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Laboratory Research

Emission Characteristics and Effect of Battery Drain in "Budget" Curing Lights

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Clinical Relevance

Clinicians should be aware that irradiance values reported by "dental radiometers" do not adequately describe the output from curing lights. "Budget" lights do not provide consistent performance during use; their light output at the tip end was highly inhomogeneous and does not cover as large an area as lights from major dental manufacturers.

SUMMARY

Recently, "budget" dental light-emitting diode (LED)–based light-curing units (LCUs) have become available over the Internet. These LCUs claim equal features and performance compared to LCUs from major manufacturers, but at a lower cost. This study examined radiant power, spectral emission, beam irradiance profiles, effective emission ratios, and the ability of LCUs to provide sustained output values during the lifetime of a single, fully charged battery. Three examples of each budget LCU were purchased over the Internet (KY-L029A and KY-L036A, Foshan Keyuan Medical Equipment Co, and the Woodpecker LED.B, Guilin Woodpecker Medical Instrument Co). Major dental manufacturers provided three models: Elipar S10 and Paradigm (3M ESPE) and the Bluephase G2 (Ivoclar Vivadent). Radiant power emissions were measured using a laboratory-grade thermopile system, and the spectral emission was captured using a spectroradiometer system. Irradiance profiles at the tip end were measured using a modified laser beam profiler, and the proportion of optical tip area that delivered in excess of 400 mW/cm^2 (termed the effective emission ratio) was displayed using calibrated beam profile

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images. Emitted power was monitored over sequential exposures from each LCU starting at a fully charged battery state. The results indicated that there was less than a 100-mW/cm^2 difference between manufacturer-stated average tip end irradiance and the measured output. All the budget lights had smaller optical tip areas, and two demonstrated lower effective emission ratios than did the units from the major manufacturers. The budget lights showed discontinuous values of irradiance over their tip ends. One unit delivered extremely high output levels near the center of the light tip. Two of the budget lights were unable to maintain sustained and stable light output as the battery charge decreased with use, whereas those lights from the major manufacturers all provided a sustained light output for at least 100 exposures as well as visual and audible indications that the units required recharging.

INTRODUCTION

Differences in the light output among dental light-curing units (LCUs) are not readily detectable by visual inspection or by use of a "dental radiometer." The International Organization for Standardization (ISO) 6050 standard for calculating the radiant exitance (irradiance) assumes that the emitted power and spectral emission profiles are homogeneously distributed across the light tip end and can be fully characterized by use of a single value.[1,2] Similarly, both the ISO 11405 bond strength test[3] and the ISO 4049 depth of cure evaluation[4] assume that LCU output is uniformly distributed across the emitting end of the light tip and that the target specimen will receive the same irradiance and wavelengths of light across its entire surface. It is now well established that both the irradiance and the distribution of the spectral emission delivered by many dental LCUs can be very inhomogeneous.[5-11] This inhomogeneity will cause non-uniform polymerization across the surface and within the depths of a photocured resin-based composite (RBC).[5,7,10-12] In addition, previous reports suggest that longer photopolymerization (40 seconds) at lower irradiance values is preferred over rapid (5 seconds or less) photopolymerization of RBCs using high irradiance levels.[13-16] With over 260 million RBC restorations placed annually worldwide,[17] any factor that could cause premature restoration failure has both significant health and financial implications. Evidence exists that the undercuring of RBCs will increase the likelihood of fracture, secondary caries, excessive wear of the restoration[13,15,16,18-24] and leaching of potentially harmful components into the body.[25,26] In addition, arbitrarily increasing exposure times in an effort to prevent undercuring may create unacceptable temperature increases in the tooth and surrounding oral tissues.[21,27-29]

Recently, the dental profession has been able to purchase dental equipment, including LCUs, directly over the Internet. A recent internet search (August 2014) revealed over 20 "budget" LCUs for sale, some for as little as US$9.00.[30] These lights claim to deliver at least 400 mW/cm^2, a value that has been reported to be the minimum irradiance necessary to cure resin composites,[19] and they offer many of the same operating features as LCUs purchased from major manufacturers but at a much lower cost. A recent evaluation of 11 such budget LCUs purchased over the Internet reported that many components were flimsy or fitted poorly and that the light guide diameters were smaller than those found from major manufacturers.[30]

Clinicians can operate light-emitting diode (LED)–based LCUs using battery power and not be bothered with power cords that may interfere with clinical treatment. When operating on battery power, it is assumed that the design of the curing light compensates for power drain to ensure that the light output remains at the same level. Without such electronic compensation, the light output would decrease with decreasing battery charge and potentially affect the polymerization of the target resin. To warn the clinician against operating the light under conditions when the light output might be insufficient, a number of different types of visible and audible indicators are used.

In light of the widespread availability of budget LCUs, it seems imperative that the claims of these budget dental curing lights need to be validated with respect to the parameters mentioned above. If their performance is inferior to units made by major dental manufacturers, then clinicians should be warned against their usage. Thus, the purpose of this study was to evaluate and characterize 1) radiant power, 2) spectral emission, 3) beam profile, 4) effective emission ratios, and 5) LCU performance among three LCUs from major manufacturers and the three budget LCUs purchased over the Internet. The null hypotheses assumed that there would be no differences in each of the above parameters among any of the LCUs tested. In addition, it was hypothesized that the manufacturer-reported radiant exitance would be within 100 mW/cm^2 of the

Table 1: *Curing Lights, Manufacturer, And Mean Radiant Power For Each Unit And Mean Radiant Power Output ± 1 Standard Deviation (SD) From One Unit Of Each Model Measured Three Times Daily For 5 Days Always Using a Fully Charged Battery*

Light-Curing Unit	LED Classification	Manufacturer and Exposure Time	Serial Number	Mean Power (mW)	Mean Power ± SD (mW) (Grouping)*
Elipar S10	Blue	3M ESPE, 20 s	939112-012777	713	720 ± 5 (C)
Elipar S10	Blue		939112-007892	720	
Paradigm	Blue		932123-000862	731	699 ± 30 (D)
Paradigm	Blue		932123-009202	671	
Paradigm	Blue		932123-004740	696	
Bluephase G2	Polywave	Ivoclar Vivadent, 30 s	P634762S607644	778	800 ± 21 (A)
Bluephase G2	Polywave		P634762S600134	801	
Bluephase G2	Polywave		P626170S560993	820	
KY-L029A	Blue	Foshan Keyuan Medical Equipment Co, 40 s	SK13L0201324	609	597 ± 12 (E)
KY-L029A	Blue		SK13L0201324	586	
KY-L029A	Blue		SK13L0301015	595	
KY-L036A	Blue		SK13L0400608	765	771 ± 14 (B)
KY-L036A	Blue		SK13L0301123	760	
KY-L036A	Blue		SK13M0501003	786	
Woodpecker LED.B	Blue	Guilin Woodpecker Medical Instrument Co, 20 s	L12B0572B	426	409 ± 20 (F)
Woodpecker LED.B	Blue		B12050175C	414	
Woodpecker LED.B	Blue		L1340459B	388	

Alpha, 0.05
Error degrees of freedom, 84
Error mean square, 59.796
Critical value of Studentized range, 4.125
Minimum significant difference, 8.235
* *Indicates power levels that were significantly different:* $p<0.05$, *Tukey* post hoc *test.*

measured output and that all LCUs could deliver their stated light output for at least 100 exposures.

METHODS AND MATERIALS

The light output from six contemporary LED-curing lights was measured in real time using a laboratory-grade spectroradiometer, a laser beam profiler, and a thermopile. The LCUs were chosen to include a selection of LED units. Major dental manufacturers provided three of the LCUs, and three LCUs were purchased over the Internet for between US$105 and US$183. To provide a representative sample, three examples of each model of LCU were evaluated, except for the Elipar S10, for which two examples of this LCU were tested (Table 1). The LCUs were tested using their high power setting for the maximum exposure time that the unit allowed. This time ranged between 20 and 40 seconds depending on the LCU (Table1). Manufacturers of the Elipar S10, Paradigm, and Bluephase G2 state that these LCUs have a 10-mm-diameter tip (geometric area 0.79 cm^2)[31-33] and the manufacturers of the KY-L029A and KY-L036A (Foshan Keyuan Medical Equipment Co, Foshan City, Guangdong Province, China) and Woodpecker LED.B (Guilin Woodpecker Medical Instrument Co, Guilin, Guangxi, China) state these units have an 8-mm-diameter tip with a geometric area of 0.50 cm^2. Table 2 shows how these tip areas are not the same as the optical tip areas.

Emitted Radiant Power

The ISO 6050 standard uses a laboratory grade thermopile[1,2] to obtain radiant power values. Thus, the power outputs from all the LCUs were measured using a laboratory-grade thermopile (PowerMax-USB power meter with a PM10 detector, Coherent Inc., Santa Clara, CA, USA). During measurement, the light tip end was positioned as close as possible to the sensor surface, without touching it. Each LCU was measured three times, with new tip placement each time. Each measurement was started using a fully charged battery, and the radiant power output was averaged over the last five seconds of the light exposure to provide the radiant power from the LCU. For one randomly chosen unit of each model of LCU, this measurement was repeated three times every day for five days (15 measurements) in a randomly determined order of lights to determine the average radiant

Table 2: *Manufacturer's Stated Irradiance and Tip End Dimensions for the LCUs Compared to The Measured Values As Well As the Proportion of Tip Area Providing Light Output Above 400 mW/cm² (Effective Emission Ratio)*

Light	Purchase Source	Manufacturer's Stated Irradiance (mW/cm²)	Mean Irradiance [Maximum Measured on Beam Profile] (mW/cm²)	Manufacturer's Stated Tip Diameter (mm) [Area cm²]	Measured Optical Tip Area (cm²)	Effective Tip Area (Emitting >400 mW/cm²) (cm²)	Effective Emission Ratio
Elipar S10	Major Manufacturer	1200	1120 [2000]	10 [0.79]	0.63	0.61	0.96
Paradigm		1200	1170 [2200]		0.63	0.60	0.96
Bluephase G2		1200	1290 [2300]		0.64	0.59	0.92
KY-L029A	Internet purchased (budget)	1700	1640 [4500]	8 [0.50]	0.37	0.31	0.83
KY-L036A		2100	1990 [14000]		0.39	0.39	0.99
Woodpecker LED.B		1000-1200	1050 [2500]		0.39	0.31	0.78

power from each model of LCU. A two-way analysis of variance (ANOVA) with model of LCU and measurement time, followed by Tukey *post hoc* multiple comparison tests, was used to determine if there was a difference in the power output from the six LCUs ($p<0.05$).

Spectral Emission

The spectral radiant power emitted from each LCU was recorded 10 times using a six-inch integrating sphere (Labsphere, North Sutton, NH, USA) connected to a fiber-optic spectrometer (USB 4000, Ocean Optics, Dunedin, FL, USA). Prior to measurement, the system was calibrated using a National Institute of Standards and Technology (Gaithersburg, MD, USA) traceable light source (Labsphere). Each light measurement recorded both the spectral radiant power and the total radiant power emitted between 350 and 550 nm.

Beam Irradiance Profile, Optical Diameter, and Effective Emission Ratio

The distribution of radiant power across the LCU tip end was measured using a laser beam profiler.[9,11,34] This device uses a CCD camera with a 50-mm focal length lens (USB-L070, Ophir-Spiricon, Logan, UT, USA) positioned at a fixed distance from the diffusing surface of a translucent ground-glass target (DG2X2-1500, Thor Laboratories, Newton, NJ, USA). The photonic count received by each camera pixel was calibrated using software (BeamGage v.6.1, Ophir-Spiricon). Images were spatially calibrated from the edge-to-edge distance of the fiber-optic bundle within each light guide tip as measured by a digital micrometer (Mitutoyo Canada Inc., Mississauga, ON, Canada). This measurement was termed the "optical diameter" of the light guide and was used to calculate the "optical area" of the light guide.

Prior to each image collection, the level of ambient light was subtracted to normalize all pixels to a similar baseline value (UltraCal, BeamGage). The LCU was then activated and allowed five seconds to stabilize, and the resulting image and data were recorded on a personal computer using software (BeamGage).[9,11] The appropriate average radiant power emission level obtained previously was then used to scale the recorded images for that given LCU, resulting in color-coded, calibrated, localized levels of irradiance values at the target screen. Irradiance values at each camera pixel were exported for further analysis into a graphics software program (Origin Pro v.9.1, OriginLab, Northampton, MA, USA). The "effective emission ratio" was defined to be the quotient of the tip area emitting radiation in excess of 400 mW/cm^2 (the "effective emission area") and the "optical tip area" of the LCU tip. This value represents the proportion of the light tip that delivers more than 400 mW/cm^2, providing sufficient irradiance for adequate light curing.[19]

Emitted Radiant Power as a Function of Battery Discharge

The real-time, radiant power output from each LCU was characterized over one full battery discharge cycle. Lights were set to run for the exposure time shown in Table 1 and were used until either the battery ran out or the LCU ceased to function. The lights were allowed to rest for 30 seconds after each exposure to allow the units to cool down, and the operator had a 15-minute rest after the 50th light exposure, and then after every 100th exposure as necessary.

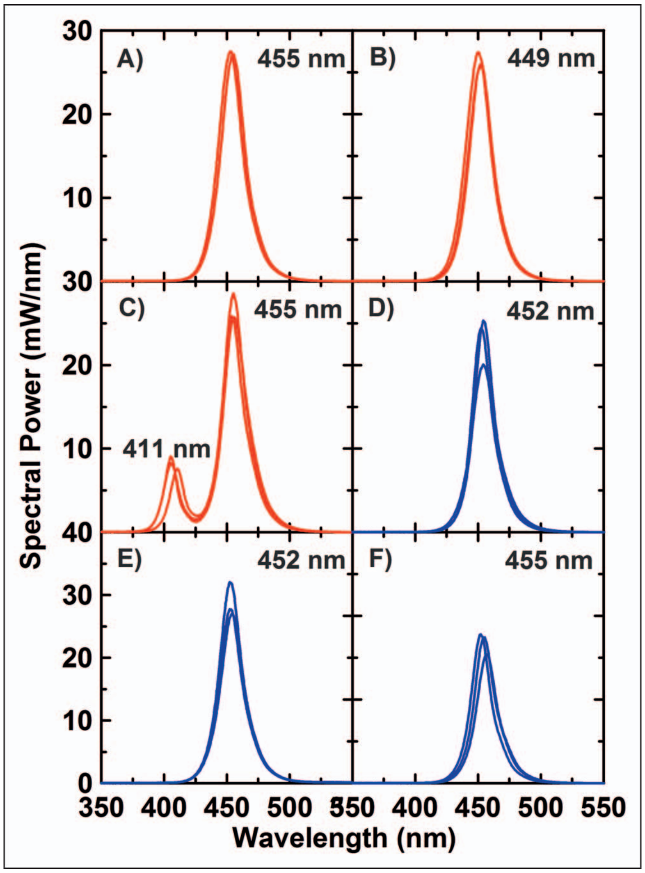

Figure 1. *Representative spectral emission profiles (360-520 nm) from the LCUs measured using an integrating sphere. All six LCUs deliver an emission peak in the 449- to 455-nm blue range. Panel (C) illustrates that the Bluephase G2 delivers a broader spectral emission with an additional violet peak at 411-nm.*

RESULTS

Emitted Power and Optical Tip Area

Table 1 lists the mean emitted power values measured from the LCUs. The two lowest power values were from budget lights purchased over the Internet. The two-way ANOVA examining the effect of model of LCU and measurement time showed that when the measurement was made had no significant effect. As the data were normally distributed, the measurement replicates were combined, and the Tukey *post hoc* multiple comparison test reported a significant difference between the power outputs of every LCU ($p<0.05$). Table 2 shows that the optical tip areas of the LCUs from major manufacturers were always greater (0.63-0.64 cm^2) than those on the budget lights (0.37-0.39 cm^2).

Spectral Emission

A representative spectrum from each of the LCUs is shown in Figure 1. The spectral emissions from five of the LCUs were very similar: Elipar S10 peaking at 455 nm, Paradigm at 449 nm, KY-L029A at 452 nm, KY-L036A at 452 nm, and Woodpecker LED.B at 455 nm. The Bluephase G2 was a polywave LED light with dual emission peaks at 411 and at 455 nm. With the exception of the Woodpecker LED.B unit, the peak power emission in the blue spectral region for all lights was between 25 and 29 mW/nm.

Geometric Distribution of Beam Energy

The averaged radiant exitance across the optical area was within 100 mW/cm^2 of the manufacturer's stated irradiance for all LCUs (Table 2). However, the nonuniformity of power distribution across the tip end (Table 2) meant that there were localized regions of high irradiance that ranged from 900 mW/cm^2 above the average irradiance for the Elipar S10 to as much as 12,000 mW/cm^2 above the average irradiance for the KY-L036A unit.

Representative beam profiles of the LCUs shown in Figure 2a illustrate the extent of inhomogeneity in light distribution observed across the tip end. Figure 2b (the KY-L036A light) has its own unique scale because the localized radiant exitance near the center of the light tip was much higher from this LCU compared to the other units. Four of the LCUs delivered the greatest radiant exitance close to the center of their tip. For the Bluephase G2 and the KY-L036A lights, the maximum exitance was not coincident with the center of the optical area. Instead, their irradiance peaks were associated with the LED chip locations or the reflections from the reflectors within the body of the LCU. A nonclinically useful region of irradiance where the emission was less than 400 mW/cm^2 was evident in some LCUs (Figure 2a).

Scaled beam profiles of the LCUs were superimposed over a premolar class II mesio-occluso-distal cavity (MOD) preparation (Figure 3). The solid black circle indicates the outer tip diameter that covers the tooth. To the clinician, this appears to be the area that is receiving blue light, but the dotted circle indicates the size of the optical tip area. The region between the two circles represents the light guide sheath that emits little or no light. Additionally, it can be seen that the effective light output (area above 400 mW/cm^2) from some light tips did not cover the entire premolar MOD preparation area. All the optical tip diameters of the budget LCUs were smaller, and had approximately 60% decrease in the tip area, compared to those from the major manufacturers (Table 2). The useful light-polymerizing regions emitting above 400 mW/cm^2 of the KY-

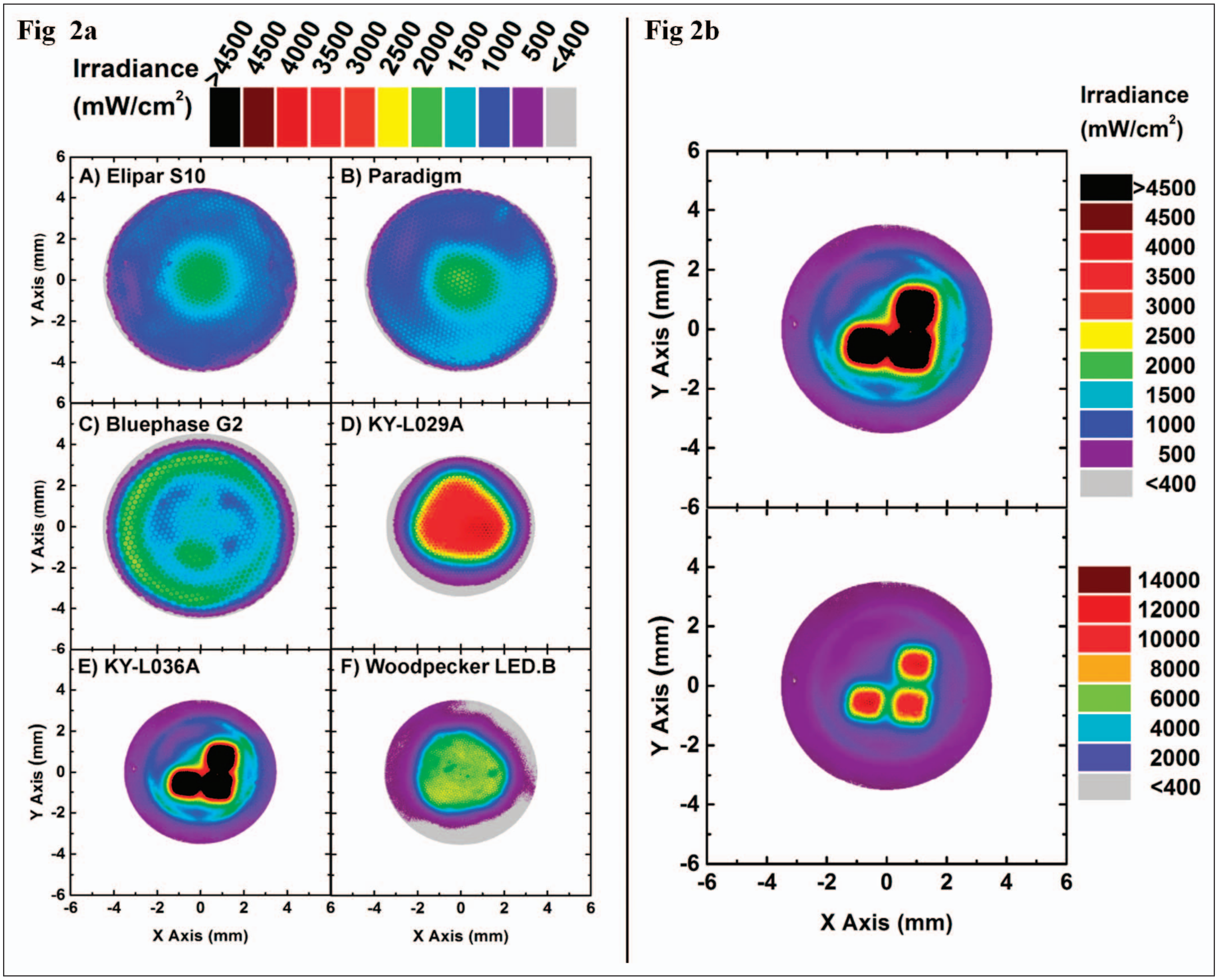

Figure 2. *(a): Representative scaled two-dimensional beam profiles showing the radiant exitance distribution from the optical tip of each LCU. The effective regions delivering >400 mW/cm^2 minimum irradiance threshold at the tip are colored according to the radiant exitance. (b): KY-L036A has been plotted on an additional unique scale to accommodate the higher maximum irradiance (14,000 mW/cm^2) delivered across a small region at the tip of this LCU.*

L029A and Woodpecker LED.B were further reduced by their nonuniform light output.

Effective Emission Ratio

The measured optical area, the effective tip area, and the effective emission ratio of one example of each LCU are reported in Table 2. For all LCU's the optical tip area was less than the manufacturer's stated tip area. The Woodpecker LED.B emitted light in excess of 400 mW/cm^2 over only 78% of its fiber-optic area, while the KY-L036A emitted light in excess of 400 mW/cm^2 over 99% of its tip area. The Elipar S10, Paradigm, Bluephase G2, and KY-L029A lights emitted light in excess of 400 mW/cm^2 over 96%, 95%, 92%, and 83% of their respective optical tip areas.

Light Output Over Time

The radiant power output was evaluated over the lifetime of one complete battery discharge for each LCU (Figure 4). The power reported for each exposure was taken from an average recorded during the last 10 seconds of LCU operation. The light output from the two KY series of LCU was not stable, and, without warning, the output decreased over time (Figure 4D,E). After every 15-minute long cool-down period, the Elipar S10, Paradigm, Bluephase G2, and Woodpecker LED.B showed a similar initial

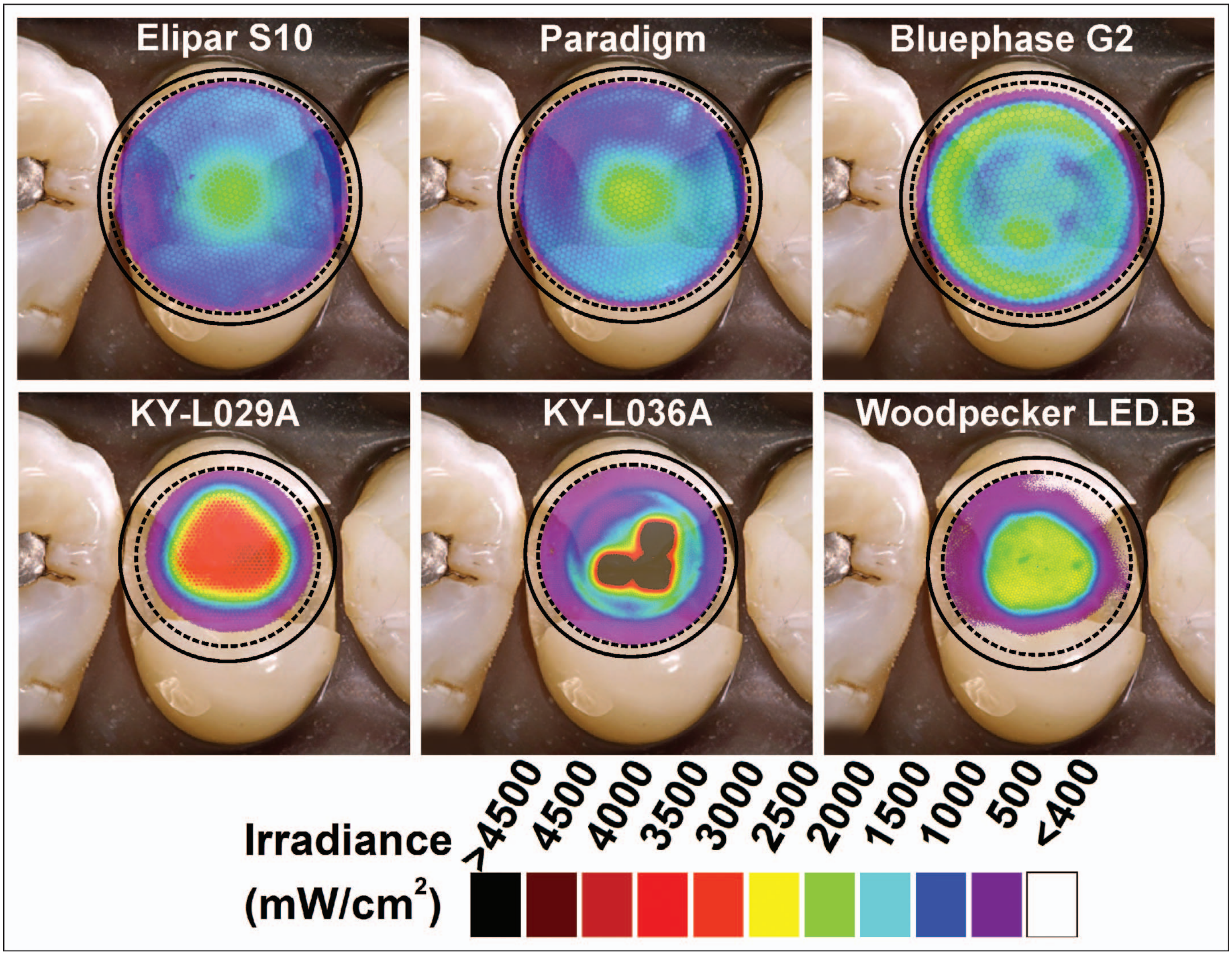

Figure 3. *Representative two-dimensional beam profiles of six LCUs superimposed over the same premolar MOD preparation. The solid black circle indicates the outer tip diameter; the dotted circle indicates the size of the optical tip area. The tip area emitting less than 400 mW/cm^2 is left clear. The wider-diameter light guides from the major manufacturers adequately cover the entire preparation. The smaller-diameter light guide tips used in the budget units do not cover the preparation and show areas of localized 'hot spots' of high irradiance values.*

spike in their radiant power output when first turned on, before decaying to a near steady-state power output. This initial spike in the Elipar S10 increased the radiant power by ~10mW (~1% of the total output), in the Paradigm by ~30 mW (~5%), in the Bluephase G2 by ~40 mW (~4%), and in the Woodpecker LED.B by ~5 mW (~1%). When initially turned on and after a cool down period, the KY-L029A delivered a lower power output that increased slightly after a couple of exposures. Figure 4 shows that the user can expect LCUs, from the major manufacturers, when new, to deliver at least 100 light exposures before requiring recharging. Of note, one of the three Bluephase G2 units delivered only 100 light exposures before indicating it was about to shut down, whereas the other two units delivered 150 exposures (Figure 4C). The Woodpecker LED.B unit delivered at least 700 exposures, however only at a low, but consistent, radiant power output.

DISCUSSION

The radiant power, the beam profiles, and the effective emission ratios were noticeably different among the dental LCUs. Thus, the null hypotheses assuming no difference in these parameters among the LCUs were disproven. The spectral emissions were similar for the five single peak LCUs, but it was different for the polywave LED unit (Figure 1). All the LCUs produced a blue light emission peak in the 449

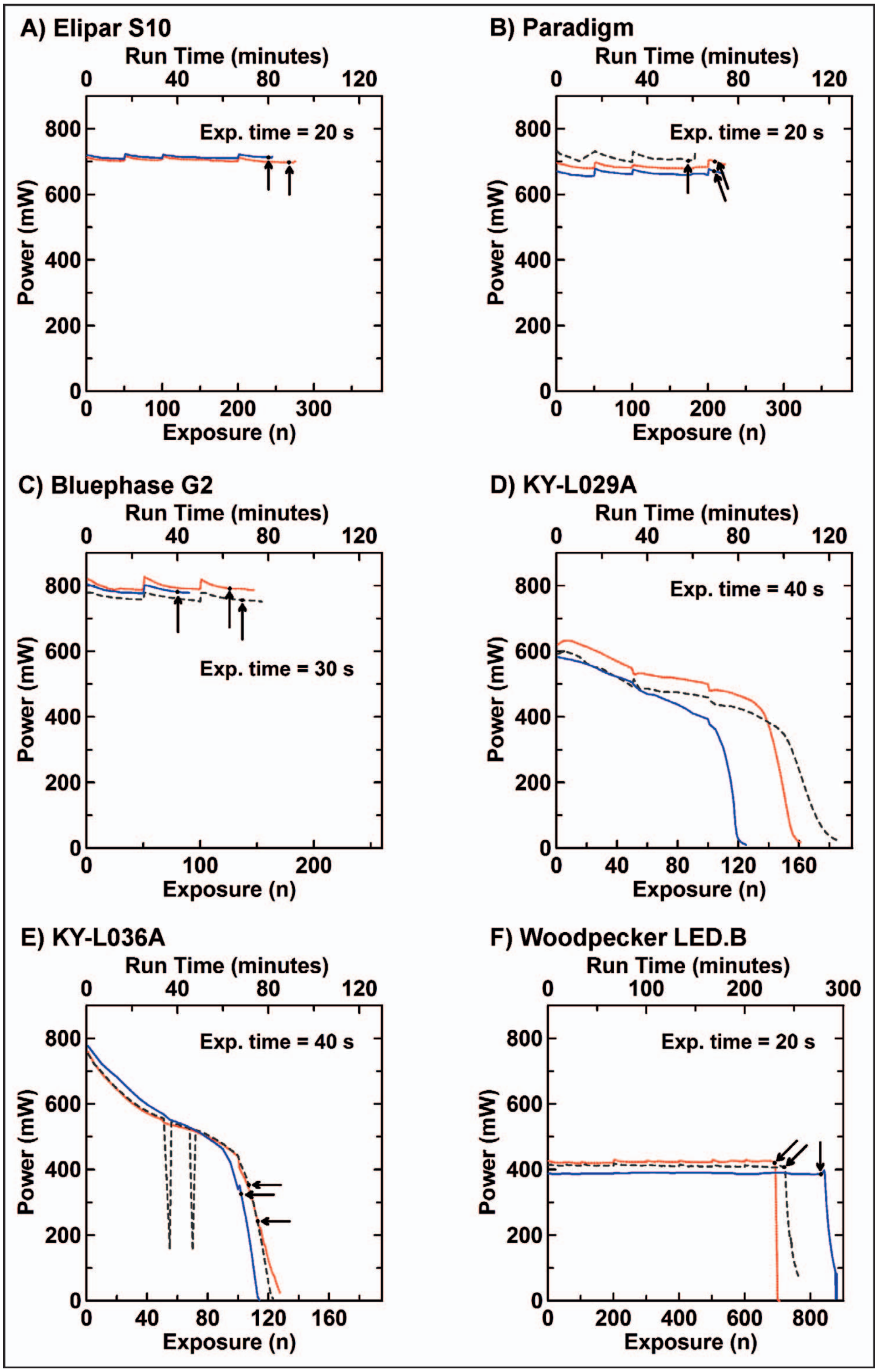

Figure 4. *Mean radiant power (mW) emitted by each LCU averaged over the final 10 seconds of an exposure shown as a function of both the total accumulated exposures and the total run time (minutes) since the last battery charge. An ↑ indicates when the LCU first gave a low battery warning.*

to 455-nm range, however the Bluephase G2 delivered an additional violet peak at 411-nm. The manufacturer-reported radiant exitance values were within 100 mW/cm^2 of the output averaged across the tip, but only 4 out of the 6 LCUs tested could deliver their stated light output for at least 100 exposures.

Clinicians assume that the light emitted from the tip end is uniformly distributed and that light is emitted from the entire tip end at levels that will adequately polymerize their restorative materials. The percentage of the light tip area that emitted light that was within 20% (a value that has been used to determine bioequivalence[35]) of the manufacturer's stated irradiance ranged from a high of 63.5% for the Elipar S10 to a low of 6.5% for the KY-L036A. Usually, the output from an LCU is described as a single radiant exitance or irradiance value that is calculated from the quotient of the radiant power and light tip optical area using the method described in the ISO 6050 standard. Results of the current work demonstrate that, because the light emission is not the same across the optical tip area, this single irradiance value represents only an averaged irradiance value (Figures 2a and 3) and can be very misleading.

In accordance with a previous report, the light guide diameters on all the budget units were smaller than those found from major manufacturers.[30] When describing the diameters of the light guides, all manufacturers appear to have quoted the outer diameter of the light guide and not the more important optical area. Knowing the effective area delivering light above 400 mW/cm^2 would be even better.

The averaged radiant exitance across the optical area was within 100 mW/cm^2 of the manufacturer's stated irradiance for all LCUs, confirming the null hypothesis for this parameter (Table 2). This small difference was considered within fabrication tolerance of a given manufacturer. To verify that the LCUs could deliver a repeatable radiant power output, the first exposure on a fully charged battery was measured 15 times over a period of five days. All lights showed a repeatable radiant power output on the first exposure ($p<0.05$) from a fully charged battery, with coefficients of variation between 0.3% and 2.2%. Despite having a significantly lower radiant power output, the Woodpecker LED.B achieved an average irradiance of 1,200 mW/cm^2 only because it has a small diameter light tip with an optical area of only 0.39 cm^2 (Table 2). The clinical consequences of having the small tip diameters found on the three budget LCUs are evident in Figure 3. When the two-dimensional beam profiles of the LCUs are superimposed over a premolar MOD preparation, they illustrate that when the KY-L029A or the Woodpecker LED.B units are used, many regions across the restoration will receive less than the minimum acceptable 400-mW/cm^2 value[19] so multiple light exposures will be required to deliver sufficient energy to the resin restoration.

Since it is unlikely that a dentist would use a curing light more than 100 times a day, all the LCUs from the major manufacturers and the Woodpecker LED.B provided acceptable battery life when new (Figure 4). Figure 4 illustrates that the Elipar S10, Paradigm, and Bluephase G2 LCUs all delivered a stable radiant power from the first to their final exposure. The performance of the Woodpecker LED.B light also fell within this acceptable profile and thus the null hypothesis related to stability of performance over multiple exposures is confirmed for these four LCUs. Figure 4 illustrates the temporal instability of all three examples of the KY-L029A and KY-L036A units, as their output was unstable throughout the battery discharge cycle. At 75% battery life (after 27 minutes of use), the KY-L029A light delivered only 90% of its initial power output. At 50% battery life (after 55 minutes of use), the unit provided only 80% of its initial power output. After 90 minutes and without any indication to the user, the output from this LCU dropped precipitously. The LCU did not turn itself off but instead continued to emit low amounts of blue light, such that the user may not realize that the unit was not functioning correctly. The KY-L036A light showed a continuous decrease in radiant power output. At 75% battery life (20 minutes), the unit delivered only 80% of its initial power output. At 50% battery life (51 minutes), only 70% of its initial power output was being delivered. Similar to the KY-L029A unit, the power output of the KY-L036A dropped sharply after 60 minutes of use. This particular LCU also displayed an anomaly at the 55th and 70th exposures. Although the light was set to emit for 40 seconds at maximum power, this unit randomly changed to a lower power setting and emitted light for only 20 seconds, but then returned to the maximum exposure setting at the next exposure cycle.

A quality light should indicate to the operator when the unit requires recharging. The Elipar S10, Paradigm, and Bluephase G2 lights all gave low battery warnings (Figure 4). They then continued to operate normally until they ceased operation after a further eight, nine, or 24 exposures, respectively. The final four pulses of the Elipar S10 were accompanied by an audible warning beep. The last pulse of the Paradigm was accompanied by an audible warning beep. The Woodpecker LED.B had a warning light and delivered an audible beep after 720 exposures. The display then flickered while the light was in use, but the unit did not cease operation. Twenty exposures after the warning light alarm, the LCU started to behave erratically and auto-reset the exposure time from 20 to 10 seconds. The KY-L036A unit had a three-bar battery status indicator light. One example of this light showed two bars after 20 exposures, one bar after 53 exposures, and no bars were illuminated after 107 exposures by which time the power output had fallen to 354 mW or 47% of its initial value. The KY-L029A gave no indication that it required recharging. It is concerning that none of the three budget LCU stopped working when the battery was delivering an inadequate power output.

Determining the active emission area from a curing light can be problematic. Reporting the radiant power from a LCU eliminates the need to define an emission area and may be a better parameter than irradiance to describe the output from a curing light. Table 1 shows that the radiant power output varied by up to 391 mW among the six LCUs tested and that the radiant power output from two budget LCUs was markedly lower ($p<0.05$), although the radiant exitance (irradiance) was similar to the lights from the major manufacturers. This "equivalence" was achieved by having a small tip diameter. In addition, most of the emitted power from the KY-L029A and the Woodpecker LED.B units was within a 4-mm-diameter circle at the center of the light tip. Consequently it is important to note that the deficiencies of these units will not be detected if the light is tested using the ISO 4049 depth of cure measurement in a 4-mm-diameter mold,[4] or if the light output is measured at the center through a small, fixed aperture, such as is often used in a handheld "dental radiometer."

The beam uniformities from all three budget lights were dramatically less than the LCUs of major manufacturers, and two of the budget units had lower effective emission ratios (Table 2). For the KY-L036A light, its low-cost, combined with the high radiant power output and irradiance, makes this LCU appear attractive. However, delivering 14,000 mW/cm^2 to localized regions of the RBC and approximately 2000 mW/cm^2 elsewhere may produce an unacceptable temperature rise within the tooth. Additionally, lower irradiance values are preferred since previous reports have suggested that high irradiance values and short exposure times may not produce optimal RBC mechanical properties[13-16] Table 2 shows that, in addition to having a larger optical tip area, more than 90% of the tip area of the LCUs from the major manufacturers delivered above 400 mW/cm^2. Thus, for LCUs made by the major manufacturers, the larger tip area and more uniform light distribution will cover more of the resin restoration with useful and more uniform irradiance. Consequently the restoration may require only a single exposure to photocure the entire restoration (Figure 3).

The results of this study and others indicate that it is inadvisable to rely on a single averaged irradiance value when describing or choosing a curing light. Instead, the radiant power output, the spectral emission, and the beam profile of the LCU should be reported.[5,6,8-11] This will provide a more informative description of the light output and prevent unintentionally incorrect, and misleading conclusions about the LCU from being reported.

CONCLUSIONS

Within the limitations of this study, it can be concluded that the performance of the three budget lights tested is inferior to units made by major dental manufacturers:

1. Despite having similar average radiant exitance (irradiance), there are significant differences among the radiant power outputs from LCUs provided by major manufacturers and budget units available for purchase over the Internet.
2. The budget lights have smaller tip diameters and higher levels of nonuniform power emission across their emitting tip end compared to units available from major dental manufacturers. Two models tested also had low effective emission ratios.
3. Some of the budget dental curing lights were not able to sustain their initial light output after repeated exposures. These units did not provide an adequate indication to the operator that a significant decrease in light output had occurred.

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Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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