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Effect of Battery Discharge on the Output from Budget Light-Curing Units

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Abstract

Objectives The manufacturers of budget light-curing units (LCUs) often claim to provide high-quality units that are equivalent to LCUs from major manufacturers. This study investigated the effects of battery discharge on the light output from different budget LCUs compared to a major manufacturer.

Materials and Methods Two brands of budget LCUs (LY-A180 and LED-CL) were compared to a control LCU from a major manufacturer (3M). The LCUs were fully charged, and their light outputs were measured over one battery discharge cycle using repeated 10-second exposures at a 0-mm distance.

Statistical Analysis Data were analyzed using one-way analysis of variance and Bonferroni post-hoc test.

Results The budget LCUs delivered fluctuating light output values. In their first exposure, the budget LCUs delivered between 205 and 444 mW power, an irradiance between 533 and 1154 mW/cm^2, and a radiant exposure between 5.3 and 11.5 J/cm^2. As the number of exposures increased, their light output decreased between 24 and 81%, while the control LCU showed only a 4.9% decrease in power and irradiance. The light outputs from the budget LCUs were significantly less than the control LCU, and they were significantly from each other.

Conclusion The budget LCUs tested could not maintain their power, irradiance, and radiant exposure output values as the battery discharged. This supports the recommendation that clinicians should be very cautious when using budget LCUs in their clinical practice.

Keywords

- budget light-curing units
- light-curing units
- battery discharge
- power
- irradiance
- radiant exposure

Introduction

To produce resin-based composites (RBCs) that achieve their intended mechanical, chemical, and physical properties, the light-curing unit (LCU) must deliver sufficient energy at the correct wavelengths to the RBC.[1–10] In most countries, LCUs are classified as medical devices and should comply with standards set by the regulatory authorities. However, some manufacturers, mainly from China, have introduced budget LCUs claiming that their devices are similar to those from major dental manufacturers, but they cost much less.[11,12] These budget LCUs are usually purchased over the Internet from websites such as amazon.com or ebay.com[11,12] and may not be approved medical devices. Since these devices may not have undergone safety tests and may not have the

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appropriate electrical safety certification, they may not be safe to use on patients.[12,13] In addition, they are often poorly made, most do not come with understandable instructions for use, the power and irradiance may not be stable, and may decline without any warning; they do not dissipate heat adequately, the battery life may be very short and may even catch on fire, the light-guide tip diameter is typically small (~7-mm), the beam profile is often inhomogeneous across the light-guide tip, and they are usually single-peak emission light-emitting diode (LED) units.[11–15] With dental students and practitioners now purchasing these LCUs due to their low price,[14,15] the question is can these budget LCUs perform as well as LCUs purchased from major manufacturers?. Also, different units from the same manufacturer might behave differently.[16] Since research is lacking in this area, more research is warranted concerning budget LCUs.

This study assessed the effect of battery discharge on the power, irradiance, and radiant exposure values from different budget LCUs over one fully charged battery discharge cycle compared to the output from an LCU from a major manufacturer. The hypotheses are:

1. The light output will be stable for all the LCUs over one full battery discharge.
2. The power, irradiance, and radiant exposure values will be similar among different budget LCUs and a control unit LCU from a major manufacturer.

Materials and Methods

Following the guidelines of King Abdulaziz University policy, the project was exempt from ethics approval by the Research Ethical Committee in King Abdulaziz University Faculty of Dentistry (Reference no. 249-06-21). Two different budget LCUs and one LCU from a major manufacturer were tested. The budget LCUs were purchased over the Internet; two examples (#1 and 2) of the Rainbow LED Curing light model LY-A180 (Guangdong, China) were purchased for 26 USD each, and two examples (#1 and 2) of the LED curing light (LED-CL) (Putian City, China) for 45 USD each. All LCUs were single-peak wavelength lights. All the budget units had a 7-mm optical diameter light tip. The Elipar DeepCure-S (3M, St. Paul, Minnesota, United States) was used as a control LCU, and its internal optical light tip diameter was 9 mm. ►**Table 1** provides the information about the LCUs used in this study. The power, irradiance, and radiant exposure were measured with a Managing Accurate Resin Curing-Light Collector (MARC-LC) laboratory-grade spectrometer (BlueLight Analytics Inc., Halifax, Nova Scotia, Canada). The position of each LCU guide tip was standardized over the MARC-LC sensor using a fixed mechanical arm with a 0-mm distance between the light-guide tip and the sensor.

All the LCUs were fully charged before the power, irradiance, and radiant exposure from each LCU was measured during every 10-second exposure cycle in the continuous mode setting. A 30-second rest interval was used between exposures until the end of one full battery charge and the LCU no longer emitted light. Each unit was tested once. From the total number of irradiation cycles, representative evenly distributed measurements were selected for analysis starting from the first exposure cycle, followed by exposure 30 (equivalent to 5 min of using the light), 50 (equal to approximately 8 min of using the light), followed by increments of 50, and ending with the last exposure cycle of each LCU (i.e., first cycle, 30, 50, 100, 150, 200, ..., the last exposure cycle). The power and irradiance measurements were plotted for a visual comparison.

Statistical Analysis

The power, irradiance, and radiant exposures at the selected exposure intervals from the same unit, among LCUs, and between the same brand of LCUs were compared. In addition, visual comparisons were performed between the power and irradiance graphs. For every LCU tested, the mean power, irradiance, radiant exposure, and percent decrease at each representative cycle were calculated and analyzed using STATA software version 17 (StataCorp. 2021. Stata Statistical Software: Release 17. College Station, Texas, United States). One-way analysis of variance (ANOVA) and Bonferroni post-

Table 1 Light-curing units (LCUs) evaluated, assigned reference, and manufacturer

LCU type	Model	Assigned reference	Brand[a]	Seller[a]	SN/Product number	Manufacturer city, country
Budget light (#1)	LY-A180	LY-A180 (#1)	Rainbow LED Curing Light	Aphrodite	X001KLMS6X/ 180130621	Guangdong, China
	LY-A180	LY-A180 (#2)	Rainbow LED Curing Light	NSKI	X001L6FWSN/ 190330087	Guangdong, China
Budget light (#2)	Not found	LED-CL (#1)	LED Curing Light	BoNew/Local dental store	Not found	Putian City, China
	Not found	LED-CL (#2)	LED Curing Light	Dr. Royal	X001YSHNB7	Putian City, China
Major manufacturer	Elipar DeepCure-S	Elipar DeepCure-S	3M	3M Certified local agent	933123008807	St. Paul, Minnesota, USA

Abbreviation: LED-CL, LED Curing Light; LCU, Light-curing unit; LED, Light-emitting diode.
[a]The brand was not listed; therefore, the name on the box and seller was listed. The same budget LCU may be available from multiple sellers and were purchased from amazon.com or a local dental store. All LCUs were single-peak lights. All the budget units had a 7-mm optical light tip diameter. The internal optical tip diameter of the Elipar DeepCure-S was 9-mm.

hoc tests were used to detect if differences from three consecutive readings at each representative cycle of the power, irradiance, and radiant exposure existed between the five LCUs. To determine the agreement between the results from the two LY-A180 and the two LED-CL LCUs, the interclass correlation coefficient was reported using equal numbers of exposure cycles from the LCUs.

Results

►**Fig. 1** shows that the positions of the LED emitters in the body of the budget units were not all well centered in the body of the LCU compared to the control LCU. ►**Figs. 2** and **3** report the power and irradiance output values at representative cycles for the budget LCUs compared to the control LCU. In general, the power, irradiance, and radiant exposure in the budget LCUs fluctuated and decreased as their battery discharged compared to the control LCU. When comparing the different budget LCU brands, each unit had a different pattern and different brands and units from the same brand did not produce similar exposure patterns or the same total number of exposure cycles. Also, the light outputs were not the same among the different budget LCUs from the same brand. In some cycles, both LY-A180 units (►**Figs. 1** and **2A** and **B**), and the LY-A180 (#1) LCU did not complete the 10-second exposure cycle. Instead, they abruptly turned off mid-cycle. In cycle 300, LY-A180 (#1) the exposure stopped at 6 seconds instead of 10 seconds, and some cycles extended inconsistently beyond the 10 seconds between 11 and 12 seconds compared to LY-A180 (#2). The power and irradiance values continued to drop at a faster rate for LY-A180 (#2) and exposure cycles were more consistent at approximately 11 seconds compared to LY-A180 (1). The LED-CL (#1) delivered very low light outputs for the first second. This then increased as if in a soft start mode, even though a soft start mode is not a setting for this LCU. In contrast, the LED-CL (#2) showed a different light output. In addition, LED-CL (#1) exposure stopped in several cycles between 9 and 12 seconds instead of 10-s. For the LED-CL (#2), the light exposure for most cycles ranged between 6.5 and 10 seconds (►**Figs. 1** and **2C** and **D**). When comparing the budget LCUs to the control (►**Figs. 1** and **2E**), the control LCU showed consistent and stable power and irradiance values and all the cycles lasted for 10 seconds. ►**Fig. 2** showed that the unit LY-A180 (#2) delivered irradiance values less than 400 mW/cm^2 starting from cycle 150 until the battery ran out, and unit LED-CL (#1) delivered irradiance values less than 400 mW/cm^2 starting from cycle 300 until the battery ran out of charge.

►**Table 2** reports the number of cycles, mean power, irradiance, and radiant exposure values at representative cycles and the percent decrease. Units from the same brand did not have similar patterns of light output nor the same total number of exposure cycles. The percent decrease in the mean power, mean irradiance, and radiant exposure among the cycles between the first and last light exposure cycle from each LCU varied. The output measurements from the LY-A180 (#1) decreased by 48.4% in power and irradiance and by 50.6% in radiant exposure due to the fluctuations in the exposure time. The LY-A180 (#2) had an 81.1% decrease in power and an 81.2% decrease in irradiance and radiant exposure. The power, irradiance, and radiant exposure output from the LED-CL (#1) decreased by 70.5% and by 24% from the LED-CL (#2). In sharp contrast, the power and irradiance from the Elipar DeepCure-S LCU decreased by only 4.9%, and there was no change in the radiant exposure.

►**Table 3** reports the mean, standard deviation, median, and interquartile range of the outputs from the LCUs. One-way ANOVA and Bonferroni post-hoc test showed that the power, irradiance, and radiant exposure values for all budget units were significantly different from the control, and LY-A180 (#1) and LED-CL (#2) LCU were significantly different from each other.

One-way ANOVA followed by Bonferroni post-hoc test comparisons among the LCU cycles showed significant differences in most exposure cycles (comparison data not shown). However, the nonsignificant cycles were minimal and did not follow any specific pattern.

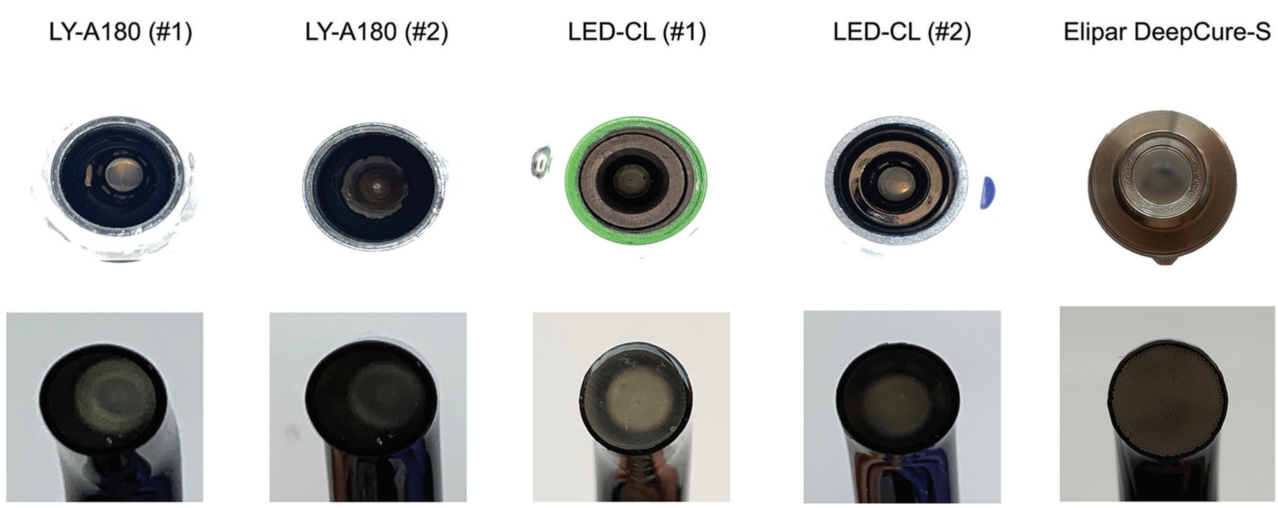

Fig. 1 The location of the light-emitting diode (LED) chips within the body of the different light-curing units.

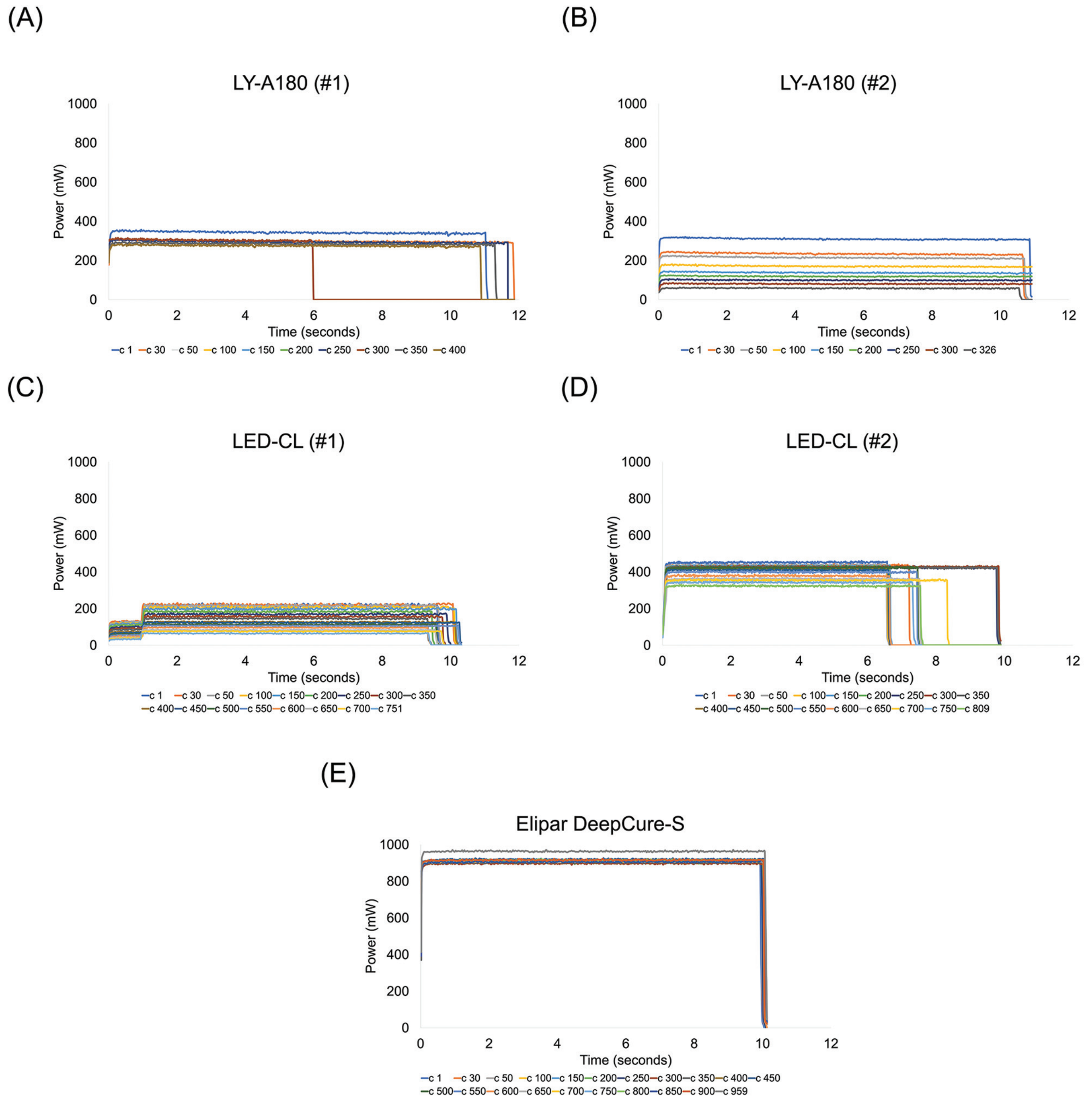

Fig. 2 The power (mW) of representative measurements of the different light-curing units from the first to the last cycle. **(A)** LY-A180 (#1) unit. **(B)** LY-A180 (#2) unit. **(C)** LED-CL (#1) unit. **(D)** LED-CL (#2) unit. **(E)** Elipar DeepCure-S unit.

The reliability test between the two LY-A180, and the two LED-CL LCUs, showed poor reliability in the interclass correlation coefficient between the two LCUs from the same brand.

Discussion

The unstable light output and the decrease in power, irradiance, and radiant exposure values as the battery discharged in the budget LCUs indicate that the electronic circuitry used in the budget LCUs could not compensate for the battery discharge and thus could not maintain a stable light output. In addition, these budget LCUs showed an inconsistent battery performance. The battery discharged rapidly, at different rates, and the LCUs stopped for no reason during some exposure cycles. In contrast, the control LCU delivered a stable light output as the battery discharged. Thus, the first hypothesis was rejected ($p < 0.01$). In addition, the approximate 50 to 81% decrease in power, irradiance, and radiant exposure from the LY-A180 (units #1 and #2), and LED-CL (#1) confirms the inability of these units to compensate for the battery discharge. Therefore, progressively worse photo-curing may occur as the battery discharges.[17]

The power, irradiance, and radiant exposure values were all different among the LCUs and the Elipar DeepCure-S consistently delivered the highest values (►**Tables 2** and **3**). Therefore, the second hypothesis was also rejected

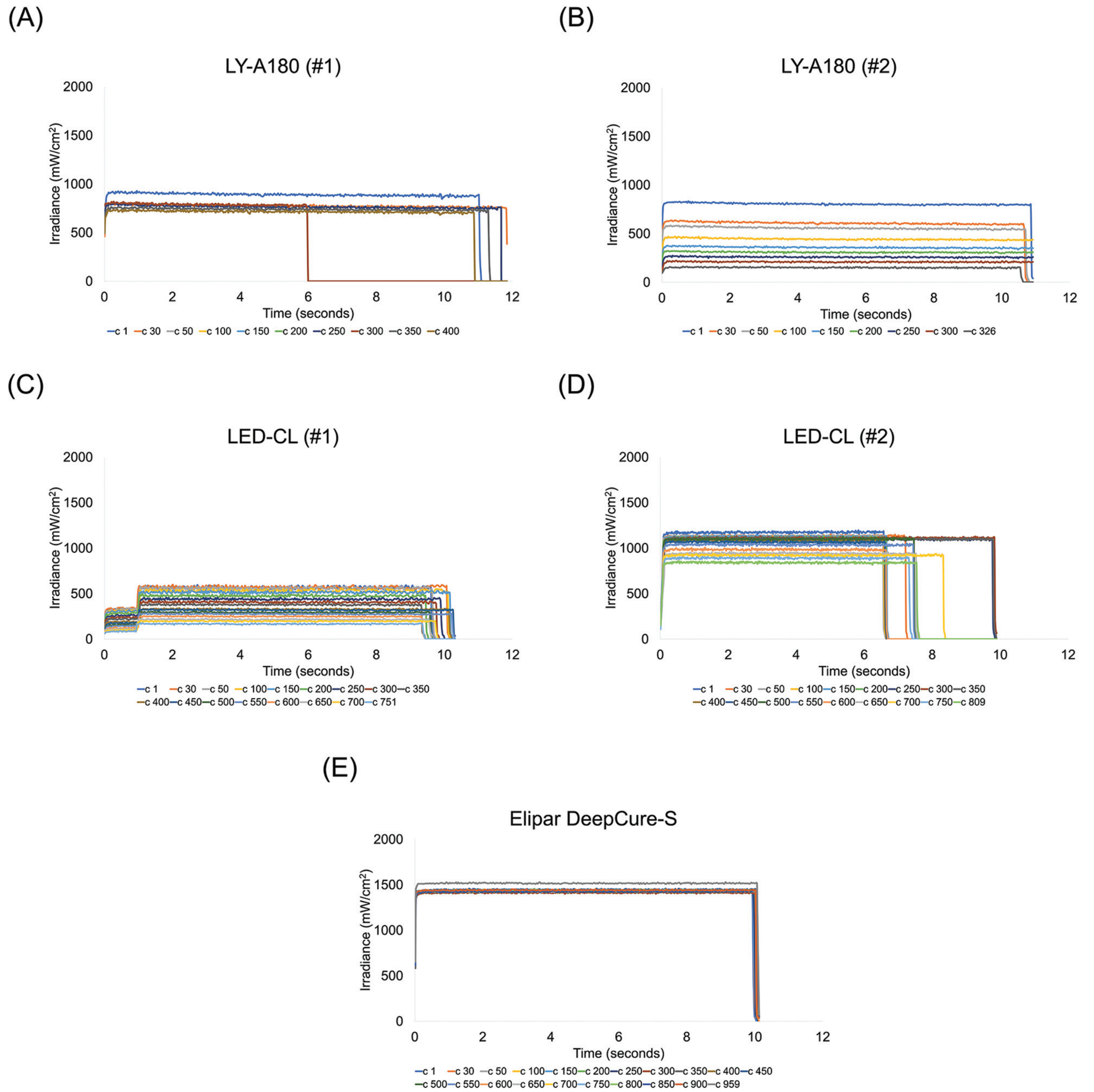

Fig. 3 The irradiance (mW/cm^2) at representative exposures from the different light-curing units from the first to the last cycle. **(A)** LY-A180 (#1) unit. **(B)** LY-A180 (#2) unit. **(C)** LED-CL (#1) unit. **(D)** LED-CL (#2) unit. **(E)** Elipar DeepCure-S unit.

($p < 0.01$). Browsing the Internet and looking at different budget LCUs to purchase, it was clear that other sellers of the budget lights had similar models, but with different brand names or they were even unbranded with only the seller's name. This could indicate that a third party manufactures the LCUs for these sellers without disclosing their company name. Unlike the Elipar DeepCure-S light from 3M, no contact information was provided for the budget LCUs and there was no website for the company. Thus, it is it impossible to contact the manufacturer if a patient is harmed, or the equipment requires maintenance.

Previous studies have also reported that different brands of budget LCUs failed to achieve and maintain high power and irradiance outputs compared to LCUs from major manufacturers.[14,18] They have also reported that the light output from different units of the same brand of budget LCU was unpredictable and unreliable. In addition, the failure to center the LED chips in the budget LCU could negatively affect their irradiance beam profile and curing ability compared to LCUs from major dental manufacturers. Therefore, the difference in the stability of the light output from the budget LCU compared to the control LCU most likely indicates a difference in the quality of manufacturing of the budget LCUs. Hence their low price.

The drop in the irradiance below 400 mW/cm^2 starting after cycle 150 for LY-A180 (#2) and cycle 300 for LED-CL

Table 2 Number of cycles, mean power (W), irradiance (mW/cm^2), radiant exposure (J/cm^2) values, and percent decrease in values for representative cycles from the first to the last cycle for the different budget LCU and control

LCU	Cycle no.	Power (mW)	Irradiance (mW/cm^2)	Radiant exposure (J/cm^2)	% Decrease (power)	% Decrease (irradiance)	% Decrease (radiant exposure)
LY-A180 (#1)	1	341.0	885.0	9.7	13.2	13.0	6.0
	30	296.0	770.0	9.1	1.0	1.2	2.6
	50	293.0	761.0	8.9	−3.1	−3.2	1.8
	100	302.0	785.0	8.7	6.3	6.4	3.3
	150	283.0	735.0	8.4	3.2	3.0	6.9
	200	274.0	713.0	7.9	4.4	4.5	1.3
	250	262.0	681.0	7.8	1.9	1.9	−0.9
	300	257.0	668.0	7.8	5.4	5.4	7.7
	350	243.0	632.0	7.2	9.9	9.8	13.8
	400	219.0	570.0	6.2	6.4	6.7	10.0
	450	205.0	532.0	5.6	14.1	14.1	14.4
	493 (last cycle)	176.0	457.0	4.8	48.4	48.4	50.6
LY-A180 (#2)	1	307.7	799.3	8.0	24.4	24.4	24.4
	30	232.7	604.0	6.0	8.7	8.6	8.6
	50	212.3	552.0	5.5	20.3	20.4	20.4
	100	169.3	439.7	4.4	19.5	19.4	19.4
	150	136.3	354.3	3.5	13.4	13.5	13.5
	200	118.0	306.7	3.1	16.4	16.3	16.3
	251	98.7	256.7	2.6	18.9	19.0	19.0
	300	80.0	208.0	2.1	27.5	27.7	27.7
	326 (last cycle)	58.0	150.3	1.5	81.1	81.2	81.2
LED-CL (#1)	1	205.3	533.7	5.3	−1.6	−1.6	−1.6
	30	208.7	542.0	5.4	2.6	2.5	2.5
	50	203.3	528.3	5.3	4.4	4.5	4.5
	100	194.3	504.7	5.0	3.1	3.1	3.1
	150	188.3	489.0	4.9	7.8	7.7	7.7
	200	173.7	451.3	4.5	7.9	8.0	8.0
	250	160.0	415.3	4.2	7.5	7.4	7.4
	300	148.0	384.7	3.8	7.4	7.4	7.4
	350	137.0	356.3	3.6	12.7	12.6	12.6
	400	119.7	311.3	3.1	2.5	2.8	2.8
	450	116.7	302.7	3.0	8.9	8.6	8.6
	500	106.3	276.7	2.8	5.6	5.9	5.9
	550	100.3	260.3	2.6	10.6	10.4	10.4
	600	89.7	233.3	2.3	13.0	13.0	13.0
	650	78.0	203.0	2.0	8.5	8.5	8.5
	700	71.3	185.7	1.9	15.0	15.3	15.3
	751 (last cycle)	60.7	157.3	1.6	70.5	70.5	70.5

Table 2 (*Continued*)

LCU	Cycle no.	Power (mW)	Irradiance (mW/cm^2)	Radiant exposure (J/cm^2)	% Decrease (power)	% Decrease (irradiance)	% Decrease (radiant exposure)
LED-CL (#2)	1	444.0	1154.0	11.5	3.3	3.3	3.3
	30	429.5	1116.0	11.2	0.3	0.3	0.3
	50	428.0	1113.0	11.1	1.6	1.8	1.8
	100	421.0	1093.5	10.9	−1.4	−1.4	−1.4
	150	427.0	1109.0	11.1	1.2	1.1	1.1
	200	422.0	1097.0	11.0	1.1	1.1	1.1
	250	417.5	1085.0	10.9	−1.1	−1.1	−1.1
	300	422.0	1097.0	11.0	0.8	0.9	0.9
	350	418.5	1087.0	10.9	1.8	1.7	1.7
	400	411.0	1068.0	10.7	1.6	1.6	1.6
	450	404.5	1051.0	10.5	−3.2	−3.3	−3.3
	500	417.5	1085.5	10.9	5.6	5.7	5.7
	550	394.0	1024.0	10.2	5.2	5.3	5.3
	600	373.5	970.0	9.7	4.6	4.5	4.5
	650	356.5	926.5	9.3	1.7	1.7	1.7
	700	350.5	911.0	9.1	4.0	4.0	4.0
	750	336.5	875.0	8.8	-0.3	-0.2	-0.2
	764 (last cycle)	337.5	876.5	8.8	24.0	24.0	24.0
Elipar DeepCure-S	1	906.3	1427.9	14.3	1.6	1.6	1.6
	30	892.1	1404.6	14.0	−1.0	−1.0	−1.0
	50	901.1	1418.8	14.2	0.2	0.2	0.2
	100	898.9	1415.8	14.2	0.5	0.5	0.5
	150	894.2	1408.8	14.1	0.1	0.1	0.1
	200	893.2	1406.7	14.1	0.1	0.0	0.0
	250	892.6	1406.3	14.1	0.5	0.5	0.5
	300	888.4	1399.2	14.0	−0.7	−0.7	−0.7
	350	894.7	1408.8	14.1	−0.8	−0.8	−0.8
	400	901.6	1420.0	14.2	−0.8	−0.7	−0.7
	450	908.4	1430.4	14.3	0.8	0.8	0.8
	500	901.1	1418.8	14.2	0.1	0.1	0.1
	550	900.0	1417.5	14.2	−0.1	−0.1	−0.1
	600	901.1	1419.6	14.2	0.0	0.1	0.1
	650	901.1	1418.8	14.2	0.1	0.0	0.0
	700	900.5	1418.8	14.2	0.1	0.1	0.1
	750	899.5	1416.7	14.2	−0.4	−0.4	−0.4
	800	902.6	1422.1	14.2	0.7	0.7	0.7
	850	896.3	1412.1	14.1	−0.9	−0.9	−0.9
	900	904.2	1424.2	14.2	−6.3	−6.3	−6.3
	950	961.6	1514.6	15.1	1.1	1.1	1.1
	959 (last cycle)	951.1	1498.3	15.0	−4.9	−4.9	0.0

Abbreviations: LCU, light-curing unit; LED, light-emitting diode; LED-CL, LED Curing Light.

Table 3 Mean (SD), median, interquartile range, and *p*-values of the different budget LCU and control

LCU	Mean	SD	Median	IQR	*p*-Value
Power					
LY-A180 (#1)	262.7[c]	45.02	296.5[d]	230.5–296.5	<0.0001
LY-A180 (#2)	155.5[d]	76.2	136[c]	98–213	
LED-CL (#1)	138.1[b]	49.76	135[b,c]	96–189	
LED-CL (#2)	400.28[b]	33.3	417.5[b]	374.5–423	
Elipar DeepCure-S	906.5[a]	19.7	900.5[a]	896.8–904.2	
Irradiance					
LY-A180 (#1)	682.8[c]	116.9	693[d]	599.5–771	<0.0001
LY-A180 (#2)	404.5[d]	198.3	354[c]	254–555	
LED-CL (#1)	359.6[b]	129.2	352[b,c]	250–492	
LED-CL (#2)	1040.2[b]	86.6	1085.25[b]	973–1098.5	
Elipar DeepCure-S	1427.7[a]	31	1418.3[a]	1412.5–1424.2	
Radiant exposure					
LY-A180 (#1)	7.6[c]	1.4	7.8[c]	6.7–8.7	<0.0001
LY-A180 (#2)	4.04[d]	1.98	3.54[d]	2.54–5.55	
LED-CL (#1)	3.6[b]	1.3	3.52[b]	2.5–4.92	
LED-CL (#2)	10.4[b]	0.87	10.85[b]	9.73–10.99	
Elipar DeepCure-S	14.3[a]	0.31	14.2[a]	14.125–14.24	

Abbreviations: IQR, interquartile range; LCU, Light-curing unit; LED, light-emitting diode; LED-CL, LED Curing Light; SD, standard deviation. Superscript letters represent significant differences among the units within each variable.

(#1) also confirms that these units are unreliable because they cannot maintain the minimum irradiance values of 400 mW/cm^2 that is required according to the ISO 10650 standard.[19,20] When choosing which LCU to purchase, dental professionals tend to buy LCUs that deliver an irradiance of at least 1000 mW/cm^2, but other aspects such as the spectral emission, beam profile, ergonomics, medical device approval, and patient safety should be taken into consideration when purchasing the LCU.[13,21] One of these many aspects is the radiant exposure that can be delivered in the exposure time that the clinician wishes to use.[2,12,21] The minimum radiant exposure ranges from 6 to 24 J/cm^2 for every 2 mm increment of RBC,[22,23] with an average of 16 J/cm^2.[24] In this study, LED-CL (#1) could not deliver 6 J/cm^2 when used for 10s. The LY-A180 (#1) delivered a radiant exposure of less than 6 J/cm^2 by the last cycle, and LY-A180 (#2) and LED-CL (#1) delivered less than 2 J/cm^2 at the last exposure cycle. These low radiant exposures would likely produce an inadequately photocured restoration. It is important to note that the units were tested under ideal conditions. The light was fixed using a mechanical arm and the light tip was at 0 mm from sensor. Such ideal conditions rarely occur in the mouth.

When choosing the LCU, clinicians need to consider how often the battery must be replaced or even can it be replaced. The LCU should be monitored using a dental radiometer; preferably, each reading should be logged from the day of purchase so that its output can be monitored.[21] Furthermore, the light-curing technique can be optimized using the MARC-PS simulator (BlueLight Analytics Inc., Halifax, Nova Scotia, Canada) to ensure that the user learns how to deliver the maximum amount of light from their LCU.[21] Also, routine maintenance that includes an examination of the light guide tip before and after light curing for any damage or debris can help prevent loss of light output.[1,2]

This study supports that using a budget light that has not been approved for use could negatively affect the polymerization of light-curable resin-based materials and adversely affect the treatment outcome and longevity of the restoration.[25] Depending on where the user practices dentistry, using a budget light may not meet the standard of care since most countries classify LCUs as medical devices.[12,15] Also, since most of the budget lights have small guide tips, they require multiple overlapping curing cycles when photo-curing large restorations. This increases the time required to photocure the restoration.[13]

Although online marketplaces can offer cheaper products, this study shows that some medical devices purchased online may not be as good as approved and tested products. Further studies would be valuable on the effects on the properties of different RBCs when other brands and other units of the same brand of LCU are used at different distances from the light tip. However, the intra-brand variability of the budget lights means that the conclusions of such a study may be difficult to interpret.

Conclusion

The light output from the budget LCUs tested from the same and from different manufacturers was inconsistent.

The budget lights tested could not maintain their power, irradiance, and radiant exposure output values as their batteries discharged. In contrast, the control LCU delivered a stable light output as the battery discharged. Therefore, it is recommended that clinicians not use budget LCUs in their clinical practice. Clinicians should be aware that the LCUs are classified as medical devices in most countries, and unapproved medical devices should not be used on patients.

Conflict of Interest
None declared.

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