Fall 2009
Volume 4 · Issue 4

ADA Professional Product Review®

A Publication of the Council on Scientific Affairs

In This Issue

Visible light-cured composite resins are commonly used in dentistry as restorative materials. In an attempt to more effectively and efficiently photo-polymerize these materials, curing lights based on different technologies have evolved over the years. Visible-light energy may be provided by different types of curing units: argon laser, quartz-tungsten-halogen (QTH) light, plasma-arc (PAC) or light-emitting diodes (LED). We evaluated seven LED lights, one QTH and one PAC light to show the differences among the different types of curing units. We focused on LED lights because of the product's popularity among respondents to our member survey.

LED lights use special semiconductors for the electroluminescence of light. Because the LED emission spectrum emits light in limited wavelength ranges, LED lights are designed to work efficiently. Manufacturers claim that their LED products don't generate as much heat as broad-spectrum sources like QTH and PAC lights, both of which need a filter that limits the emitted light to the violet-blue range. Also, LED lights can operate without a cooling fan and power cord, features that make these products portable and generally lighter than QTH and PAC lights. These are some of the qualities that have helped LED lights gain popularity in the marketplace.

This article offers one expert's opinion on what you should consider when buying a curing light for your practice. You'll learn about the various product features of the devices so that you can make an informed purchase decision based on your clinical preferences.

Unbiased.
Scientifically Sound.
Clinically Relevant.
User-Friendly.

Editor:
David C. Sarrett, DMD, MS

Senior VP, Science/ Professional Affairs:
Daniel M. Meyer, DDS

Director, Professional Product Review:
Mandy Chia, DDS, MBA

Director, Research and Laboratories:
John C. Kuehne, DDS, MS

Manager, Scientific Information Development:
Anita M. Mark

Scientific Writer:
Clayton A. Luz

Letters to the Editor/ Reprints and Permissions:
Mandy Chia, DDS, MBA
ppreditor@ada.org

www.ada.org/goto/ppr

ADA American Dental Association®
America's leading advocate for oral health

211 East Chicago Avenue
Chicago, Illinois 60611-2678

ISSN 1930-8736

Spectral Curing Lights and Evolving Product Technology

The Bottom Line, *David C. Sarrett, DMD, MS: Editor*

ACE Panel members selected the curing units reviewed in this issue, with each light offering its own advantages and disadvantages. In our laboratory testing, all of these lights met minimum standards for Irradiance (power density) and Depth of Cure at both 2 mm and 9 mm distance from the composite material when used according to the curing light manufacturers' recommendations for exposure time. Some lights provide a higher irradiance with a shorter exposure time, while others recommend or provide a lower power, or "soft cure," option with a longer exposure time. Size, weight, access, aesthetics and, of course, cost also are important personal considerations that affect the choice of a curing light. This issue provides a thorough discussion of the various considerations involved with selection and use of a curing light for your office. In short, any of these lights can perform adequately using a well-controlled clinical technique (e.g., good proximity, angulation and coverage of the light beam to the restoration and a fully charged battery). It appears that incremental curing of 2-mm thick layers of composite also continues to be the best way to ensure maximal curing with any light technique. Potential advantages as well as concerns using a trans-illumination curing technique also are discussed.

Aurora
Parkell
800.243.7446
www.parkell.com

Demi
Kerr Corp.
800.537.7123
www.kerrdental.com

Q-Lite
DiaDent
877.342.3368
www.diadent.com

Bluephase 16i*
Ivoclar Vivadent
800.533.6825
www.ivoclarvivadent.us

Fusion
DentLight, Inc.
877.570.9748
www.dentlight.com

Sapphire Plasma Arc Curing Light
DenMat
800.445.0345
www.denmat.com

Bluephase G2
Ivoclar Vivadent
800.533.6825
www.ivoclarvivadent.us

Optilux 501
Kerr Corp.
800.537.7123
www.kerrdental.com

Smartlight IQ2 LED Curing Light
DENTSPLY Caulk
800.LD.Caulk (800.532.2855)
www.caulk.com

* According to the manufacturer, the Bluephase 16i model was discontinued earlier this year and a new model, the Bluephase 20i, has been introduced.

Table 1. **Curing Light Product Features According to Manufacturer.**

Product Manufacturer	Light Source	Power Options	Radiometer Included (yes/no)	Cure Time Options (seconds)	Battery Type Replacement Cost	Time to Fully Charge*	Manufacturer Stated Weight (ADA measured weight†)	Price‡ Warranty§
Aurora Parkell	LED	Cordless	No	20, 40 s	Li-Ion $29.99	4 hours	113 g (132 g)	$399 2 years, including battery
Bluephase 16i Ivoclar Vivadent	LED	Cordless with corded option	Yes	5, 10, 15, 20, 30 s	Li-Ion $150	2 hours	269 g (288 g)	$1495 3 years 1 year on battery
Bluephase G2 Ivoclar Vivadent	LED	Cordless with corded option	No	5, 10, 15, 20, 30 s	Li-Po $165	2 hours	255 g (257 g)	$1200 3 years 1 year on battery
Demi Kerr Corp.	LED	Cordless	No	5, 10, 20 s	Li-Ion $108.15	2.5 hours	155 g (155 g)	$1390.29 2 years 1 year on battery
Fusion** DentLight, Inc.	LED	Cordless with corded option	No	5, 10, 20 s (80 s continuous run time with options for 5 s on: off ratios of 1:4 s, 2:3 s, 3:2 s and 4:1 s)	Li-Ion $88	1.5 hours	110 g (113 g)	$739 1 year, extension available for purchase
Optilux 501 Kerr Corp.	Halogen	Corded	Yes	10, 20, 30, 40 s and continuous	NA	NA	249.5 g (255 g)	$1463.95 2 years
Q-Lite DiaDent	LED	Cordless	No	Maximum power: 5, 10 s 2-step curing program, Soft start mode	Li-Ion $60	2.5 hours	150 g (151 g)	$800 1 year
Sapphire Plasma Arc Curing Light DenMat	Plasma-Arc	Corded	Yes	Four user-adjustable settings: 1 s increments 1-hour whitening mode with 15 minute session Three continuous options for multi-placement	NA	NA	227 g (185 g)	$3995 1 year
Smartlite IQ2 LED Curing Light DENTSPLY Caulk	LED	Cordless	Yes	10, 15, 20, 30, 40, 60 s	Li-Ion $113.60	2 hours	227 g (272 g)	$1508.60 2 years

* From fully depleted battery
† Weight of unit as used clinically, measured by ADA laboratories. All LED lights were weighed as cordless units. Sapphire Plasma Arc Curing Light and Optilux 501 were each measured with two feet of cord included.
** All tests for Fusion were performed with the standard head.
‡ Manufacturer's suggested retail price as of February 2009. Actual price may vary.
§ Warranty terms and conditions vary between manufacturers. Check with the manufacturer for details.

Laboratory Notes

We evaluated seven LED, one PAC and one QTH curing lights in the ADA Laboratories. We assessed the lights' irradiance (intensity), beam footprint, spectral distribution and battery life. We also evaluated their effect on depth of cure,[1] temperature rise, and polymerization shrinkage stress and rate on two composites: Heliomolar HB (Ivoclar Vivadent), which uses only camphorquinone as a photoinitiator, and Tetric EvoCeram (Ivoclar Vivadent), which uses co-photoinitiators: Lucirin TPO (BASF) and camphorquinone. A brief description of each test method is provided. For more detailed information on our testing methods, visit the *Review* at "www.ada.org/goto/ppr".

We selected the products in this review based on a total of 625 Web-based survey responses from members of the ADA Clinical Evaluators (ACE) Panel. This panel comprises a volunteer group of ADA dentists who contribute feedback for the clinical input segments of the ADA Professional Product Review program. Product selection does not imply endorsement, approval or disapproval by the ADA.

Statistical Analysis of the Data

Graphs represent the average values for each brand of curing light along with the standard error of the mean. Standard error of the mean is calculated from the average of three readings from each of the three units. Standard error of the mean is more appropriate for describing the variation or spread of the data from unit to unit in a given population.

There's More on ADA.org
For a complete description of Standard Error of the Mean and how it relates to interpretation of the data, visit the *Review* at "www.ada.org/goto/ppr".

Irradiance

Characteristic Tested. Irradiance, which is commonly referred to as the intensity of the light, is a measure of the power striking a specific unit area, also termed "power density" in some literature.

Basic Methods. We measured the power (or energy per unit time) striking a surface equal to the area of the light tip, with the light tip at 2 mm from a power sensor. We also took the same measurement at a distance of 9 mm. The same surface area (i.e., the area of light tip) was used at both distances.

To do this test, we first measured the diameter of the light-emitting area of each manufacturer's curing light with a traveling microscope. We then fabricated a corresponding fixture for each manufacturer's light with an aperture opening equal to that area (see Figure 1). Thus, there were nine custom made fixtures (one for each manufacturer). We centered the light tip and positioned it at either 2 mm or 9 mm above the aperture opening. The power meter recorded the average power striking the sensor in milliwatts, which was then divided by the cross-sectional area of the aperture opening for that particular curing unit to yield an irradiance value in mW/cm^2.

Figure 1. **Cross-section of irradiance measurement test set-up.**

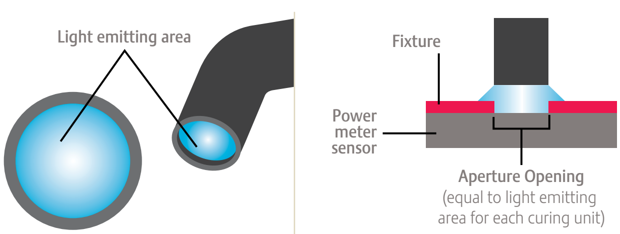
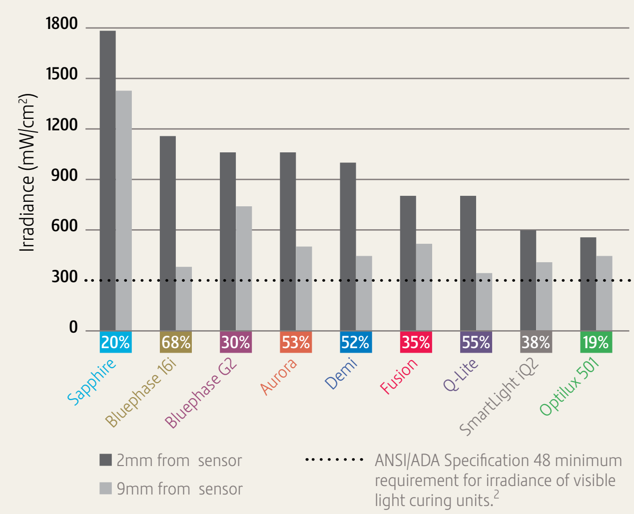


Diagram showing a cross-section of the test set-up for irradiance measurement.

Results. Figure 2 shows the mean irradiance values when the light tip was positioned at 2 and 9 mm from the power sensor. The percentage values above the bars represent the decrease in irradiance between the 2- and 9-mm distances. Major factors in the drop of irradiance values with distance for an individual curing unit are uniformity of the energy across the beam and beam collimation. In the latter case, the more collimated, or channeled, the light is, the less it diverges and spreads as the light is moved away from the target. *(NOTE: Compare the decrease in irradiance results, Figure 2, with the Footprint photographs at 2 and 9 mm, Figure 3).* Results show that at the 9-mm distance, all curing lights still met the minimum requirement for irradiance of 300 mW/cm^2 as specified by the ANSI/ADA standard.[2]

NOTE: You may notice a difference between the irradiance values obtained during our testing and those reported by the manufacturer. Any of several factors may account for such differences. For example, how the area of the light beam is defined and the distance for which the measurement is made can influence the irradiance values.

Figure 2. **Percentage decrease in irradiance between the 2- and 9-mm distances.**



Beam Footprint

Characteristic Tested. This test provides a qualitative sense of beam divergence and intensity loss when the light tip is 2 and 9 mm from a graph paper target. In this case, "intensity" is the visual evaluation of the illuminated area struck by the light beam. You can estimate the loss of intensity at these distances by looking at a specific circle on the graph paper and noting the difference in brightness at the different distances.

NOTE: Compare these photos to the percentage decrease in irradiance between distances of 2 and 9 mm (Figure 2, above).

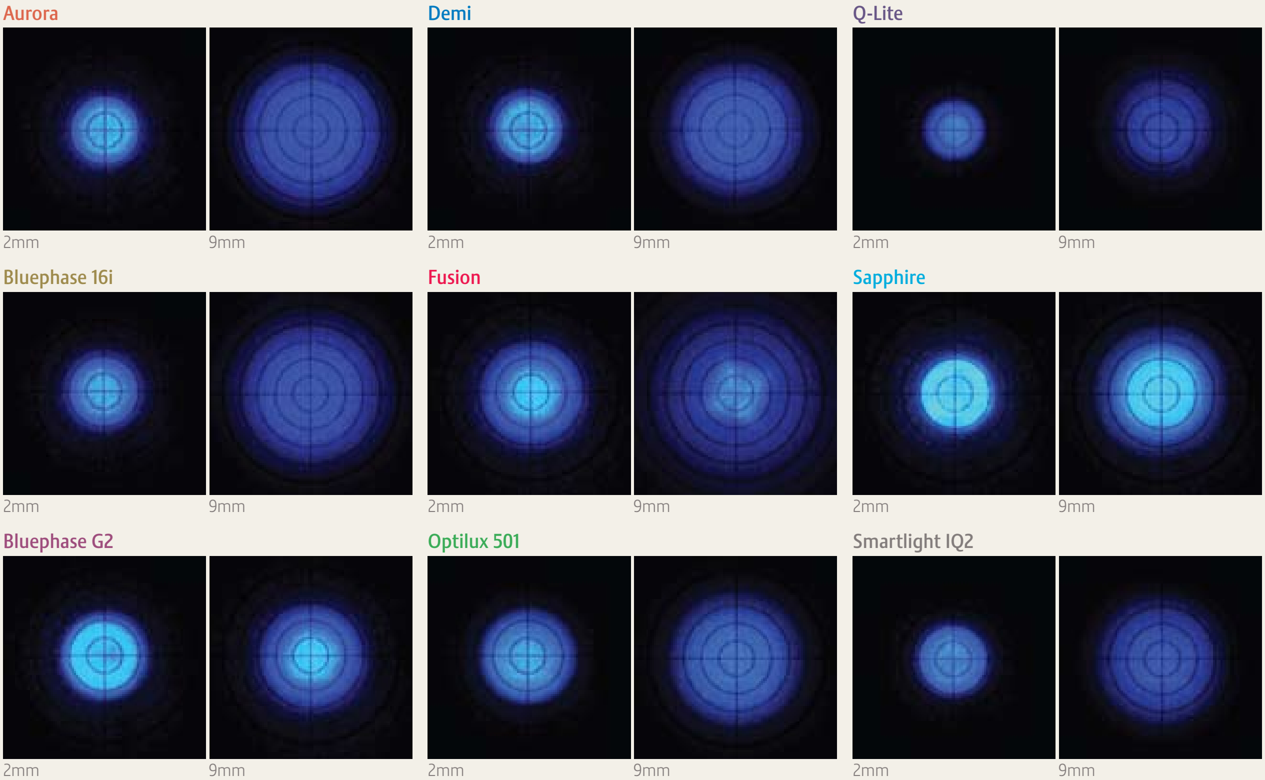
Basic Methods. We mounted the individual curing units on an optical positioning system along with a camera and a target with concentric circles spaced with their outer diameters 2 mm apart. For each curing unit, the tip was set flat against the center of the target and then moved 2 mm away from the target using an optical slide and turned on. The camera was mounted on the optical slide on the other side of the target from the curing unit and was used to collect the images, with a neutral density filter placed between the target and the camera. The curing unit was then moved 9 mm away from the target, and the procedure was repeated.

Results. Figure 3 shows the beam footprint for each light at distances of 2 and 9 mm.

Continued on next page

Continued from previous page

Figure 3. **Beam footprints taken with light tip at 2 and 9 mm from a target.***



* Distance between circles equal 2 mm.

Spectral Distribution

Characteristic Tested. This test identifies the relative amount of energy emitted by the curing unit at each wavelength. This is important because the curing unit must emit a sufficient amount of energy at the proper wavelength, i.e., wavelengths within the absorption range of the photo-initiator for the material being cured, to sufficiently cure a photo-polymerizable material (See discussion on understanding effective light ranges of LEDs, p.14).

Basic Methods. We determined the spectral distribution for each curing unit by using a spectroradiometer.

Results. From the collected light, spectral distribution graphs were plotted that show the distribution of radiance with respect to wavelength. In Figure 4, the spectral distribution graph of selected curing units is shown.

From these curves, we also determined the effective spectral range for each LED curing unit. To do this for each LED product, we plotted a curve of the average spectral distribution of three curing units. From this average curve, the peak wavelength was determined. We then divided the relative amplitude value corresponding to the peak wave in half. This value was used to determine the corresponding wavelengths at half-height of the peak amplitude, and the range between the half-height values was determined and termed the "effective spectral range" of the curing unit (see discussion on "full-width-at-half-height" and "effective spectral range," p.14). Table 2 gives the values for the effective spectral range of the LED curing units along with full spectral range of all curing units, which can be compared to the manufacturer's stated range. Figure 5 illustrates the "effective spectral range" of each of the LED curing units (p.6). In the figure, the shaded region represents the "peak absorption range" of camphorquinone, which was defined by taking the wavelength corresponding to the absorption peak (468 nm) ±13 nm.

Table 2. **Results for Peak Wavelength, Full and Effective Spectral Ranges.**

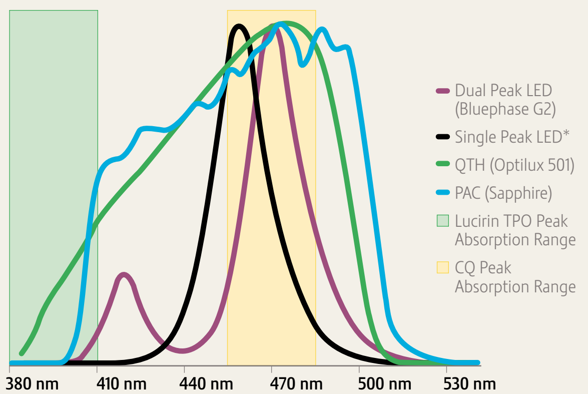
Curing Light	Manufacturer's Stated Range	ADA PPR Test Results		
		Full Spectral Range (nm)	Peak Wavelength (nm)	Effective Spectral Range (nm)*
Aurora	420-480	412-493	451	441-462
Bluephase 16i	430-490	420-493	450	439-461
Bluephase G2	380-515	392-515	468	459-479
Demi	450-470	425-500	457	446-467
Fusion	395-490	415-500	457	447-468
Optilux 501	400-505	380-506	472	NA
Q-Lite	430-490	423-500	452	442-463
Sapphire	380-780	392-540	471	NA
Smartlite IQ2	400-505	410-500	459	446-470

* Based on the range of wavelengths at more than half the height of the relative peak amplitude on the Spectral Distribution curve for LED lights only.

Continued on next page

Continued from previous page

Figure 4. **Normalized spectral distribution curves for selected lights.**

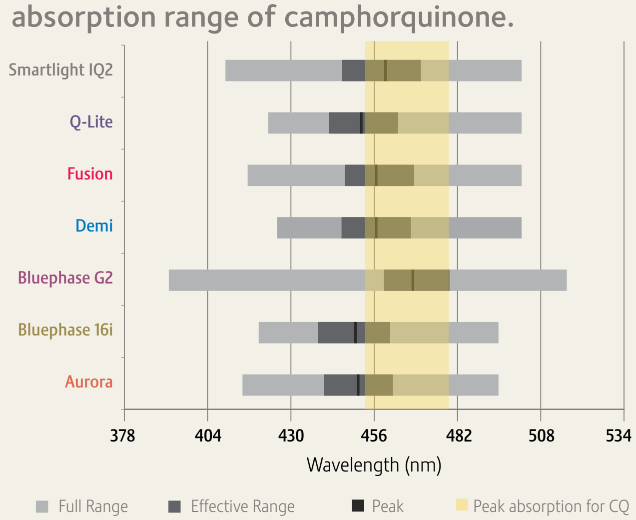


* This is a representative curve for the single-peak LED curing lights: the Aurora, Bluephase 16i, Demi, Fusion, Smartlite IQ2, and the Q-Lite all have the same shape but with different peak wavelengths, effective spectral range and full spectral range. See Table 2 and Figure 5 for a comparison of these parameters among the different LED curing lights.

The radiance values have been plotted as relative amplitudes with respect to the total radiance over the entire spectrum of wavelengths and then normalized so that the peak amplitude of each of the units is the same. Thus, as stated above, the plots represent the spectrum of wavelengths over which energy is emitted for the different curing units.

The yellow and green shaded regions in Figure 4 represent the peak absorption range of camphorquinone and Lucirin TPO, respectively (For discussion of camphorquinone see p.14).

Figure 5. **Effective spectral range of LED curing lights compared to the peak absorption range of camphorquinone.**



NOTE: The effective spectral range represents the wavelength range where energy for that light is concentrated. See Figure 5, which shows a graph comparing the effective spectral range of the different tested lights with the peak absorption range of camphorquinone, specifically 455 to 481 nm. The graph shows how the peak absorption range of camphorquinone overlaps the effective spectral range of the different evaluated LED lights. As the graph shows, different units have different effective ranges that influence how much light is available to optimally interact with the photoinitiator. However, as discussed in this report, overall curing efficacy is a combination of energy, wavelength and curing time.

Depth of Cure

Characteristic Tested. This test measures, according to a standard method, the depth to which a cylinder of A2 shade composite is cured when irradiated with a curing light.[1]

Basic Methods. To evaluate the lights' performance when activating different photoinitiators, we used two types of composites: Heliomolar HB, which uses camphorquinone as a photoinitiator, and Tetric EvoCeram, which uses the co-photoinitiators Lucirin TPO and camphorquinone. We conducted the tests with the light tip at distances of 2 and 9 mm, which represented "best case" (easily accessed area) and "worst case"(not easily accessed area) scenarios, respectively.

Where the curing unit manufacturer specified a curing time for these particular composites, that time was used for the 2-mm distance. If the curing unit had a "soft start" mode, that mode was used here. At the 9-mm distance, this time was doubled as the curing light manufacturers' general recommendation was to increase time when distance is increased. The mode used was "high" or "maximum" power (if the light provided that option) at the 9-mm distance. *(NOTE: The manufacturer of Bluephase G2 and Bluephase 16i recommend specific times for each composite at both the "soft start" and "high power" modes.)* Some manufacturers recommend specific times for shade A2, which we used. If the curing unit manufacturer did not specify a curing time, the material was cured according to the composite manufacturers' recommended cure time (20 seconds for a 2-mm increment thickness for both Heliomolar HB and Tetric EvoCeram) at both the 2- and 9-mm distances.

Because the curing unit manufacturers recommend different curing times, we also tested each light the using the 20-second cure time recommended by the composite manufacturers.

Results: When we used the curing unit manufacturers' recommended times, all curing lights cured both types of composites at the 2- and 9-mm distances to an average depth greater than 1.5 mm, satisfying the ISO requirement for this test.[1] Figures 6a-h show performance of the curing units in the depth of cure tests.

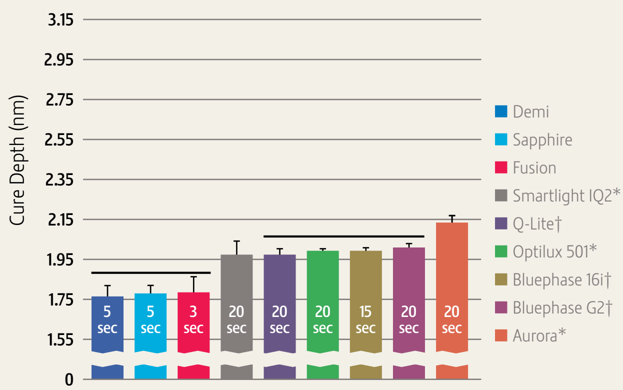
Continued on next page

Continued from previous page

NOTE: We found a statistically significant difference between the cure depths of the two materials, both at the 2- and 9-mm distances, when cured according to the light manufacturer's recommended cure time (according to a t-test for independent samples). Likewise, when curing for the composite manufacturer's recommended cure time of 20 seconds, we found a statistically significant difference between the cure depths of the two materials when the light was positioned 2 mm from the composite. Our results thus suggest that the additional photoinitiator, Lucirin TPO, may contribute significantly to depth of cure.

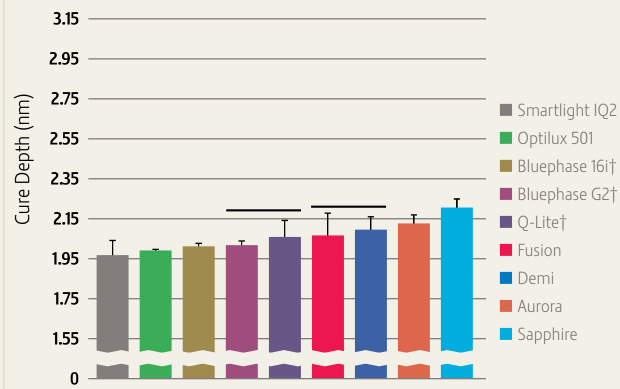
Figure 6a–h. **Depth of cure for Heliomolar HB and Tetric EvoCeram using tested curing lights at 2 and 9 mm from the composite.**

Figure 6a. **Heliomolar HB sample placed 2 mm from the light tip when using the curing light manufacturers' recommended cure times.**



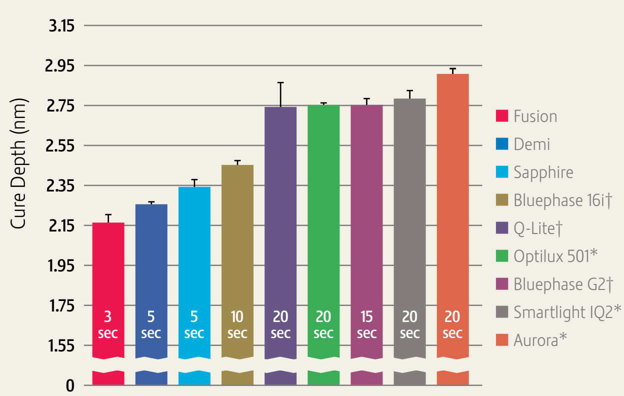
Mean depth of cure and standard error of the mean for each light is shown (n=3 based on three specimens for each of three units). Curing time for each light is indicated in its respective bar. Horizontal bars represent products that are not statistically different (Two-way ANOVA followed by the Bonferroni *t*-test for multiple comparisons, $p < 0.05$).

Figure 6b. **Heliomolar HB sample placed 2 mm from the light tip when using the composite manufacturer's recommended cure time (20 seconds).**



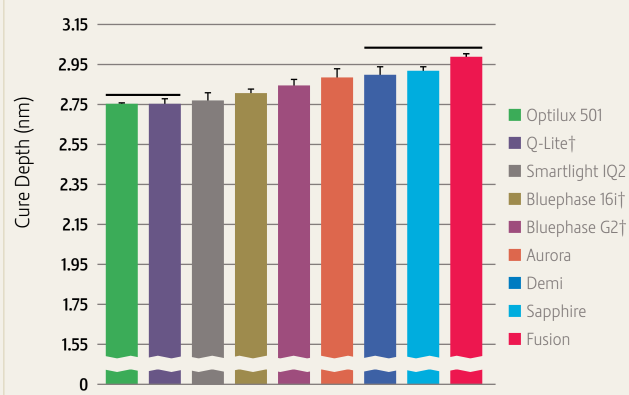
Mean depth of cure and standard error of the mean for each light is shown (n=3 based on three specimens for each of three units). Horizontal bars represent products that are not statistically different (Two-way ANOVA followed by the Bonferroni *t*-test for multiple comparisons, $p < 0.05$).

Figure 6c. **Tetric EvoCeram sample placed 2 mm from the light tip when using the curing light manufacturers' recommended cure time.**



Mean depth of cure and standard error of the mean for each light is shown (n=3 based on three specimens for each of three units). Curing time for each light is indicated in its respective bar. Horizontal bars represent products that are not statistically different (Two-way ANOVA followed by the Bonferroni *t*-test for multiple comparisons, $p < 0.05$).

Figure 6d. **Tetric EvoCeram sample placed 2 mm from the light tip when using the composite manufacturer's recommended cure time (20 seconds).**



Mean depth of cure and standard error of the mean for each light is shown (n=3 based on three specimens for each of three units). Horizontal bars represent products that are not statistically different (Two-way ANOVA followed by the Bonferroni *t*-test for multiple comparisons, $p < 0.05$).

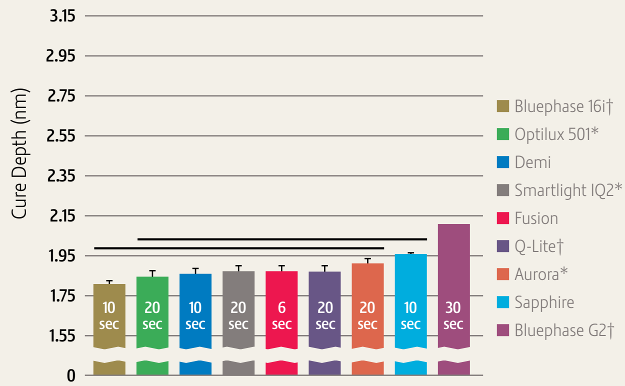
* The manufacturer did not specify a curing time for these lights. We used a curing time of 20 seconds.
† These manufacturers recommend a Soft Start Mode, which was used for this test.

Continued on next page

Continued from previous page

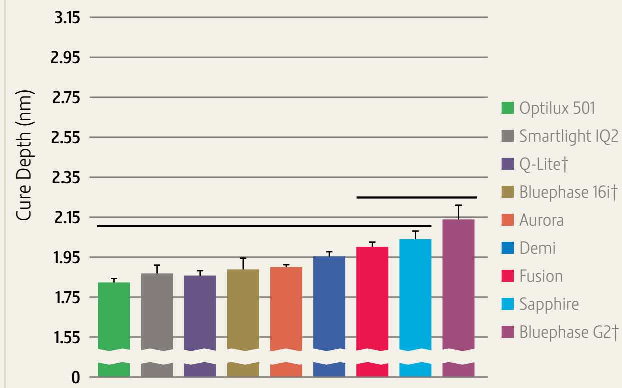
Figure 6a-h. **Depth of cure for Heliomolar HB and Tetric EvoCeram using tested curing lights at 2 and 9 mm from the composite.** *Continued*

Figure 6e. **Heliomolar HB sample placed 9 mm from the light tip.**



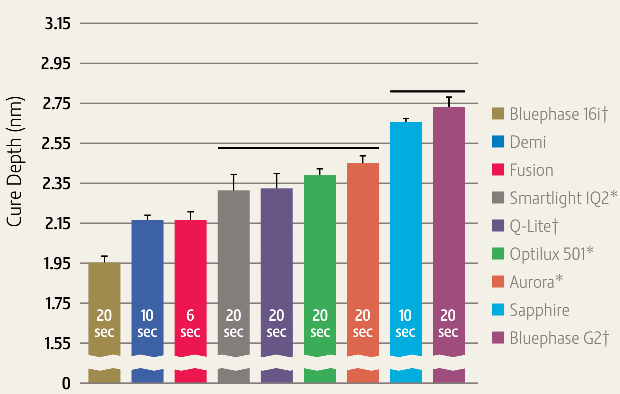
Mean depth of cure and standard error of the mean for each light is shown (n=3 based on three specimens for each of three units). Curing time for each light is indicated in its respective bar. Horizontal bars represent products that are not statistically different (Two-way ANOVA followed by the Bonferroni *t*-test for multiple comparisons, $p < 0.05$).

Figure 6f. **Heliomolar HB sample placed 9 mm from the light tip when using the composite manufacturer's recommended cure time (20 seconds).**



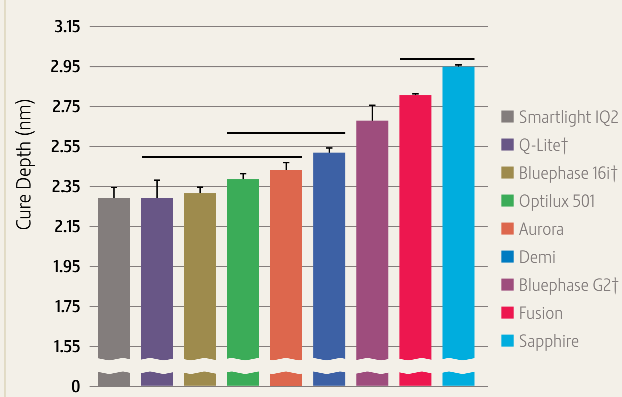
Mean depth of cure and standard error of the mean for each light is shown (n=3 based on three specimens for each of three units). Horizontal bars represent products that are not statistically different (Two-way ANOVA followed by the Bonferroni *t*-test for multiple comparisons, $p < 0.05$).

Figure 6g. **Tetric EvoCeram sample placed 9 mm from the light tip.**



Mean depth of cure and standard error of the mean for each light is shown (n=3 based on three specimens for each of three units). Curing time for each light is indicated in its respective bar. Horizontal bars represent products that are not statistically different (Two-way ANOVA followed by the Bonferroni *t*-test for multiple comparisons, $p < 0.05$).

Figure 6h. **Tetric EvoCeram sample placed 9 mm from the light tip when using the composite manufacturer's recommended cure time (20 seconds).**



Mean depth of cure and standard error of the mean for each light is shown (n=3 based on three specimens for each of three units). Horizontal bars represent products that are not statistically different (Two-way ANOVA followed by the Bonferroni *t*-test for multiple comparisons, $p < 0.05$).

* The manufacturer did not specify a curing time for these lights. We used a curing time of 20 seconds.
† These curing lights have a "high power" or "maximum power" mode, which was used for this test.

Continued on next page

Continued from previous page

Temperature Rise

Characteristic Tested. This test measures the temperature rise caused by a curing light, which includes both the heat generated by the light as well as the heat generated by the polymerization reaction (which occurs clinically), when curing a photo-polymerizable composite material. High temperatures can be damaging to the pulp, but not all of the heat generated reaches the pulp chamber because of the insulating effects of the surrounding tooth structure, among other factors. Although the specimen mold used in these experiments does not match the thermal properties of tooth structure, the use of a standard test set-up, as described below, does provide relative comparisons among curing units with respect to the amount of heat generated through a standardized volume of material.

NOTE: It is not known what amount of heat is clinically harmful or considered unsafe to pulpal tissues. Therefore, as described above, this test offers a relative comparison, with less heat production per unit time being preferred, consistent with providing adequate light intensity and wavelength to yield a good depth and rate of cure.

Basic Methods. For each curing unit, a 4-mm diameter by 3-mm-thick mold with a thermocouple mounted at the bottom was filled with composite material (either Heliomolar HB or Tetric EvoCeram), which was then cured with the tip of the curing unit placed directly on top of the composite. We used the curing time as described in the Depth of Cure test for the curing light manufacturer recommendations at 9mm to provide a relative comparison among lights. Temperature rise was measured by subtracting the average baseline temperature of the composite after insertion into the mold from the peak temperature reached over the course of the polymerization reaction.

Results. Table 3 shows a comparison of temperature rise measurements for the two composites.

NOTE: Since the curing times used vary and the mold used is not representative of the thermal properties of tooth structure, direct clinical applications based on these results alone should be made with caution.

Table 3. **Mean Temperature Rise of Heliomolar HB and Tetric EvoCeram for Tested Curing Lights.**

Curing Light	Curing Time* (seconds)	Heliomolar HB		Tetric EvoCeram	
		Mean† (ºC)	Std Error	Mean† (ºC)	Std Error
Aurora	20 s	7.51[a,b]	0.41	8.35[c]	0.47
Bluephase 16i	10/20 s‡	7.62[a,b]	0.48	8.07[c,d]	0.50
Bluephase G2	30/20 s‡	9.53[a]	0.42	9.09[c]	0.16
Demi	10 s	7.55[a,b]	0.14	6.11[d,e]	0.22
Fusion	6 s	7.75[a,b]	0.56	7.44[c,d,e]	0.47
Optilux 501	20 s	6.53[b]	0.33	8.32[c]	0.43
Q-Lite	20 s	5.68[b]	0.43	6.07[d,e]	0.24
Sapphire	10 s	8.85[a]	0.18	9.08[c]	0.47
Smartlite IQ2	20 s	5.64[b]	0.41	5.31[e]	0.11

* We used the curing time recommended by curing light manufacturer for use at the 9-mm distance (as described in the Depth of Cure test, p. 6) to approximate the maximum temperature rise the light would give in a clinical situation.

† Identical superscripts indicate products that are not statistically different (Two-way ANOVA followed by the Bonferroni *t*-test for multiple comparisons, $p < 0.05$).

‡ The manufacturer of these products recommended specific times for each composite. Times are listed as Heliomolar HB / Tetric EvoCeram.

NOTE: No statistically significant difference was found in the temperature rise between Heliomolar HB and Tetric EvoCeram.

Polymerization Shrinkage Stress and Rate

Characteristics Tested. This test measures parameters related to the shrinkage resulting from polymerization.

NOTE: High shrinkage stress and stress rate are undesirable. Rate of stress can occur quickly or can be more gradual. See discussion of transillumination and the "soft cure" technique to minimize polymerization shrinkage away from the tooth structure, p.16.

Basic Methods. We measured polymerization shrinkage stress and rate of stress imparted by the curing lights by curing specimens of Heliomolar HB and Tetric EvoCeram using the curing light manufacturer's cure time recommendation for use at a distance of 9 mm (as described in the Depth of Cure test, p. 6). For both products, the maximum stress and rate of stress were recorded for 60 minutes, including the time of light curing.

Results. Table 4 shows the shrinkage stress and rate for the tested products. Lower values are preferred. The amount and rate of polymerization shrinkage stress produced by the curing lights was not significantly different for any of the lights for Heliomolar HB.

Continued on next page

Continued from previous page

Table 4a. **Mean Maximum Polymerization Shrinkage Stress and Stress Rate for Tested Lights When Curing Heliomolar HB.**

Curing Light	Curing Time* (seconds)	Maximum Stress (MPa†) (std error of mean)	Stress Rate‡ (MPa/minute) (std error of mean)
Aurora	20 s	1.48 (0.05)	2.76 (0.25)[a]
Bluephase 16i	20 s§	1.53 (0.19)	3.27 (0.70)[a]
Bluephase G2	20 s§	1.76 (0.03)	3.29 (0.17)[a]
Demi	10 s	1.44 (0.12)	3.31 (0.07)[a]
Fusion	12 s	1.55 (0.11)	3.18 (0.14)[a]
Optilux 501	20 s	1.70 (0.11)	3.51 (0.19)[a]
Q-Lite	20 s§	1.39 (0.05)	2.69 (0.13)
Sapphire	10 s	1.64 (0.07)	3.63 (0.26)[a]
Smartlite IQ2	20 s	1.52 (0.07)	2.93 (0.28)[a]

* We used the curing time recommended by the curing light manufacturer for use at the 9-mm distance (as described in the Depth of Cure test, p. 6), except with FUSION, which was operated for 12 seconds because this was the minimum cure time in which complete curing of the specimen could be achieved in the testing apparatus.

† MPa stands for megapascal, a unit of strength (force/unit area) (1 MPa=145 psi; 1 MPa=1 Newton/mm²).

Table 4b . **Mean Maximum Polymerization Shrinkage Stress and Stress Rate for Tested Lights When Curing Tetric EvoCeram.**

Curing Light	Curing Time* (seconds)	Maximum Stress (MPa†) (std error of mean)	Stress Rate‡ (MPa/minute) (std error of mean)
Aurora	20 s	1.10 (0.05)[b,c]	1.66 (0.12)[d,e]
Bluephase 16i	20 s§	0.90 (0.07)[b,c]	1.16 (0.19)[e]
Bluephase G2	20 s§	1.11 (0.07)[bc]	1.76 (0.14)[d,e]
Demi	10 s	0.74 (0.05)[c]	1.24 (0.12)[e]
Fusion	12 s	0.79 (0.11)[b,c]	1.45 (0.19)[e]
Optilux 501	20 s	1.19 (0.04)[b]	2.06 (0.05)[d,e]
Q-Lite	20 s§	0.70 (0.02)[c]	1.04 (0.07)[e]
Sapphire	10 s	1.16 (0.07)[b,c]	2.85 (0.11)[d]
Smartlite IQ2	20 s	0.89 (0.02)[b,c]	1.26 (0.03)[e]

‡ Identical superscripts indicate products that are not statistically different from one another (Two-way ANOVA followed by the Bonferroni *t*-test for multiple comparisons, $p < 0.05$)

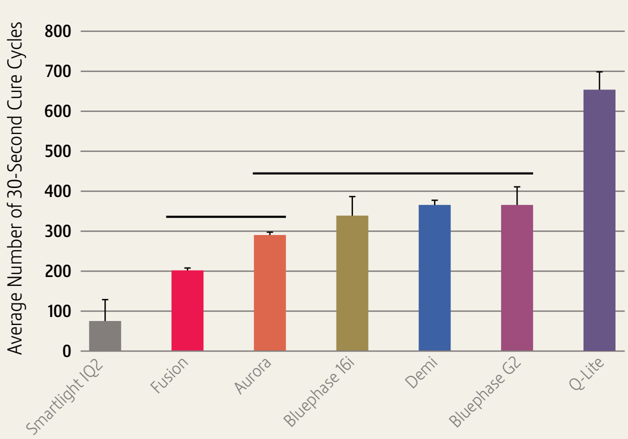
§ These curing lights have a "high power" or "maximum output" mode, which was used for this test.

LED Battery Life

Characteristic Tested. This test measures the battery life of each rechargeable curing unit.

Basic Methods. Each LED light was fully charged before testing, and all units were tested at the highest power setting. Using a test set-up with a power meter similar to the one shown in Figure 1, p. 4, we continuously monitored the power output for each curing unit as it was repeatedly operated for cycles of 10 seconds on and 20 seconds off. This 30-second on/off cycling of the curing unit was continued until the irradiance dropped below 300 mW/cm². We recorded the number of 30-second cycles taken to reach this point as the battery life.

Figure 8. **Mean battery life of tested LED curing lights**



Vertical bars and error bars represent the mean and standard error of the mean, respectively, based on three specimens for each of three units (see statistical note, p. 3). Horizontal bars represent products that are not statistically different (one-way ANOVA followed by the Student-Newman-Keuls method for multiple comparisons, $p > 0.05$).

Results. The mean battery life in 30-second cycles (10 s on/20 s off) is represented in Figure 8. Figure 9 plots the irradiance of the curing light against time. Table 5 lists both the manufacturers' stated battery life and the battery life identified in the ADA laboratories during testing.

Table 5. **Battery Life of Tested Curing Lights as Stated by Manufacturer and Evaluated in ADA Laboratories.**

Curing Light	Mfr Stated Battery Life*	Mean Number of 30-second Cycles*†	Std Error of the Mean in 30-second cure cycles	Mean Battery Life‡
Aurora	5 seconds 500 times	10 seconds 292 times	5	2 hours 26 min
Bluephase 16i	20 seconds 135 times, High Power	10 seconds 344 times, High Power	42	2 hours 52 min
Bluephase G2	20 seconds 180 times, High Power	10 seconds 367 times, High Power	48	3 hours 3 min
Demi	10 seconds 350 times	10 seconds 362 times	15	3 hours 1 min
Fusion	at least 40 seconds 60 times	10 seconds 201 times	5	1 hours 40 min
Q-Lite	10 seconds 700 times	10 seconds 651 times, High Power	46	5 hours 25 min
Smartlite IQ2	10 seconds 300 times	10 seconds 79 times	52	39 min

* Seconds given indicate the interval for which the lights were on during "on/off" cycles of the test.

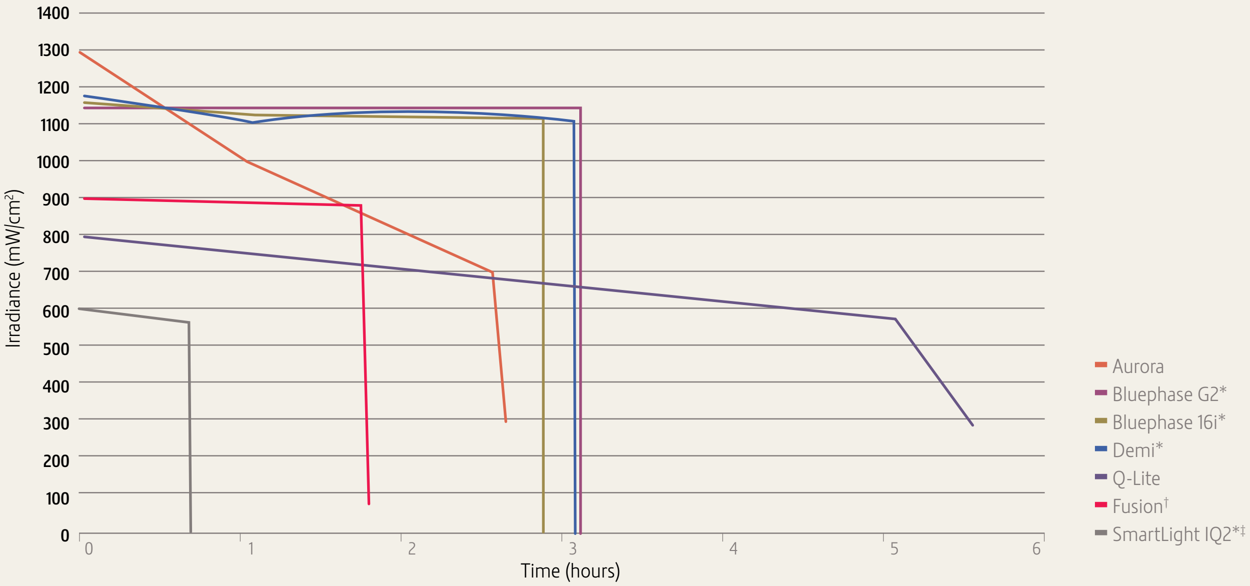
† Each cycle is 10 seconds with the light on, 20 seconds with the light off.

‡ Calculated by multiplying the number of cure cycles by 30 seconds.

Continued on next page

Continued from previous page

Figure 9. **Mean battery life of tested LED curing lights as measured by irradiance vs. time.**



* Light shut itself off at the point where the curve sharply drops to zero.
† Irradiance sharply dropped from 889 mW/cm². Testing was then stopped for this light as its irradiance had dropped below the threshold of 300 mW/cm².
‡ Two of the three tested batteries for Smartlite IQ2 lasted 10-15 minutes before failing.

NOTE: In Figure 9 above, the point at which the plotted line sharply drops to zero indicates that the light shut off at this point and would not turn back on. This is not necessarily a negative finding since you cannot determine the light output visually but still want to know that you have a consistent, reliable irradiance value throughout every complete curing cycle. Therefore, irradiance values at the time the light last operated could be important if you think you might get to that point before recharging. This will prevent the unit from being used at power levels that would result in an unsuccessful cure procedure.

References

1. International Organization for Standardization. ISO No. 4049—2000, Dentistry—Polymer-based filling, restorative and luting materials. Geneva: ISO.
2. ANSI/ADA Specification No. 48 Visible Light Curing Units. August 2004 (Modified adoption of ISO No. 10650—1:2004 Powered polymerization activators—Part 1: Quartz tungsten halogen lamps. Geneva: ISO.) Chicago: ANSI/ADA.

Practitioner Input

Through a Web-based survey, 710 dentists reported having used a resin-composite curing light within the last year. We collected data about their experiences with the curing lights featured in this report. Participants were drawn from the ADA Clinical Evaluators (ACE) Panel and a random sample of other ADA members. *NOTE: Bluephase G2 and Q-Lite had too few responses to reliably report clinical impressions and are not included in this section of the report.*

Dentists rated products based on performance features such as access in the mouth, ease of use/comfort, acceptable cure time, sufficient light guide options, durability, counter space requirements, purchase price and customer/technical support.

Figures 10 through 17 show how performance ratings compare among the products.

Join the ACE Panel!

Are you an ADA member who is practicing clinical dentistry? If so, we want to hear from you. We count on the ADA Clinical Evaluators (ACE) Panel to tell us how products featured in the *Review* perform clinically.

Currently more than 2,000 ACE Panel members volunteer a few hours per month to answer electronic surveys. At times, there also will be opportunities to participate in telephone interviews and panel discussions.

We value the contribution that the ACE Panel makes to this program and are always looking for ways to say thank you. For example, active panel members currently receive discounts on merchandise purchased through the ADA Catalog.

Join the ACE Panel by e-mailing us at "pprclinical@ada.org" or by calling the ADA's toll-free number on the back of your membership card and asking for Ext. 3528.

Figure 10. **Access in the mouth.**

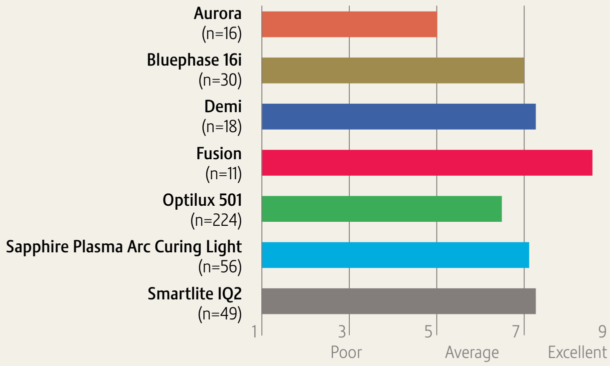


Figure 11. **Sufficient light guide options.**

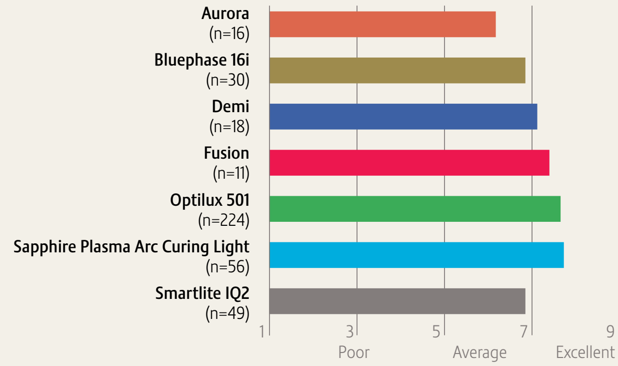


Figure 12. **Ease of use/comfort.**

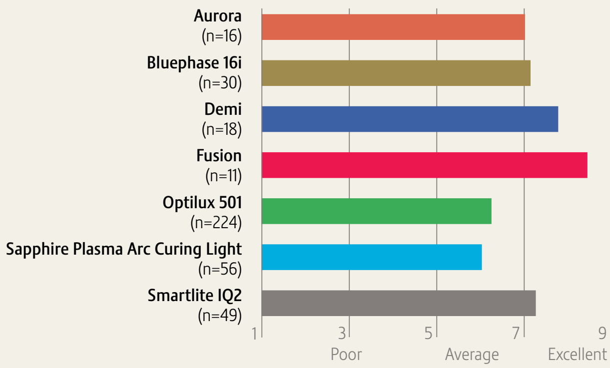


Figure 13. **Durability.**

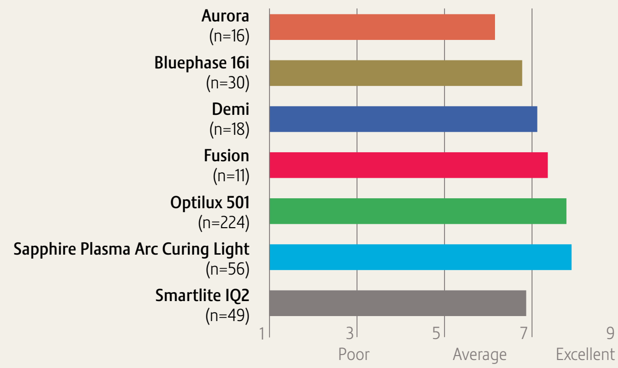


Figure 14. **Acceptable cure time.**

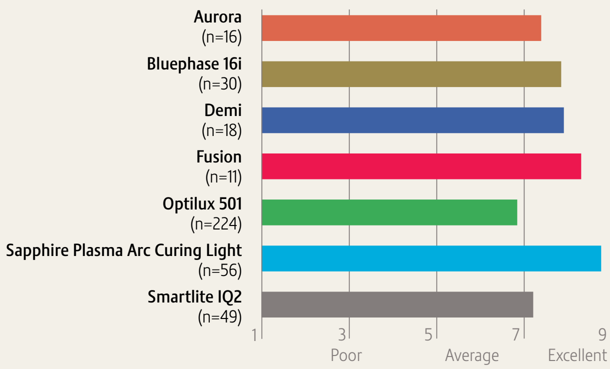


Figure 15. **Counter space requirements.**

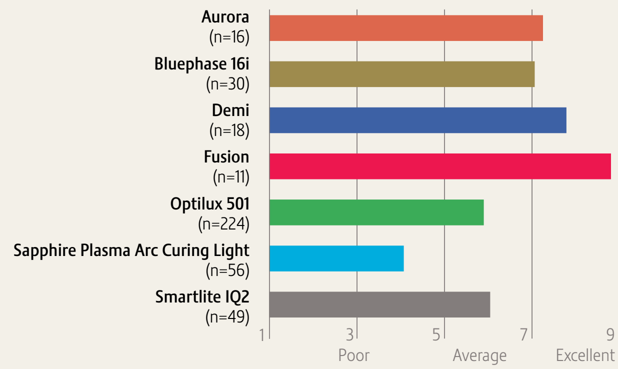


Figure 16. **Purchase price.**

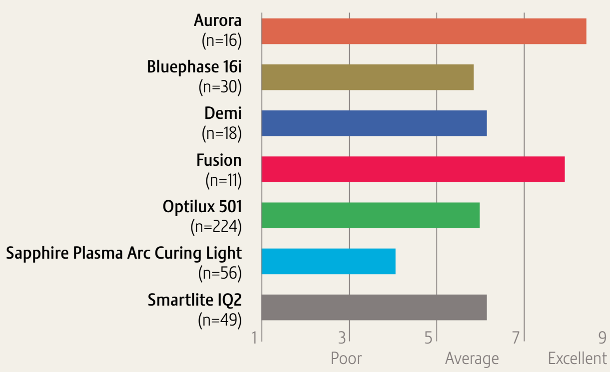
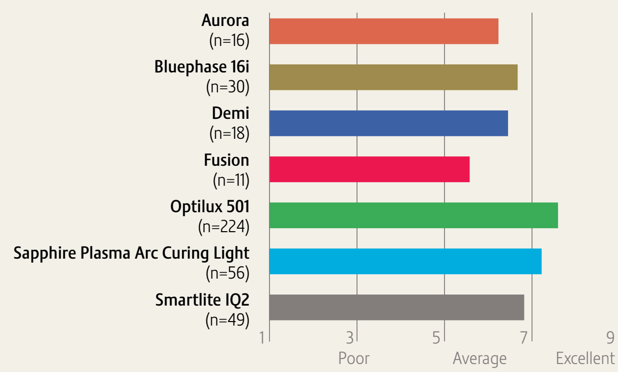


Figure 17. **Customer/technical support.**



Continued on next page

An Expert's Buying Guide for Curing Lights

Frederick A. Rueggeberg, DDS, MS
Professor and Section Director
Dental Materials, School of Dentistry
The Medical College of Georgia
Augusta, GA

Dr. Rueggeberg has published extensively on research related to curing lights. Dr. Rueggeberg has received research grants from 3M/ESPE, Ultradent, Kerr Dental Corp., Ivoclar Vivadent, LD Caulk, DENTSPLY, deTrey, Coltene Whaledent, Addent, IMTEC and Brasseler.

Clinicians should ask themselves if they are satisfied with the curing unit they already own. Just because something can do things a little bit differently doesn't necessarily mean it's better. For example, the blue light emitted by an LED contains photons of the same energy as the blue light from a plasma arc (PAC), or from a quartz tungsten halogen (QTH) unit. The only difference is how the photon is created at a specific wavelength. It's the total number of photons delivered to a restoration and the range of their frequencies (colors) that determines the energy supplied to the material and the potential efficacy of a dental light curing unit. If you get a new light, don't throw out the old light. Should something go wrong with your new light, you'll have a light curing unit as backup so you can keep doing dentistry.

Quartz Tungsten Halogen Lights
As technology evolves, QTH lights face challenges in the market place. For example, clinicians may not be able to buy an incandescent light (a light with a filament, such as the bulb in a QTH dental light) in the future because of government regulations and/or manufacturing availability. So, it may be a good idea for owners of the QTH lights to purchase extra replaceable parts such as light bulbs, retro-fit kits of the filtering system and light guides. Performing this type of "preventive maintenance" will help your investment last longer.

Plasma Arc Curing Lights
The PAC light has an extremely high output, but its bulb doesn't contain any filament like the QTH lights. It has two rods that arc and form a continuous spark when the unit is activated. Over time, these bulbs may degrade or decrease in output intensity. On the other hand, the liquid light guide is not likely to deteriorate with time because it does not contain glass fibers but rather a special liquid to absorb further unwanted wavelengths. As was true for QTH lights, owners of PAC lights may want to purchase extra bulbs and tips to sustain the usefulness of the investment.

NOTE: Some of these types of light sources can only be replaced by the manufacturers.

LED Curing Lights
Regarding light-emitting diode (LED) curing lights, there's an array of types, costs and features available. It can be staggering to consider them all and determine which one is "the best." But there are some guidelines that dentists can use:

Power source: Corded or battery powered, or both. Each type has its advantages, and it is really a personal preference. I prefer a corded power source because you'll never have to wonder about the unit's battery charge level, and you'll not have to pay auxiliary personnel to maintain and monitor charging status of lots of different lights.

Cost: Buyer, beware. I would suggest you take time to look at the product package and read the enclosed product literature. If you can't find the name of the manufacturer (their address and contact information), not just the supplier [or distributor], on the package or in the literature, you may want avoid that product because you might have trouble if service is needed. In addition, less expensive lights are less likely to provide sophisticated methods to compensate and automatically adjust light output levels from changes in the chip temperature as it is being operated. Thus, if the light is used for multiple, sequential, very closely spaced exposures, the output of the unit may decline quickly from exposure to exposure. The result is that the polymerization of the restorative material on first use may be better than that of the material that is exposed last.

Heat dispersion: A quick screening check for the ability of an LED light unit to disperse heat can be done by removing the battery from the unit. If the unit feels really light without the battery, chances are that it doesn't have a metallic heat sink for heat dispersion. Sometimes LED chips are driven beyond their capacity so that curing light manufacturers can claim high output levels. As a consequence, the chips themselves get very hot, and the heat generated at the chip needs to be removed by the metallic heat sink. It is usually a piece of copper or other metal. Some pencil-type LED lights have a metallic body serving as a heat sink to provide a large surface area to help dissipate the heat caused by the chip. If heat is not removed, the light output can greatly decrease, even during a single exposure. The chip also may be protected by a built in thermostat, so that the unit is inoperable until the temperature at the chip has decreased to a certain level. Lastly, the chip may melt its internal solder connections and permanently turn off.

Unit integrity for infection control considerations: Before buying an LED light, squeeze the handle. If you hear creaks or see sections of the plastic molded and joined pieces opening and closing, fluid or disinfectants used between patients may seep into those slots. Also, look closely at the activation buttons on the units. Ideally, activation buttons should be blister-covered to prevent fluids from entering and interfering with the electronics of the light.

Energy needed for polymerization. Composites need a certain amount of energy to be adequately cured. It doesn't matter how fast the energy is delivered to the surface. When curing a material, the energy driving the reaction

Continued on next page

Continued from previous page

greatly diminishes with composite depth. Thus, energy requirements should be based on the amount needed to polymerize the bottom-most layer of the restoration, not the material above it.

Use of a hand-held radiometer: You can bring a hand held radiometer to the trade show to compare the light intensity from one LED light to another. When you do this, be aware that the absolute numbers may be different from what is reported by the manufacturer or researchers. However, readings from the same radiometer can be used to compare different lights on a relative scale.

At your office, it is important to periodically check your curing light with a radiometer to see if the output levels of your light unit system are falling. If there is a significant drop, the light may need to be recharged or even repaired.

Beam divergence and footprint of light: A quick, easy way to gauge both the uniformity of light within a beam as well as how fast that light spreads laterally with increased tip-to-target distance, is to hold a business card in your hand and shine the curing light through it. You will see some areas in the beam that are brighter than others. Also, when you move the tip away from the card, you will see how fast and how wide the beam diverges with small increases in distance.

> Each time a tooth is exposed to the light and not allowed to return to baseline temperature, an accumulation of heat may occur in the tooth.

Turbo tip and focal effect: Turbo tips are used for LED lights to increase the power density (power per unit area being irradiated) but the light unit itself isn't generating any more power. Turbo tips focus the power over a smaller area, so the power per unit area, or the irradiance of the light that's falling on the surface, is increased. The disadvantage of turbo tips is that the area exposed to the light is smaller and therefore you need to use multiple, repeated, overlapping exposures if you're trying to cure the whole occlusal surface of an upper or lower first molar.

The turbo tip also has a focal effect. The focal point is the distance from the light tip where the power density is greatest. Beyond this distance you're actually getting a lower power density than a conventional light guide. In many instances, the conventional 8 and 10 mm tips perform extremely well. They tend to have a more uniform distribution of light over the surface of the beam; they don't have the focusing effect of the turbo tips; you can radiate a large area within a given exposure; and you don't have to give multiple, repeated exposures.

For LED units not using light guides, the optics at the tip end will be made of either glass or a disposable plastic often with lenses to limit the divergence of the light

Understanding effective light ranges of LEDs: Just because a manufacturer claims that their product is a blue LED doesn't necessarily mean that product emits the same frequency of light as another unit labeled as a blue LED. A small change in the color (frequency) of blue light being emitted can profoundly affect the polymerization process. Typically, LED curing light manufacturers state the full spectrum output range of their units. A better approach for determining the range is termed the "full-width-at-half-height." This will give you the "effective spectral light range" of that particular light, which is approximately ±13 nm of the reported peak amplitude. Most contemporary dental light cured materials contain the photoinitiator camphorquinone, which has a broad absorption profile with respect to frequency, with a peak frequency at 468 nm.[1] For the most "effective" use of an LED light toward camphorquinone, you should look for a light that has a peak output range near this specific frequency (468 nm ±13 nm). Thus, the LEDs that are most effective toward camphorquinone would have output wavelengths running between 455 and 481 nm (see Figure 4 for illustration of effective spectral range of the different curing units in this study, p. 6).

Multiple frequencies: The ability of an LED light to emit multiple frequencies has become a selling point for many units: so called "poly-wave" lights. This feature is based on the use of different photo-initiators in various formulations of composites and bonding agents. Problem is, rarely does the dental material manufacturer inform the clinician that the product requires a particular frequency to properly polymerize, because the restorative material contains a specific photoinitiator. To get around this, curing light manufacturers have developed lights that emit multiple frequency outputs covering more than just the range of blue light. By combining these colors, the generated spectrum more closely matches that from a QTH light. However, the output is not as continuous as it is when using a PAC or QTH source (see Figure 4 for representative plots of poly-wave LED, PAC and QTH curing units from this study, p. 6). But potentially, any restorative material placed within its beam will be cured.

If the light is simply a blue LED, it probably will activate camphorquinone only and that light is all you will need. For example, Heliomolar HB utilizes a photoinitiator that is sensitive only to blue light. However, Tetric EvoCeram uses a combination of photoinitiators: one that requires blue

Continued on next page

Continued from previous page

light and another that requires violet. If both colors of light are present on the surface, maximal composite curing can occur at the surface. The thing that may not be understood is that the different colors of lights emitted from LED lights that generate multiple colors (frequencies) do not mix well in the beam. So, you'll have one area of the composite that may receive only violet light and not blue, and vice-versa. The majority of the area will receive blue. In addition, the violet light falling on the composite surface is almost totally absorbed at the surface and doesn't penetrate into the composite very well. These types of problems do not occur with curing lights that have continuous spectral outputs, like the QTH and PAC lights.

To compensate for the disparity of power across a light curing tip or for the different frequencies of an LED light in the beam, the clinician should slowly move the tip over the surface being irradiated, instead of holding it in one place during an exposure. Consider photons being emitted from a light curing tip to be like droplets of water being delivered from a garden hose sprayer. If you're trying to water a section of lawn at a distance from you with a garden hose, you don't hold the hose in one position. You move it back and forth, trying to uniformly cover the area with water. It's the same concept when trying to uniformly cover the restorative area with light. You don't do it rapidly, but slowly, and do not remove the light from the body of the restoration.

Intrapulpal temperature: Dentists are concerned with postoperative sensitivity problems, and these issues might be related in part to excessive heat having developed inside the pulp chamber from exposing the tooth and/or gingivae during the restorative process. That's a valid concern. Unfortunately, there's no in-vivo, human study that can provide a definitive answer to this issue. Theoretically, the stronger the light output, the more the intrapulpal temperature will rise. It happens as a result of the "photothermal" effect. *(NOTE: Dehydration also may play a role in post-operative hypersensitivity.)* The first-generation LED lights generated very low levels of power, and this resulted in very low levels of heat generation. However, with the very high levels of light produced by most contemporary LED lights, high temperature values can be measured in the lab. The temperature of exposed gingiva being irradiated can also become elevated. It is not uncommon for patients to complain of a "burning sensation" in their gingivae following restoration of Class V lesions if a rubber dam is not used. **Clinicians should see how much heat they can detect when shining the light on the underside of the wrist. If the curing light causes a response that is uncomfortable when applying the suggested exposure duration, clinicians should think twice about using the light for more than that time on the tooth. However, the clinician can decrease the potential for postoperative intrapulpal temperature rise by directing an air stream across the tooth during the curing process. If using a directed stream of air to help cool the tooth, longer times probably could be used without adverse reactions.** For example, when the dentist is curing a tooth from the facial, the assistant can direct the air syringe on the lingual surface of that tooth. Or, the assistant can hold the high-speed suction on the lingual surface and draw air across it.

Repeated exposures also may cause intrapulpal temperature rise. Each time a tooth is exposed to the light and not allowed to return to baseline temperature, an accumulation of heat may occur in the tooth. During all multiple exposures, this air streaming process should be performed.

Bulk curing technique: A technique to fill a whole restoration as one large bulk rather than in step-wise curing increments claims to have little-to-no clinical issues. We have done some lab testing looking at the efficacy of the bulk technique and found that the ability to adequately cure composite in the center of a Class I restoration that has been placed in bulk and then irradiated by directing light through the buccal and lingual surfaces of the remaining tooth structure, is very sensitive to shade. For this trans-tooth curing technique to provide similar curing performance as conventional incremental filling, you need to use extremely light shades or highly translucent composite. With shades darker than VITA A1, you see significant lowering in the hardness in the middle of a composite compared to the incremental layering technique.[2]

Other clinical light curing techniques: If the clinician is going to use trans-tooth polymerization, he or she should realize that, for each millimeter light is passing through remaining tooth structure to reach the composite, you're losing just as much light as going through a similar thickness of cured composite.[3] So, if you're trying to shine light through 6 mm of tooth, enamel and dentin, to cure composite, you should ask yourself how comfortable you'd be trying to cure composite by placing a similar thickness of restorative material on the end of the light guide. To accomplish that task, you generally have to greatly increase exposure duration.

NOTE: Air cooling the tooth when using a longer exposure time (see discussion "intrapulpal temperature" discussion, this page) might provide a lower overall increase in temperature as well as minimize or eliminate the negative effect of the polymerization shrinkage stress away from the tooth structure. Again, there is no in-vivo way to accurately compare the intrapulpal temperature of the variations in techniques and this must ultimately be a clinical judgment for any given situation.

If you are using trans-tooth polymerization to restore a Class I or Class II preparation, you should place the first increment on the axial wall and on the pulpal side (and gingival floor) of the preparation from which the light will first be shone through. Repeat this application method on the opposite side of the preparation. At this time, you will only be partially curing the composite. Then, expose both

Continued on back cover

Continued from previous page

of these composite pieces from the top to maximally cure them. This would minimize the stresses and the vectors of composite shrinkage would direct the restorative material to be initially "pulled" toward the bonded interface, from which the curing light is coming. Finally, place an increment in the middle, joining together the two already-cured sections. Expose this layer from the top, and that should do it.

Battery life: When considering battery-powered models, you should make sure that the light isn't powered by a nickel cadmium (NiCad) type battery. *NOTE: None of the tested lights had this NiCad-type battery.* These types of batteries do not provide long lasting charges and have a tendency to build up a "charge memory" that may be difficult to keep fully charged over time. The lithium-ion type battery currently is really state of the art.

Regarding repeated exposures, dentists should think of the longest exposure duration they usually provide and then consider how many times in sequence that exposure is given. In our lab, we run a repeated exposure profile on every light that we test. This test consists of a series of twelve, 10-second exposures spaced three to five seconds apart. This scenario is similar to that which many dentists use when delivering anterior veneers where the first exposure is from the lingual for 10 seconds, and then from the facial for 10 seconds for each tooth in succession. For the six anterior teeth, this leads to 12 sequential 10-second exposures. That's one quick way to determine if a light curing unit is going to be able to withstand such a test.

Again, take a hand-held radiometer to a trade show. If you're interested in a curing light, look at the value of power the meter indicates over those relative exposures, and see if it drops or not. Some lights won't survive this approach. Also, some lights markedly drop off in power during this sequence. As a result, the composite exposed toward the end of this sequence might be remarkably less cured than it is at the beginning. You don't really want that when trying to fabricate restorations with consistent, predictable properties.

NOTE: See p.10 for ADA testing of battery life.

Eyewear safety: **When operating a curing light, you should always wear blue blockers (safety eyewear).** As a rule of thumb, the redder tint of the lenses, the better will be the protection provided. Blue blockers will not allow ultraviolet, violet or blue light to pass on to your eyes. Instead, it allows all the other remaining visible wavelengths. That's why things look orange or red when you wear them. However, looking directly at blue light or at reflected blue light is extremely dangerous to your eyes. Blue light directly interacts with cells in the retina and causes irreversible burning if there is sufficient intensity. Thus, it's extremely important to wear these glasses for safety as well as to see what you're doing.

References

1. Anusavice KJ, ed. Phillips' Science of Dental Materials. 11th ed. St. Louis: Saunders; 2003.
2. Lazarchik DA, Hammond BD, Sikes CL, et al. Hardness comparison of bulk filled/trans-tooth and incremental filled/occlusally irradiated composites. J Prosthet Dent 98:129-40.
3. Price RB, Murphy DG, Dérand T. Light energy transmission through cured resin composite and human dentin. Quintessence Int 2000;31:659-67.