the Journal of CONTEMPORARY DENTAL PRACTICE
at www.thejcdp.com
Volume 8 Number 2 February 1, 2007

Radiometric and Spectrophotometric Analysis of Third Generation Light-Emitting Diode (LED) Light-Curing Units

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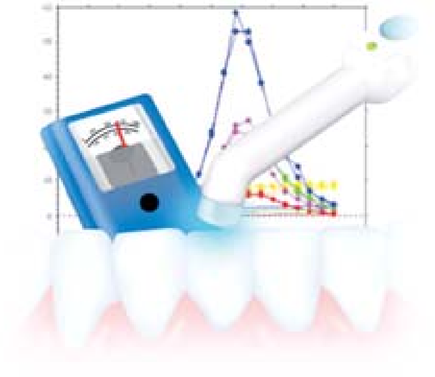


Abstract

Aims: Light-emitting diode (LED) polymerization of dental restorative materials has become increasingly popular. However, individual light-curing unit (LCU) functions (intensity and/or wavelength emission) may not conform to manufacturer specifications due to quality control issues. The purpose of this study was to evaluate the quality of irradiance, in terms of power density (intensity) and spectral distribution (peak wavelength), emitted from LED and quartz-tungsten halogen (QTH) LCUs *in vitro*. The battery expenditure of these LED units was also tested.

Methods and Materials: The intensity and spectral distribution from four third generation LED (Smartlite PS, Coltolux LED, radii Plus, Diopower) and one QTH (Schein Visible Cure) light sources were measured using six different dental curing light meters (Coltolux, Cure Right, Demetron 100, Demetron LED., Hilux, and Light Meter-200) and a visible-ultraviolet light spectrophotometer (Hitachi Elmer-Perkins). The battery life was also plotted for each light source following a 1500 second duration period. The data obtained from radiometric and spectrophotometric analysis was compared to manufacturer specifications.

Results: Radiometric evaluation revealed LED light units tested did not satisfy manufacturer claims for minimum intensities. Spectral emissions from the LED light sources did meet manufacturer requirements. No clinically appreciable battery drain was evidenced from testing all re-chargeable LED units.

Conclusion: Despite limitations LED technology appears to be an effective alternative for curing of light-activated esthetic restorative materials. Additional advantages associated with LED curing lights include ergonomic handling capabilities, negative heat generation, and minimal maintenance concerns.

Keywords: Light-emitting diode, LED, composite polymerization, dental light meter, spectrophotometry

Citation: Owens BM, Rodriguez KH. Radiometric and Spectrophotometric Analysis of Third Generation Light-Emitting Diode (LED) Light-Curing Units. J Contemp Dent Pract 2007 February;(8)2:043-051.

Introduction

Visible light polymerization of resin composite and other esthetic restorative materials has been accomplished in previous decades by quartz-tungsten halogen (QTH) irradiation. Although QTH technology has been "relatively" efficient through low cost, heat production from wasted energy has been the primary disadvantage of this type of material activation.[1-5] Light-emitting diode (LED) technology developed for dental application has been shown to effectively polymerize dental restoratives using gallium nitride semiconductors, generating unfiltered blue light.[5,6-10] These units require minimal energy consumption, are ergonomically designed, and can be battery powered with an expected service period of several thousand hours compared to the QTH bulb life of approximately 100 hours.[8-10]

The visible wavelength range for LED polymerization is between 400–515 nanometers (nm) and closely matches the absorption spectrum of camphorquinone (CQ), the most common photoinitiator incorporated into esthetic restorative materials.[5,8,10-14] CQ is most efficiently activated or converted by light energy in the 450–490 nm spectra, with maximum absorption occurring between 465-470 nm.[1,5,15,16]

The International Standards Organization (ISO) has developed standards for dental materials, instruments, and equipment which are periodically updated. Light intensities of three regions are considered: 190-385 nm, 400-515 nm, and >515 nm.[17] Although this criterion was formulated for QTH light sources this information also pertains to LED units pending further published standards.

Parameters of illuminance include power density (intensity) and spectral emission or wavelength distribution. The quality of light produced by a dental light-curing unit (LCU) has a direct influence on the polymerization of restorative materials and is highly dependent upon the intensity or strength of irradiation, the peak wavelength emission, the interactions between these functions, and their correspondence with the requirements of the individual restorative.[18-20] Knowledge of the absorption spectrum of a material's photoinitiator chemistry is critical for effective polymerization. Only when those corresponding wavelengths match the maximum absorption of a material's photoinitiator does efficient light polymerization occur.[21,22]

LCU generation of spectral emissions beyond the traditional 515 nm limit produces wasted energy evidenced through excess heat production and glare, possible pulpal sequela, and inadequate material polymerization.[11,12,23,24]

During material polymerization light is absorbed and scattered by the restorative material and tooth structure causing a decrease in effectiveness, or attenuation of the intensity as the depth of the material increment increases.[25,26] Additional factors influencing material conversion include LCU irradiation distance from the restorative material, duration of exposure, curing tip diameter, and the condition of the unit.[27-29] Material physical characteristics including filler particle and resin matrix interactions control the optical translucency and shading variables, refractive index, and transmission coefficient that can also effect the depth of cure and/or hardness of the restorative.[19,20,27,30-33] Due to the dependence of material polymerization on radiant emittance (radiant flux per unit area of guide tip aperture), manufacturers have developed more powerful LCUs emitting increased intensities matched with appropriate wavelength spectra.

Portable, hand-held dental light meters have been developed to measure the light intensity produced by LCUs in the range of 400 to 515 nm.[34] Light meters can be useful in obtaining the measurement of LCU intensity for evaluation of the curing potential of an individual light source and, consequently, the restorative material. Many clinicians are unaware of the performance of their LCU and may be uncertain of the availability and effectiveness of dental light meters. Although these instruments are relatively inexpensive and easy to use, the consistency and accuracy has been challenged.[35]

The present study was designed to evaluate the intensity using six light meters and spectral distribution (peak wavelength) through spectrophotometric analysis of four third generation LED LCUs and one QTH unit. The battery expenditure of these LED units was also tested.

Methods and Materials

The products evaluated in this study include LED and QTH LCUs (Table 1). The four LED lights are all wand or pen style with ergonomic designs as a marketable attribute. The Coltolux (CX) (Coltene/Whaledent, Cuyahoga Falls, OH, USA), radii Plus (RP) (Southern Dental Industries, Bayswater, Australia), and Smartlite PS (PS) (Dentsply/Caulk, Milford, DE, USA) lights are self contained re-chargeable units. The PS light utilizes a novel inductive re-charging facility, while the Diopower (DP) (CMS Dental, Copenhagen, Denmark) light contains separate battery components that can be changed as required. The curing guide tip diameters are different sizes, comparing all light sources. All LCU curing guides are tinted except the DP light guide, which is clear and emits blue light.

Radiometric and spectrophotometric analysis of the LCUs was performed with the testing of battery expenditure for each re-chargeable LED LCU.

Radiometric Measurements

The intensity of five commercially available LED and QTH light sources was measured using six portable dental curing light meters (Table 2). The Coltolux (Coltene/Whaledent, Inc., Mahwah, NJ, USA); Cure Right (EFOS, Inc. Williamsville, NY, USA); Demetron 100 (Demetron Research Corp., Danbury, CT, USA); and Hilux (Benlioglu Dental Inc. Ankara, Turkey) light meters were developed for conventional QTH light testing.

The Demetron L.E.D. (Demetron Research Corp., Danbury, CT, USA) is specifically calibrated for evaluation of LED light sources, while the Light Meter-200 (TPC Advance Technology, Inc., Diamond Bar, CA, USA) is calibrated for both LED and QTH measurements. The Demetron 100 and Demetron L.E.D. light meters are powered by the curing light source, while the remaining light meters are battery powered and produce a digitally-based reading. The intensities of all LCUs were measured five times with each light meter, and the readings were averaged for data Hi analysis. Each LED light source was fully charged prior to testing.

Table 1. Light-curing units tested.

Light	Code	Manufacturer	Type	Light Guide Diameter (MM)
Coltolux	CX	Coltene/Whaledent Cuyahoga Falls, OH, USA	LED	11.0
Diopower	DP	CMS Dental Copenhagen, Denmark	LED	8.0
radii Plus	RP	Southern Dental Industries Bayswater, Australia	LED	12.0
Smartlite PS	PS	Dentsply/Caulk Milford, DE, USA	LED	8.0
Schein Visible Cure (QTH control)	VC	Sullivan-Schein Dental Melville, NY, USA	QTH	9.0

Table 2. Radiometers tested.

Radiometer	Manufacturer	Scale	Aperture Diameter (MM)
Coltolux Light Meter	Coltene/Whaledent, Inc. Mahwah, NJ, USA	Digital	8.0
Cure Rite Visible Curing Light Meter	EFOS, Inc. Williamsville, NY, USA	0 – 1999 mW/cm2 Digital	6.0
Demetron 100	Demetron Research Corp. Danbury, CT, USA	0 – 1000 mW/cm2 Analog	7.0
Demetron L.E.D.	Demetron Research Corp. Danbury, CT, USA	0 – 2000 mW/cm2 Analog	7.0
Hilux Dental Curing Light Meter	Benlioglu Dental Inc. Ankara, Turkey	Digital	12.0
Light Meter-200 Curing Light Meter	TPC Advance Technology, Inc. Diamond Bar, CA, USA	0 – 5000 mW/cm2 Digital	5.5

Table 3. Energy output (intensity) of LCUs.

Light Meter (mW/cm^2)							
Light Code	Coltolux	Cure Right	Demetron 100	Demetrom LED	Hilux	Light Meter-200	Average
CX	792.8	885.0	664.0	648.0	913.2	900.0	800.5
DP	590.8	425.0	406.0	400.0	411.4	535.0	461.4
RP	714.8	1953.0	698.0	620.0	1889.2	960.0	1139.2
PS	801.0	988.0	803.0	700.0	724.0	1128.0	857.3
VC	823.8	936.1	846.0	700.0	801.8	1041.0	858.2

Spectrophotometric Analysis

The spectral distribution generated by each LCU was determined by passing the light through a Model 139 Hitachi Elmer-Perkins Spectrophotometer (Elmer-Perkins, Wellesly, MA, USA). A slit width of 0.25 mm was used with a spectral evaluation over a wavelength range of 350-550 nm. The unit was calibrated prior to usage. The spectrum of radiation measured from each LCU was analyzed twice.

LED Battery Expenditure

The battery life of each re-chargeable LED LCU was performed by taking a single light meter (Coltolux) reading at baseline and every 60 seconds thereafter for 1500 seconds total. From these readings the battery expenditure was plotted for each LED LCU. Again, each LED light was fully charged prior to testing.

Results

The average intensity (mW/cm^2) values were determined from each light meter for all LCUs as shown in Table 3. The RP LED light source revealed the highest mean intensity with the DP LED showing the lowest mean value.

The spectral wavelength distributions as determined by spectrophotometer analysis are presented in Figure 1.

The LED light sources revealed a rather narrow spectrum with peak wavelength readings ranging from 470 to 500 nm. The QTH irradiation presented a broad, flat distribution, peaking at 520 nm.

Tested values were compared to manufacturers' claims for intensity and spectral emittance.

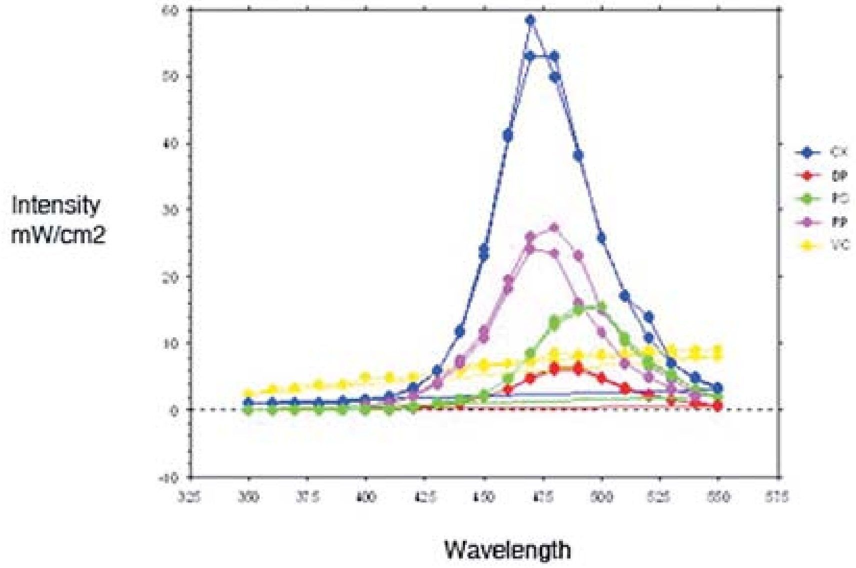
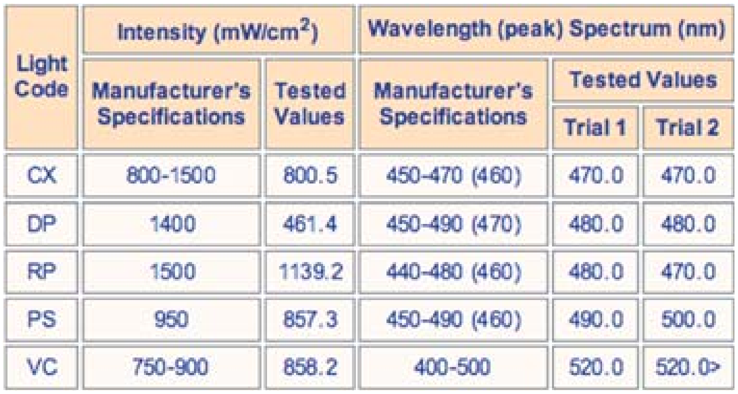


Figure 1. Light curing unit spectral distribution.

Table 4. Curing light intensity/peak wavelength values.



Light Code	Intensity (mW/cm²)		Wavelength (peak) Spectrum (nm)		
	Manufacturer's Specifications	Tested Values	Manufacturer's Specifications	Tested Values	
				Trial 1	Trial 2
CX	800-1500	800.5	450-470 (460)	470.0	470.0
DP	1400	461.4	450-490 (470)	480.0	480.0
RP	1500	1139.2	440-480 (460)	480.0	470.0
PS	950	857.3	450-490 (460)	490.0	500.0
VC	750-900	858.2	400-500	520.0	520.0>

Among the LCU lights tested, none fulfilled both radiometric (intensity) and spectrophotometric (wavelength emittance) qualifications. The LED lights were below the target intensity values (except the CX light), while the QTH light satisfied manufacturer intensity goals. All LED lights (except the PS unit, Trial 2) were within the manufacturers' claims for wavelength distribution. The QTH light mean values (peak wavelength, both trials) were outside the effective CQ activation range (Table 4).

The battery life of each re-chargeable LED light is graphically represented in Figure 2. The results show no appreciable decrease in intensity would be noted, clinically following the 1500 second evaluation period comparing all LED LCUs.

Discussion

In the present study substantial variation comparing light meters was exhibited based upon radiometric measurements of the LED and QTH lights. Considering intensity, the Schein Visible Cure (QTH control) (VC), QTH, and CX LED lights were the only LCUs within manufacturer specifications. The DP light revealed a mean intensity of 461.4 mW/cm^2, which was well below the manufacturer's threshold of 1400 mW/cm^2. Although target intensity values were not always satisfied in this study, based upon previous research and pre-existing published ISO standards (ISO:10650, 1999), an intensity reading of 300 mW/cm^2 would produce adequate material polymerization at 2.0 mm material depth.[29,36,37]

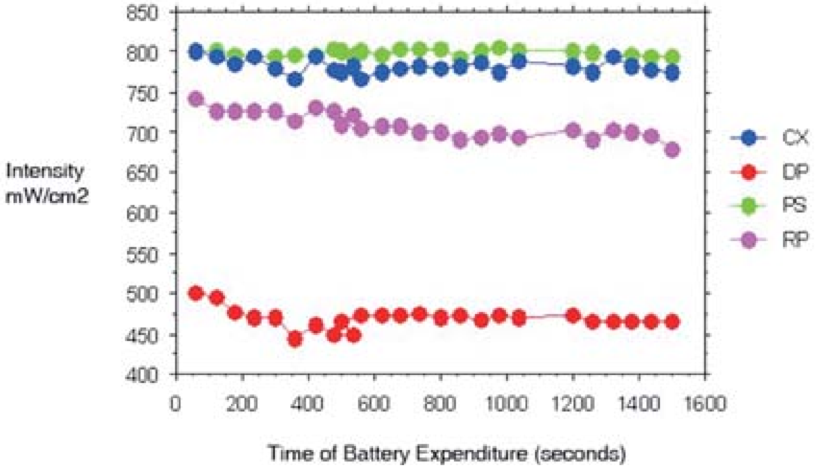


Figure 2. LED battery expenditure.

Spectrophotometric analysis of the LED LCUs revealed a narrow spectral distribution, ranging from 470 to 500 nm. All LED LCUs were within the manufacturer specifications, except the PS light, Trial 2. Trial 2 of the PS light exhibited a reading of 500 nm which is slightly greater than the 490 nm manufacturer limit. The CX and DP lights revealed peak wavelength values (470.0 and 480.0, respectively), which were closest to manufacturers' peak targets. The QTH LCU showed broad, flat spectral distributions, with wavelength values peaking at 520 nm, also above manufacturer's assessments. These higher readings indicate the production of wasted energy in the form of heat, that could potentially be detrimental to the dental pulp and restorative material through inadequate polymerization and possible restoration replacement.[23,24]

Variation in radiometric assessment can be dependent upon curing tip diameter and guide condition, voltage fluctuation, and bulb/filter condition.[35] All light guides were tinted except the DP light guide which was clear. The DP light emitted blue light in a quite uncontrollable fashion making it difficult to shield from the examiner's eyes. As the intensity results were substantially lower using this light compared to the other LED units, the clear guide with escaping blue light energy could have been a negative contributing factor.

Individual light meters with fixed-diameter apertures may have a small aperture for taking peak intensity measurements or a large aperture for averaging the intensity from the entire light guide area.[35] In this investigation, the Hilux instrument was the only light meter with a large (12.0) aperture, while each of the LCU light guide diameters were as large or larger than the radiometer apertures (except Hilux). Research has determined LCUs exhibit different intensity values depending upon different diameter light guides. Leonard et al.[38] reported, "given the same light source, larger diameter tips provide lower irradiance (mW/cm^2) values than smaller diameter tips and larger diameter tips may be less effective than smaller diameter tips in polymerizing light-activated materials." However, in this study LCUs with larger light guides (CX-11.0 mm and RP-12.0 mm) produced divergent measurements. The DP LCU with a light guide diameter of 8.0 mm (among smallest in present study) produced the lowest average intensity (461.4 mW/cm^2). Consequently, this study showed no correlation between light guide diameter and the degree of light intensity.

Conclusion

Analysis of the data in the present study showed the individual LCUs displayed similar intra-intensity values (same light meter), but when using different light meters, significant variations were encountered. Overall, the Coltolux (CX) light was the only LED LCU that satisfied manufacturers claims regarding both intensity and spectral emission parameters. Following battery expenditure testing, none of the LED LCUs showed a significant decrease in light intensity. Commercial dental light meters, despite their limitations and varied measurement spectrums, can be inexpensive and reliable instruments for monitoring the efficiency of LCU performance and ultimately the polymerization of dental restoratives. From information gathered in this study, LED technology appears to be an effective alternative to QTH irradiation of light-activated esthetic restoratives.

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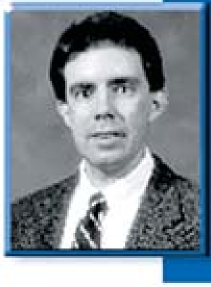

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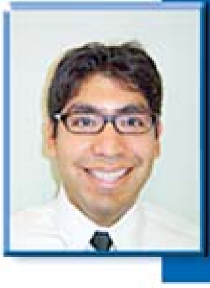

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Acknowledgement

This study was supported in part by the University of Tennessee Alumni Research Training Grant.