DC ratios with the hybrid resin composite, whereas LEDemetron 1 and SmartLite iQ produced significantly higher DC ratios with the microfill resin composite.

*Colonel, USAF Dental Corps, and director, Dental Materials and Testing, USAF Dental Investigation Service, Great Lakes, IL, USA
†Colonel, USAF Dental Corps, and fellow, Department of Biomaterials, Marquette University Dental School, Milwaukee, WI, USA
‡Lieutenant Colonel, USAF Dental Corps, and clinical flight commander, Kirtland AFB, NM, USA
§Colonel, USAF Dental Corps, and deputy program director, Advanced Education in General Dentistry, Keesler AFB, MS, USA

The UltraLume LED 5, Allegro, and Optilux 501 had significant reductions in mean DC ratios at curing distances of 1 and 5 mm with both resin composite types. For dispersion of light, significant differences were found in Top Hat factor and divergence angle ($p < .001$). SmartLite iQ had overall the highest Top Hat factor and lowest divergence angle of tested lights. A linear regression analysis relating pooled DC with pooled Top Hat factors and divergence angles found a very good correlation ($r^2 = .86$) between dispersion of light over distance and the ability to polymerize resin composite.

CLINICAL SIGNIFICANCE

The latest generation of LED curing lights provides DC ratios similar to or better than the halogen curing light at a curing distance of 5 mm. Dispersion of light plays a significant role in the DC of resin composite. To maximize curing effectiveness, light guides should be maintained in close proximity to the surface of the light-activated restorative material.

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Dental professionals have a variety of curing lights available to them, such as quartz-tungsten-halogen (QTH), plasma arc, laser, and light-emitting diode (LED). The relatively broad emission spectrum of QTH curing lights allows them to initiate polymerization of all known photoactivated resin-based restorative materials. The principal output from these lamps is infrared energy with the generation of high heat. Filters are used to reduce the heat energy to oral tissues and to provide further restriction of visible light to better correlate with the narrower absorbance spectrum of photoinitiators. Finally, a silver-coated dichroic reflector passes infrared energy out the back and reflects and focuses the light forward to provide a focal area of energy at a defined distance. Ultimately, 99.5% of the original radiation is eliminated.[1] Owing to high operating temperatures, QTH bulbs have a limited lifespan. The reflector, bulb, and filters can degrade over time, reducing the light's curing effectiveness.[1,2]

LED curing lights use special semiconductors to generate electroluminescence rather than the hot filament found in QTH lights. This difference reportedly provides a longer life span, more consistent output, and lower power consumption.[3] No significant ultraviolet or infrared light is emitted, thereby reducing induced heat and minimizing the need for a noisy fan. Since the energy is clearly defined by the semiconductor, most of the light emitted is concentrated in a narrow band around 470 nm, which is ideally suited for composite resins that use the photoinitiator camphorquinone (CQ). The decreased power demand of LEDs allows the use of battery-powered units.[4]

The first generation of LED curing lights had low irradiances.[5,6] These lower values required longer exposure times to deliver equivalent energy densities and depth of cure. The latest-generation LED lights generally have much higher irradiance values and potentially a much greater depth of cure.[7] Also, studies have suggested that LED curing lights demonstrate greater curing efficiency than do QTH lights. The narrow emission spectrum of an LED curing light reportedly provides greater depth of cure than a halogen curing light at similar irradiance levels.[8,9]

Depth of cure of resin composite may be affected by composite-related and light-related factors. Composite-related factors include shade, translucency, type and concentration of photoinitiator, and filler-particle size, load, and distribution. Light-related factors include irradiance, spectral distribution, exposure time, and light dispersion.[10,11] As the intensity of the light source increases, more photons are available for absorption by the photoinitiators. With more photons available, more CQ molecules are raised to the excited state to react with the amine activator and form free radicals for polymerization.[12] At the top surface, polymerization is greater because of the unhindered availability of photons. However, deeper in the composite, attenuation of light leads to the gradation of cure within the depths of the material and is responsible for what has become known as depth of cure.[12] To compensate for this gradation of cure, the duration of exposure can be increased, within practical limits determined by the properties of the material and light source, providing enhanced opportunity for creation of free radicals.[13] Reduced degree of conversion (DC) may adversely affect the mechanical properties of resin composites. There appears to be a good correlation between decreasing DC and decreasing hardness,[14] fracture toughness,[15] and abrasive wear resistance.[16]

Emission from curing lights that is minimally divergent and evenly distributed horizontally across the face of the light guide may maximize curing effectiveness. Different curing-light guides can have a dramatic influence on the focusing effect, or dispersion of the emitted light. Price and colleagues found that as the distance from the tip of a light guide increased, the irradiance decreased, but the rate of decrease was greater for turbo light guides than for standard light tips.[17] This difference is clinically important because the light guide cannot always be positioned immediately adjacent to the photoinitiated material.

Beam analyzers have been used to evaluate the quality of laser beam emissions.[18] The technology of beam analyzers using camera sensors has advanced rapidly.[18] Commercial instruments are now available from multiple vendors. A complete beam diagnostic system includes a camera to capture the beam, a monitor to display the results, and a computer with software for beam analysis.[18] Beam analysis of dental curing lights has not been accomplished and may provide additional quantitative information.

The purpose of this study was to evaluate the effect of light dispersion of halogen and LED curing lights on monomer conversion of two classifications of contemporary resin composite materials: a hybrid and a microfill. The hypothesis tested was that curing lights showing the least beam dispersion would demonstrate the greatest ability for resin composite polymerization at greater curing distances.

MATERIALS AND METHODS

Degree of Conversion

One QTH and five LED curing lights were used in this study and are listed in Table 1. Specimens were made using hybrid (Z100, 3M ESPE, St. Paul, MN, USA) and microfill (A110, 3M ESPE) composite resins. Specimens were fabricated in 8 mm diameter by 2 mm thick polytetrafluoroethylene molds placed on a clear polyester sheet (Mylar, DuPont, Wilmington, DE, USA) on a flat glass slide (1 mm thick). The resin composite was placed in the mold, and then covered with another clear polyester sheet. The resin composite was covered with a second glass slide under pressure to extrude excess and to provide a smooth, non-air-inhibited surface. A new, clean polyester sheet was used for each specimen.

The top surface was polymerized with one of the curing lights for 5 seconds with the light guide tip touching the glass slide in half the specimens and the light guide tip positioned 4 mm away from the glass slide in the other half. A 5-second exposure time was selected to prevent specimens from maximally polymerizing and to allow relative comparisons of curing ability between curing lights. The curing lights were held in place by a clamp and positioned so that the light would be directed at 90° to the composite specimen surface. Each specimen was measured with an electronic digital caliper (Max-9, Fowler Ltd., Louisville, KY, USA) to ensure a uniform thickness of 2.0 ± 0.1 mm. Five specimens were created per curing light and composite type ($n = 5$).

TABLE 1. CURING LIGHTS TESTED.

Curing Light	Manufacturer	Type of Light Guide	Light Guide Diameters: Entrance/Exit (mm)
Allegro	Den-Mat, Santa Maria, CA, USA	Uncoated solid acrylic	14/8
FLASHlite 1001	Discus Dental, Culver City, CA, USA	Aperture only	NA/7.5
LEDemetron 1	SDS/Kerr, Orange, CA, USA	Coated fiber optic	12/10
Optilux 501 (halogen)	SDS/Kerr	Coated fiber optic	12.5/8
SmartLite iQ	Dentsply Caulk, Milford, DE, USA	Coated fiber optic	13/7.5
UltraLume LED 5	Ultradent Products, South Jordan, UT, USA	Aperture only	NA/10 × 14

The LED curing lights were charged according to manufacturers' directions and placed back in their battery chargers after each specimen was polymerized. To minimize the effect of a battery running low from continuous use, the curing lights were used in sequence with a different brand of light for each specimen.

The DC of the composite specimens was analyzed on the bottom surface using micro-Fourier Transform Infrared (FTIR) spectroscopy (Perkin-Elmer FTIR Spectrometer, Wellesley, PA, USA) 10 minutes after light activation. The specimens were stored dry in a light-proof container and then placed on the Attenuated Total Reflectance window (Universal ATR Sampling Accessory, Perkin-Elmer) and held in place horizontally with uniform pressure to ensure intimate contact with the surface of the specimen. Spectral analyses were performed using the provided software (Spectrum One, Perkin-Elmer).

Each specimen was scanned by the FTIR on three separate runs. The intensities of the carbon double bond (C=C) absorbance peak at 1637.3 cm^{-1} and aromatic (C—C) reference peak at 1608.3 cm^{-1} were measured with four scans at a resolution of 4.0 cm^{-1}. The ratio of the absorbance of aliphatic (C=C) 1637.3 cm^{-1} and aromatic (C—C) 1608.3 cm^{-1} peaks before and after polymerization were measured using the baseline technique to calculate the DC.[19] The DC at the bottom of the 2 mm specimen was expressed as a percentage of the mean maximum DC to prevent errors when comparing groups with top surfaces that had cured less. In a study by Vandewalle and colleagues,[20] acceptable polymerization of a resin composite (Z250, 3M ESPE) was found to have occurred when a test specimen's bottom surface DC was at least 80% of the maximum. The maximum DC was measured by curing five specimens of both composites for 40 seconds on each side using the Optilux 501 curing light and determining a mean maximum (Z100 42.5%, A110 49.4%). Percent mean DC ratios and SDs were calculated for each light under each testing condition. Data were analyzed by a three-way analysis of variance (ANOVA)/Tukey's test (α = .05) to evaluate the effects of composite type, tip-to-target distance, and curing light type on mean DC ratios using SPSS software (SPSS, Chicago, IL, USA).

Light Distribution and Divergence

A beam analyzer (LBA-700, Spiricon, Logan, UT, USA) was used to record the emitted light from the curing lights. The curing lights were held in place by a clamp and positioned so that the face of the light guide was directed at 90° to a white optical screen (Da-Mat no. 40465, Da-Lite Screen Co., Warsaw, IN, USA). The curing lights were mounted on a moveable stage, and the light guide was placed at 0 and 5 mm distances from the screen. Correct distances were maintained with the use of an electronic digital caliper (Max-9) mounted on the stage. The transmitted light projection was imaged with the beam analyzer mounted at distance of 1.35 m from the screen.

Five images were recorded per light and distance (0 and 5 mm) and analyzed with the provided software (LBA/PC Version 4.06, Spiricon). The power was measured for each light at each distance using a power meter (PowerMax 5200 and PM10 probe, Molectron, Portland, OR, USA). The two-dimensional image was encircled, and the total area was assigned the corresponding power value. The software determined the irradiance levels in a color-coded distribution across the image. A Top Hat factor was determined (LBA/PC Version 4.06) and used to compare the quality of the emitted beam profile. Examination of a plot of a beam's energy fraction versus its normalized fluence derives the Top Hat factor. The energy fraction is defined as the fraction of total energy above a particular fluence value. The area under the energy fraction curve describes the quality of a Top Hat's energy distribution. The equation below describes how the curve of a particular beam profile is derived from pixel intensity data[18,21]:

$$E(f) = \sum_{i=Pk}^{f} \frac{i \times NPix}{Total}$$

where E is the fraction of energy contained between the fluence value and the peak value, f is the fluence value, Pk is the peak fluence value, *Total* refers to the total energy in the beam, and $NPix$ represents the number of pixels that have the value of 1.

The Top Hat factor (F) is the sum of the area under the curve formed from the equation above, as shown below. A perfect Top Hat has vertical sides and uniform intensity across the top. A factor of 1.0 describes the perfect Top Hat[18]:

$$F = \frac{\displaystyle\sum_{f-1}^{Pk-1} \frac{E_f + E_{f+1}}{2}}{Pk}$$

The divergence angle of the light projections from vertical was also determined in the x- and y-axes (LBA/PC Version 4.06).[18,21] The divergence angle was determined from the captured images at 0 and 5 mm curing distances for each light using the following formula:

$$\text{Divergence} = 2 \cdot \tan^{-1}\left[\frac{W_C - W_R}{2 \cdot S}\right]$$

where W_R represents the width of the beam at the near location, W_C represents the width of the beam at the far location, and S is the separation distance between the two beams.

Mean values and SDs were calculated for each light under each testing condition (0 and 5 mm, x- and y-axes) and analyzed by a two-way ANOVA/Tukey's test ($\alpha = .05$) to evaluate the effects of distance and curing light on mean Top Hat factor, and also the effects of axis and curing light on mean divergence angle.

The irradiance over distance was measured for each light using a power meter (PowerMax 5200 and PM10 probe). The curing light was held in place with a clamp and ring stand, and the window of the power meter probe was dropped from the light guide in 1 mm increments from 0 to 20 mm on a moveable stage. Correct distances were maintained with the use of an electronic digital caliper (Max-9) mounted on the stage. Three separate recordings were made for each light. Mean irradiance values and SDs were calculated for each 1 mm increment. However, the tip of the UltraLume LED 5 aperture did not completely fit into the well of the probe of the power meter owing to the unique, flat design of the handpiece. Power readings were made at only a 7 mm distance.

Light diffusion images were obtained by mounting each curing unit on a ring stand and projecting the light parallel across the surface of flat black paper. Images were captured with a digital camera (Nikon D1, Belmont, CA, USA), mounted on a ring stand and maintained at identical exposure settings for each light.

The emission spectra of the curing lights were recorded with a spectrophotometer (PR-650, Photo Research Inc, Chatsworth, CA, USA) at a distance of 1 m from a standardized white reflecting surface. The spectral absorbance of CQ (ScienceLab, Kingwood, TX, USA) was determined in methanol using an ultraviolet-visible spectrophotometer (8452A, Hewlett Packard, Palo Alto, CA, USA).

RESULTS

The mean DC ratios resulting from the different curing lights are summarized in Table 2. Significant differences were found in DC ratios based on composite ($p < .0001$), distance ($p < .0001$), and curing lights ($p < .0001$). However, significant interactions were present. The data were analyzed by a one-way ANOVA with Tukey's post hoc test ($\alpha = .05$) by curing light at each curing distance. Significant differences were found based on curing light and distance ($p < .05$). At 1 mm, Optilux 501 and FLASHlite 1001 produced significantly higher DC ratios with the hybrid resin composite. No differences were found between lights with the microfill at 1 mm. At 5 mm, SmartLite iQ, FLASHlite 1001, LEDemetron 1, and UltraLume LED 5 produced significantly higher DC ratios with the hybrid resin composite, whereas LEDemetron 1 and SmartLite iQ produced significantly higher DC ratios with the microfill resin composite. The UltraLume LED 5, Allegro, and Optilux 501 had a significant reduction in mean DC ratios between 1 and 5 mm curing distances with both resin composite types.

The mean Top Hat factors and divergence angles resulting from the different curing lights are summarized in Table 3. Figures 1 and 2 illustrate the intensity profile displays of SmartLite iQ and Optilux 501 in two-dimensional (2-D) color contours and three dimensional (3-D) isometric views on the face of the light guides (ie, 0 mm). Significant differences were found in Top Hat factor based on distance ($p < .0001$) and curing light ($p < .0001$). Significant differences were also found in divergence angle based on curing light ($p < .0001$). No significant difference was found on divergence angle based on axis ($p > .245$). SmartLite iQ had the overall highest Top Hat factor and lowest divergence angle of tested lights. A linear regression analysis was performed relating pooled DC with pooled Top Hat factors and divergence angles using SPSS software. A linear function of the following equation was determined with an r^2 equal to .86:

$$DC = 37.47 + (26.37 \times \text{Top Hat}) - (0.04 \times \text{Angle})$$

Lateral light projections recorded with the Nikon camera are shown in Figure 3. The mean divergence angles calculated with the beam analyzer are superimposed on the images. The percentages of maximum irradiance over a 20 mm distance from the tip of each light guide are shown in Figure 4. The

TABLE 2. MEAN DC RATIOS OF COMPOSITE RESINS AT 1 AND 5 mm AFTER 10 MINUTES.*

Curing Light	Irradiance (mW/cm²) 1 mm	Mean DC Ratios† (SD) for Z100 1 mm	Mean DC Ratios† (SD) for Z100 5 mm	Mean DC Ratios† (SD) for A110 1 mm	Mean DC Ratios† (SD) for A110 5 mm
SmartLite iQ	679	69.4 (4.6) Ab	68.3 (2.5) Aa	38.6 (3.1) Ba	38.0 (2.0) Bab
LEDemetron1	598	68.0 (2.3) Ab	67.7 (3.1) Aab	38.3 (4.2) Ba	40.0 (4.1) Ba
FLASHlite 1001	1,032	73.8 (4.1) Aab	68.2 (7.4) Aa	41.4 (3.4) Ba	29.7 (6.5) Cbc
UltraLume LED 5	> 581	69.7 (3.7) Ab	62.1 (4.0) Babc	39.4 (3.7) Ca	20.7 (4.3) Dd
Allegro	1,390	70.3 (2.6) Ab	59.5 (4.9) Bbc	42.8 (2.5) Ca	24.4 (4.2) Dcd
Optilux 501	1,052	77.8 (2.7) Aa	54.2 (2.5) Bc	45.0 (3.7) Ca	28.2 (3.4) Dcd

*Upper case letters denote significant differences within each row. Lower case letters denote significant differences within each column.
†Mean DC ratios expressed as percentage of bottom DC/maximum DC.

TABLE 3. MEAN TOP HAT FACTORS AND DIVERGENCE ANGLES FROM VERTICAL FOR EACH CURING LIGHT.*

	Mean Top Hat Factor (1.0 = ideal) (SD)			Mean Divergence Angle in Degrees (SD)		
Curing Light	0 mm	5 mm	2-Way ANOVA	x	y	2-Way ANOVA
SmartLite iQ	0.759 (0.007)	0.565 (0.008)	a	13.6 (0.2)	13.6 (0.2)	a
LEDemetron 1	0.690 (0.005)	0.578 (0.010)	b	20.9 (0.7)	21.1 (0.9)	b
FLASHlite 1001	0.648 (0.006)	0.565 (0.005)	c	36.9 (1.8)	36.4 (1.9)	c
Optilux 501	0.565 (0.006)	0.546 (0.004)	d	46.6 (4.0)	47.5 (4.1)	d
UltraLume LED 5	0.593 (0.011)	0.453 (0.006)	e	64.3 (3.5)	59.3 (2.7)	e
Allegro	0.713 (0.014)	0.382 (0.007)	d	73.0 (1.4)	73.0 (3.2)	f

*Letters denote significant differences between lights by factor or angle.
ANOVA = analysis of variance.

irradiance of the Allegro dropped dramatically over distance, whereas SmartLite iQ maintained its irradiance relatively well.

The emission spectra of the six curing lights are displayed in Figure 5. The LED curing lights have narrow emission spectrums that peak near the absorption peak of CQ. The UltraLume LED 5 has a bimodal emission spectrum with a second peak near 400 nm.

DISCUSSION

The experimental data supports the stated hypothesis. Curing units demonstrating the least dispersion of light demonstrated the greatest resin composite polymerization at greater distances (5 mm). A very good correlation ($r^2 = .86$) between the dispersion of light and the DC was demonstrated in this study. Clinically, a light with a more evenly distributed energy across the face of the light guide (e.g., a higher Top Hat factor) may provide a more uniform polymerization of the restorative material, especially in cases involving larger surface areas. Also, a light with a lower divergence angle maintains its irradiance at greater curing distances, which would be significant when attempting to cure to the depth of proximal boxes. It was interesting to note that the SmartLite iQ and LEDemetron 1 curing lights, with relatively lower irradiances, were in the highest

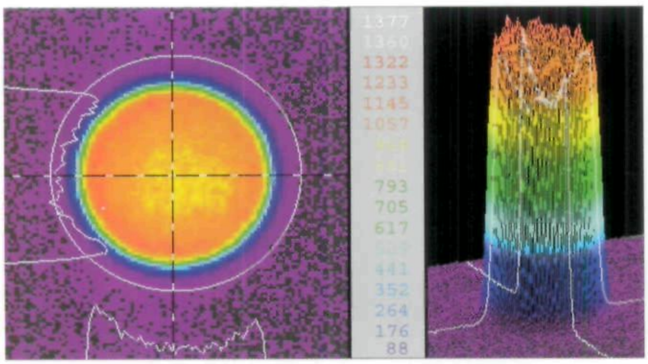

Figure 1. Two-and three-dimensional beam profiles of SmartLite iQ at 0 mm (Top Hat factor = 0.759) and corresponding irradiances in milliwatts per square centimeter. Total irradiance (white circle) *= 679 mW/cm²*.

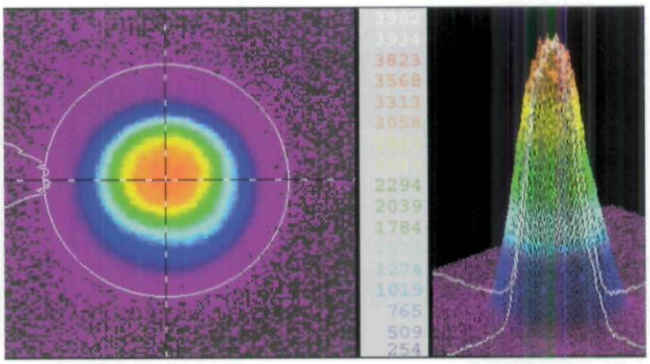

Figure 2. Two-and three-dimensional beam profiles of Optilux 501 at 0 mm (Top Hat factor = 0.565) and corresponding irradiances in milliwatts per square centimeter. Total irradiance (white circle) *= 1,052 mW/cm²*.

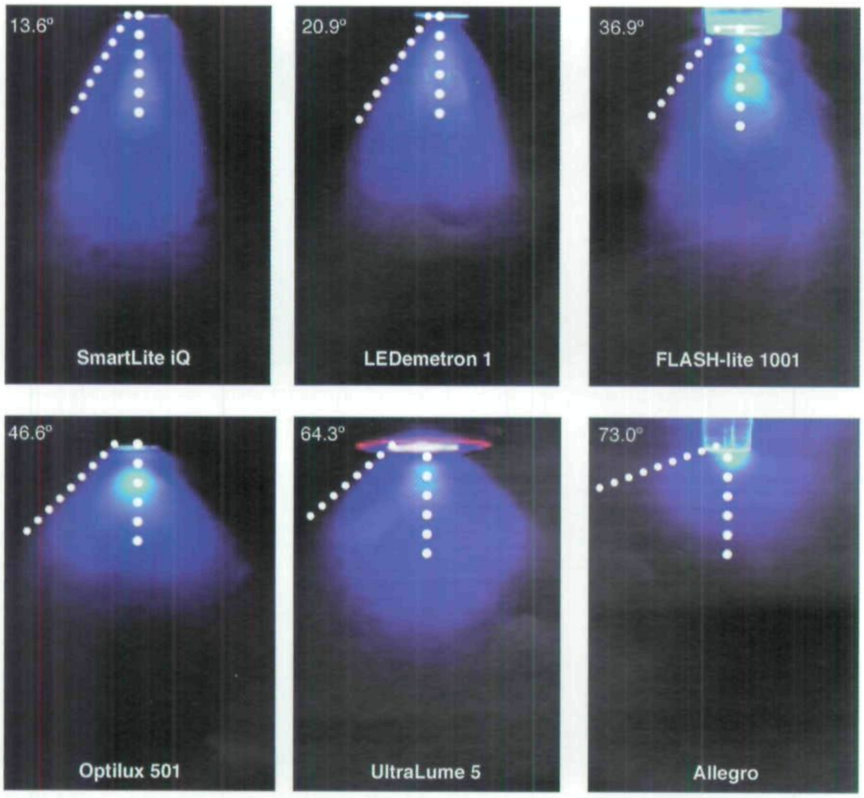

Figure 3. Camera images of light dispersion from the six tested curing lights and mean divergence angles (x-axis) from vertical measured with a beam analyzer.

group for the DC of both composite types at a curing distance of 5 mm, which is considered the average distance from the tip of a molar cusp to the pulpal floor of an average occlusal preparation.[17] The SmartLite iQ and the LEDemetron 1, both with fiber-optic tips, maintained irradiance more effectively over distance with higher Top Hat factors and lower divergence angles. The more uniform distribution and lower divergence of light may have contributed to increased curing efficiency. Possible factors contributing to a greater dispersion of light with other tested curing lights include the use of a solid acrylic light guide with the Allegro and the simple aperture opening with the UltraLume LED 5 and FLASHlite 1001. The standard fiber-optic tip of the LEDemetron 1 maintained the collimation of light better than the turbo tip used with the Optilux 501 curing light. However, the SmartLite iQ also used a turbo tip and was still able to collimate the light well. The differences may be related to the distribution and/or size of the individual fiber-optic bundles.

The precise distribution of a beam profile can affect the quality of the energy application. Depending on the application, the ideal beam profile is usually either a uniformly flattop beam (Top Hat factor = 1.0), often used to perform surface ablation with lasers and photoinitiated polymerization with dental curing lights; or a Gaussian distribution (Top Hat factor = 0.5), used to obtain the highest possible energy concentration in lasers used for excisions.[18] Beam profilers enable a user to visualize a beam by creating an intensity-profile display. These profiles are shown usually as 2-D color contours or 3-D isometric views. Both flattop and Gaussian beam profiles were found in this study as shown in Figures 1 and 2. Other information provided with the curing light beam analysis are peak irradiance levels and color-coded distributions of irradiance.

Another factor to consider when evaluating the curing efficiency of light curing units is the emission spectrum of the light. Studies have suggested that LED curing lights have greater curing efficiency over QTH lights.[8,9] These initial investigations used prototype, laboratory LED lights with a relatively large number of LEDs or reduced the output of the QTH light to coincide with the lower output of the LED light. Stahl and colleagues developed a model to explain the LED's curing effectiveness over QTH lights, stressing the importance of looking at the higher "integrated relative curing potential" of the

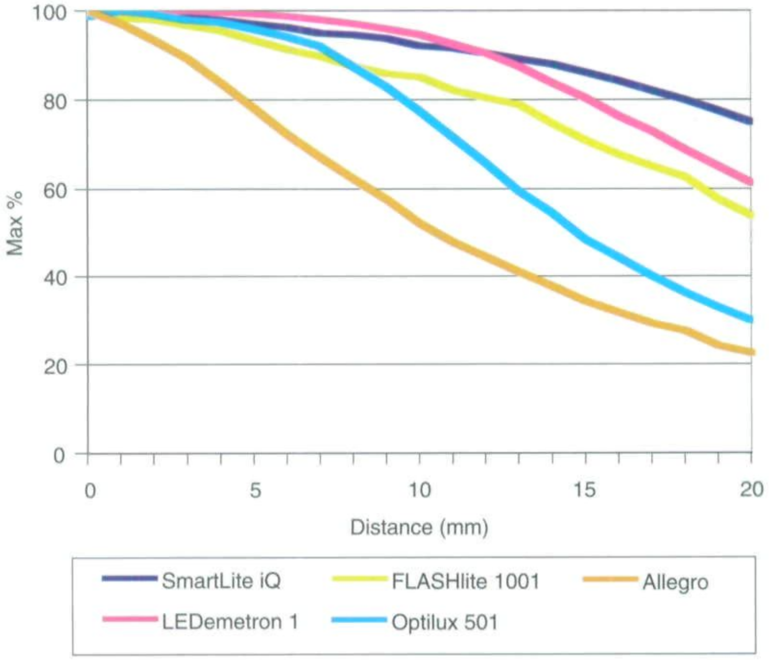

Figure 4. Percentage of maximum irradiance over a 20 mm distance from the tip of the light guides.

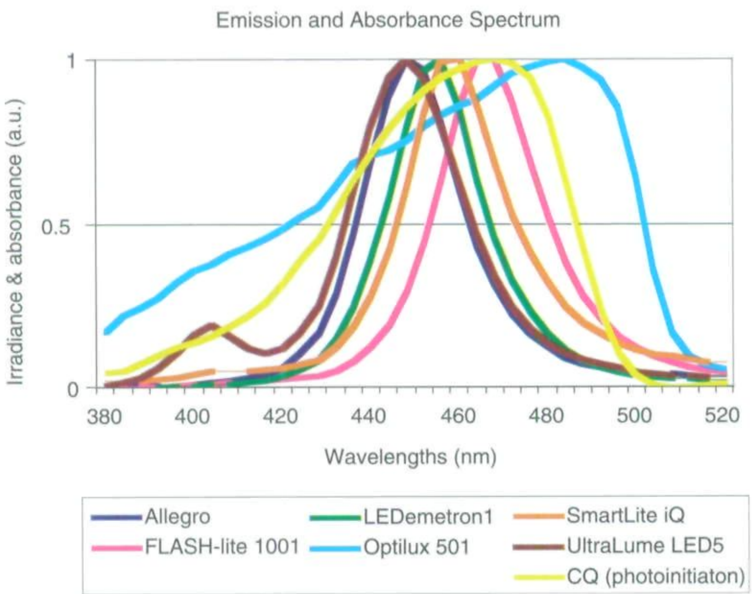

Figure 5. Spectral emissions of the curing lights and the absorption spectrum of camphorquinone (CQ).

LED with its narrow but more efficient emission spectrum.[22] Leonard and colleagues found that LED lights have a higher percentage of their output in the absorption spectrum of CQ compared with QTH curing lights.[6] However, a recent study by Halvorson and colleagues found that despite a 31% greater relative efficiency, "scrapeback" lengths from composite polymerized using the LED light were only 6% greater than those polymerized with a QTH light at similar energy densities.[23] Additionally, more recently published abstracts comparing commercially available LED and QTH lights have found no difference in curing efficiency at equal energy densities.[24,25] Using the same light guide, a study by Vandewalle and colleagues found no statistically significant differences in Knoop hardness ratios resulting from the use of a commercial LED curing light and a commercial halogen curing light at maximum output and similar power, irradiance, and energy densities in 2 mm composite specimens at curing distances of 1 or 5 mm.[26]

Traditionally, adhesive and resin composite systems have contained CQ, a visible-light-sensitive diketone photoinitiator responsible for initiating free-radical polymerization. CQ absorbs energy in the visible-light region of 400 to 500 nm with a peak at 468 nm. Photons associated with this frequency range are absorbed by CQ, raising it from the ground state to an excited, but short-lived, activated triplet state. When the excited triplet reacts with an amine co-initiator, an aminoalkyl free radical forms that is capable of initiating polymerization.[27,28] In a few products, new photoinitiators introduced by manufacturers (eg, phenyl-propanedione, Lucirin TPO [BASF Corporation, Florham Park, NJ, USA]) absorb light energy in shorter wavelength regions of the visible-light spectrum.[29] However, the emission spectra from most LED curing lights are so narrow, they may not be absorbed by the new photoinitiators. Without proper absorption, free radical polymerization may not occur.[4] UltraLume LED 5 is an LED curing light that contains multispectrum LEDs that reportedly cure all current photo-initiated dental materials.[30]

The assessment of the effectiveness of polymerization may be done directly or indirectly. Indirect methods include surface hardness,[14] optical,[31] and scraping.[32] Direct methods include laser Raman spectroscopy and infrared spectroscopy.[19,33] DeWald and Ferracane compared four modes of evaluating depth of cure of light-activated composites and found that the optical and scraping methods correlated well but that both overestimated the depth of cure when compared with hardness and DC values.[34] The DC was the most sensitive testing mode for evaluating depth of cure and was used in this study.

It was not surprising to find that the microfilled resin composite demonstrated a decreased DC ratio compared with the hybrid resin composite. Kawaguchi and colleagues showed that microfilled composites have a lower transmission coefficient and depth of cure than do hybrid and small particle composites.[35] Microfilled composite resins may be more difficult to cure because the natural agglomeration of their small filler particles may cause light to scatter, decreasing the effectiveness of the curing light.[36]

One disadvantage to this study, as with most studies evaluating curing light performance, was that only one light unit and guide was tested per brand. Significant variations in irradiance levels and light distribution could exist among individual lights made within the same manufactured unit types.

CONCLUSIONS

Based on the limitations of this study, the following conclusions may be made concerning the light curing units tested:

1. Overall, the latest generation of LED curing lights provided similar or better DC ratios than did the halogen curing light at a curing distance of 5 mm.
2. Dispersion of light plays a significant role in the DC of resin composite.
3. SmartLite iQ had the most uniform distribution and lowest divergence angle of light.
4. A beam analyzer allows quantitative measurements of curing light distribution and divergence.

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 United States Government. The authors do not have any financial interest in the companies whose materials are discussed in this article.

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Reprint requests: Kraig S. Vandewalle, DDS, MS, USAF SAM/DIS, 310C B Street, Building 1H, Great Lakes, IL, USA 60088; e-mail: ksvandewalle@nidbr.med.navy.mil

COMMENTARY

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

Fred Rueggeberg, DDS, MS*

The authors approached the problem of curing-light irradiance change over distance using elaborate analytic systems. Their methodologies were both novel and sound, and the results are extremely relevant to the practice of everyday dentistry. More than likely, all new dental light-curing units will be evaluated using these parameters.

**Professor and section director, Dental Materials, Department of Oral Rehabilitation, School of Dentistry, The Medical College of Georgia, Augusta, GA, USA*

Light diverges as it exits from the output end of a light guide or emitting element. The divergence can arise from a wide variety of factors. Whatever the factor, the extent of this divergence logically affects the rate at which power density decreases as the emitting end is moved away from the tooth (target) surface: the less the divergence, the less is the power density loss with increasing distance.[1–5] There are many clinical scenarios in which access to close placement of the light source to the target is greatly limited, resulting in lowered power density perhaps affecting the cure potential of the target restorative material, for example, the gingival floor of a deep Class II preparation inhibited by the top of the matrix band, and the pulpal floor of a deep Class I preparation interfered with by high, close cusp tips.[6]

The homogeneity of light across the exiting beam is also of importance. Because of the viscous nature of resin composites, conversion started in one location where high levels of light fall does not spread widely to others, meaning that uniform conversion does not occur on the top surface (nor underneath it) if the light striking the surface is not evenly distributed across the beam. Also, if the beam is not homogeneous, the nonuniform areas only get larger with distance, and the impact on restorative material cure may be even more severe.

The main results of this study indicate a large difference in beam divergence values among LED light types. The effect of this divergence on monomer conversion also indicated that the two were directly related. However, Top Hat factor (a measure of beam homogeneity; 1 = homogeneous) also decreased remarkably with tip-to-target distance but showed great differences in change among light types and was not correlated with beam divergence. The light unit demonstrating the least divergence and Top Hat factor closest to unity also demonstrated the least difference in conversion with tip movement for either composite type. Even though the emitted power density of this light was less than that for some of the others tested, at 5 mm distance, its performance was among the highest of all lights examined.

This article clearly demonstrates the large differences among contemporary LED curing lights. Even though units may generate similar power density levels at close distances, their performance may differ greatly when the clinician is forced to position the tip end away from the target. Also, units displaying lower power density up close may perform better than higher-powered units that have a greater light dispersion. It also nicely shows that merely placing card stock against the end of the curing tip and visually tracing the light divergence provides as precise a measure for divergence as does sophisticated laboratory instrumentation. Thus, clinicians can compare units for divergence at trade shows by tracing the patterns of sample lights on display and comparing them.

Today's curing-light market is literally flooded with different models, each seeming to make various claims on curing ability and features. However, the testing of power density (as with a hand-held dental curing radiometer) and comparison of dispersion values should give the clinician valuable information as to the probable performance level of a light.

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