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1972

THESIS APPROVAL PAGE FOR MASTER OF SCIENCE IN ORAL BIOLOGY

Title of Thesis: **"Irradiance of Curing Lights using a New Chairside Spectrometer-Trained System"**

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Irradiance of Curing Lights using a New Chairside Spectrometer-Trained System

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USU Operational Gap: IV, C

Abstract

The quality of resin-based restorations is greatly influenced by the light-curing unit (LCU). BlueLight Analytics (Halifax, Canada) recently introduced CheckUP, a dental radiometer trained using an ISO 10650:2018 compliant integrating sphere and spectrometer. **Objectives:** The focus of this study was to compare the irradiance of 7 LCUs using the novel CheckUP system to the two gold standards; integrating sphere-based spectrophotometer (LabSphere) and thermopile (Ophir) and two chairside radiometers (Bluephase Meter I, Bluephase Meter II, Ivoclar Vivadent). **Methods and Materials:** The irradiances of 7 different LCUs were measured 10 times with each system. Data were analyzed with linear regression and ANOVAs/Tukeys ($\alpha=0.05$). **Results:** Significant differences in mean irradiance were found between the five meters depending on LCU ($p<0.05$). Bivariate regression analysis demonstrated that the irradiances correlated better between the CheckUP and the integrating sphere ($r^2=0.980$) or the thermopile ($r^2=0.933$) than between the Bluephase Meter I (BM I) radiometer and the integrating sphere ($r^2=0.387$) or the thermopile ($r^2=0.189$), or between the Bluephase Meter II (BM II) and the integrating sphere ($r^2=0.493$) or the thermopile ($r^2=0.585$). The absolute mean percent difference from the CheckUP was 7.2 ± 2.0% (integrating sphere), 7.0 ± 3.6% (thermopile), 21.5 ± 16.1% (BM1), and 13.1 ± 7.1% (BMII). **Conclusion:** The new chairside spectrometer system (CheckUP) provided the best correlation and the lowest overall percent deviation in irradiance from the integrating sphere and the thermopile compared to other radiometers tested.

Introduction

With the wide variety of LCUs and composite resin restorative materials available today, it is important that practitioners have a basic understanding of the factors related to photopolymerization in order to provide adequate light exposure. Photopolymerization of composite resin is affected by factors related to both the composite and the light. Composite-related factors include shade, translucency, photoinitiator type and concentration, and filler particle size, load, and distribution. (Ferracane 2011) Light-related factors include intensity, exposure time, spectral distribution, and light dispersion. (Ruggeberg 2017; Price 2020) The primary purpose of LCUs is to drive the composite resin polymerization process by initiating the production of reactive free radicals, from which the propagation of resin monomers into polymers can be generated. The polymerization process transforms composite resin from a moldable, pliable, and hydrophobic product into a solid that has physical properties desirable for long-term success as a dental restorative material. (Cadenaro 2019)

Since the quality of composite resin restorations depends greatly on the curing efficiency of LCUs, the American Dental Association recommends that practitioners regularly monitor the irradiance of their LCUs to ensure that they meet the manufacturer's specifications and functions. (Roulet 2014) The gold standard in laboratory testing of any dental LCU output is laboratory-grade spectrometers (e.g., integrating sphere, thermopile). (Shimokawa 2016) Due to the cost of such testing equipment, historically conscientious dental practitioners have utilized various handheld radiometers as a cost-effective alternative to determine LCU efficacy. However, previous studies have reported that such devices are unable to reliably make accurate measurements of the light output from LCUs. (Leonard 1999, Roberts 2006, Sulaiman 2010, Price 2012, Marovic 2013, Kameyama 2013, Shortall 2021) The shortcomings of these handheld radiometers are the inability to be calibrated, a fixed size of the sensor aperture, and the difficulty in applying results to the specific resin composites used by the dental practitioner. (Price 2012, Shortall, 2015) BlueLight Analytics (Halifax, Canada) recently introduced CheckUP, an integrated wireless, handheld spectrometer designed to overcome these clinical challenges. The CheckUP device features a 17mm diameter uniform active light collection port, which sits on top of a 28 mm x 28 mm array sensor which is large enough to capture all the light exiting the LCU's tip. This non-linear sensor is trained using a database of over 600 laboratory-grade spectrometer LCU measurements to correct for the non-linear response and tip-reflection interaction for each individual model and then transfer the readings via Bluetooth to a proprietary application that is downloadable onto an Android or iOS-based phone. (BlueLight Analytics website) The dental practitioner is also able to use the application to select specific composite resins and shades utilized in the clinic. Based on the spectrometer results, the CheckUP application provides the irradiance and then calculates an appropriate curing time for the chosen composite resin and light combination. No research has been published evaluating the novel CheckUP system.

The focus of this research was to compare the irradiance of various LCUs using the novel chairside spectrometer-trained system (CheckUP) to that of an integrating sphere-based spectrometer (LabSphere, North Sutton, NH), a thermopile (Ophir, North Logan, UT), and two chairside radiometers (Bluephase Meter I, Bluephase Meter II, Ivoclar Vivadent, Amherst, NY). No research has been published evaluating the CheckUP system. The null hypotheses were that there would be no difference in the LCU's irradiance measured with the five meters and that there would be no difference in the percent irradiance change of CheckUP from the other 4 meters.

Materials and Methods

Seven contemporary LED LCUs, representatives of different commercially available devices, were evaluated in this study using five-meter types: two spectrometer systems, two chairside radiometers, and the novel chairside spectrometer-trained system. The active area of the tip of each LCU was measured using a digital micrometer to the nearest 0.1 mm. See Table 1.

Light Curing Unit (LCU)	Manufacturer	Multi-Spectrum	Measured Active Optic Area (cm^2)	Manufacturer Reported Irradiance (mW/cm^2)
Bluephase G4	Ivoclar Vivadent	Y	0.636	1200
Bluephase Style	Ivoclar Vivadent	Y	0.622	1100
Bluephase 20i	Ivoclar Vivadent	Y	0.430	1200 (High); 2000 (Turbo)
Demi Ultra	Kerr	N	0.490	1100 - 1330
Paradigm	3M ESPE	N	0.622	1200
SmartLite Pro Cure	Dentsply	N	0.785	1250
SPEC 3	Coltene	N	0.407	1600 (High); 3000 - 3500 (3K)

Table 1: Active optic area and reported irradiance of the LCUs utilized in this study

Ten measurements were made of each LCU with each of the five meters. The LCUs were held in place during measurements with a fixed-retaining device.

(1) A 15cm diameter laboratory-grade integrating sphere (LabSphere) with a 19mm entrance port linked to a calibrated spectrometer (Flame-T-VIS-NIR, Ocean Insights, Orlando, FL) was used to evaluate the power per LCU. Each LCU's power spectrum (optic-to-entrance distance = 0 mm) was integrated from the 350-550 nm range and then converted to average irradiance (i.e., power / each tip's cross-sectional active area)

(2) A thermopile sensor (PM10, Coherent Inc, Santa Clara, CA) was connected to a laptop computer via a 4-channel interface (Pulsar-4, 7Z01201, Ophir, North Logan, UT) to evaluate the power per LCU. The light tips of the LCUS were held close but not in contact with the sensor using a rigid stand. Measurements were analyzed using the thermopile's proprietary software (StarLab 3.0, Ophir, North Logan, UT) and were converted to irradiance (i.e., power / each LCU tip's cross-sectional active area).

(3) A chairside radiometer (Bluephase Meter I) was used to measure the irradiance of each LCU with a light source-to-sensor distance of 0 mm.

(4) A chairside radiometer (Bluephase Meter II) was used to measure the power of each LCU with a light source-to-sensor distance of 0 mm. The measured diameter of the light tip was entered into the unit. The power was then converted to irradiance by the meter.

(5) A portable spectral calibrated dental radiometer (CheckUP) was used to measure the irradiance of each LCU. See Figure 1. Each LCU's output was collected by

placing the tip of the LCU on the light collection area (optic-to-sensor distance = 0 mm). The output was uploaded utilizing the Bluetooth connection to the CheckUP application on an iOS-based phone (iPhone 11, Apple, Cupertino, CA). The specific LCU tip active area, spectrum, mode, and time were analyzed, and the CheckUP software computed the LCU's average irradiance.

The emission spectrums of the LCUs were recorded using the 17mm diameter sensor of a spectrophotometer (MARC Light Collector, Blue Light Analytics, Halifax, Canada).

The irradiance data were analyzed with a Pearson correlation to evaluate the relationship of the irradiance measurements of the LCUs between the integrating sphere and thermopile from CheckUP and the integrating sphere and thermopile from the two radiometers. A one-way ANOVA with Tukey's post hoc tests (alpha=0.05) was used to analyze the effect of meter type on irradiance for each of the seven LCUs and to evaluate the percent change difference between the CheckUP from each of the other 4 meters using a statistical software program (SPSS 20, IBM SPSS, Chicago, IL).

Results

Significant differences in mean irradiance were found between the five meters depending on the LCU brand ($p<0.05$). See Table 2. Bivariate regression analysis demonstrated that the irradiances correlated better between the CheckUP and the integrating sphere ($r^2=0.980$) or the thermopile ($r^2=0.933$) than between the Bluephase Meter I radiometer and the integrating sphere ($r^2=0.387$) or the thermopile ($r^2=0.189$), or between the Bluephase Meter II and the integrating sphere ($r^2=0.493$) or the thermopile ($r^2=0.585$). The lowest percent irradiance change from the CheckUP occurred with the thermopile (7.0 ± 3.6%) and integrating sphere (7.2 ± 2.0%), but it was not significantly different ($p=0.73$) from the Bluephase Meter II (13.1 ± 7.1%). The greatest percent irradiance change from the CheckUP occurred with the Bluephase Meter I (21.5 ± 16.1%), which was significantly greater than the integrating sphere ($p=0.032$) or the thermopile ($p=0.029$). The emission spectrums of the seven LCUs are displayed in Figure 2.

Light Curing Units	Light Meters					Percent Irradiance Change from Checkup			
	Thermopile	Integrating Sphere	CheckUP	Radiometer		Thermopile	Integrating Sphere	Radiometer	
				BM I	BM II			BM I	BM II
Bluephase G4	1049 (10) A	1056 (13) A	1111 (11) B	1135 (14) C	1357 (11) D	-5.6	-4.9	2.2	22.2
Bluephase Style	965 (14) B	978 (6) B	1047 (8) C	914 (37) A	1234 (7) D	-7.8	-6.6	-12.7	17.9
Bluephase 20i	1224 (25) B	1231 (11) B	1339 (7) D	1130 (19) A	1255 (15) C	-8.6	-8.1	-15.6	-6.2
Demi Ultra	1413 (63) D	1225 (57) B	1359 (8) C	711 (19) A	1495 (15) E	4.0	-9.8	-47.7	10.0
Paradigm	1040 (9) B	1091 (6) C	1173 (5) D	935 (25) A	1303 (13) E	-11.3	-7.0	-20.3	11.1
SmartLite Pro Cure	1105 (26) B	1119 (7) B	1234 (7) C	750 (16) A	1485 (20) D	-10.3	-9.3	-39.2	20.3
SPEC 3	1619 (37) CD	1563 (28) B	1640 (12) D	1424 (68) A	1577 (13) BC	-1.3	-4.7	-13.2	-3.9
Groups with the same letter per row are not significantly different (p>0.05)						Absolute % change from all LCUs tested			
						7.0 (3.6) A	7.2 (2.0) A	21.5 (16.1) B	13.1 (7.1) AB

Table 2: Mean irradiance measured by the five meters for each of the seven LCUs and percent irradiance change from CheckUP.

Figure 1: The CheckUP unit featuring a 17mm-diameter uniform active light collection port.

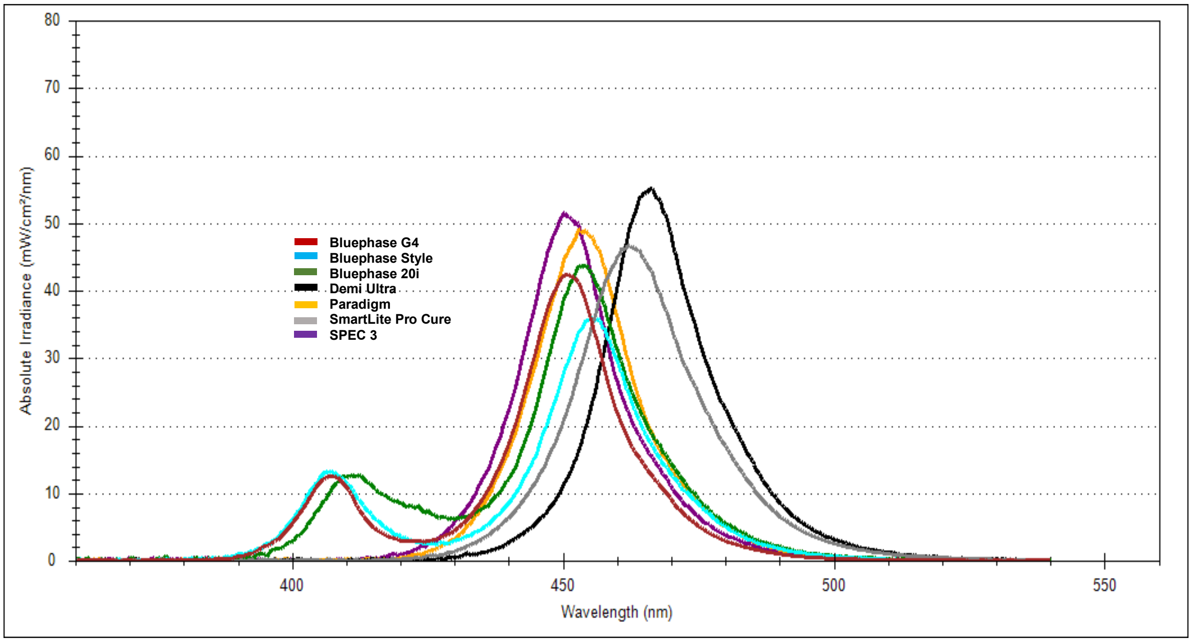

Figure 2: The emission spectrums of the 7 LCU recorded with the spectrophotometer.

Discussion

The repetitive usage of LCUs is often associated with routine wear and tear and damages, possibly caused by chemical disinfectants, light-guide autoclaving, accidental dropping, or restorative material adhering to the LCU's light guide. (Price 2017) Periodic assessment of the irradiance of LCUs by the dental practitioner is highly recommended to make sure the light features meet the manufacturer's specifications and remain stable over time. (Rueggeberg 2017, Giannini 2019) Insufficient light irradiance may be responsible for increased marginal leakage, discoloration, recurrent caries, and post-operative sensitivity. (Assaf 2020) Chairside radiometers have been used to monitor the performance of LCUs due to their ease of use and relatively low expense. Multiple studies, however, have reported that the radiometers provide only limited reliability for accurate irradiance measurements. (Leonard 1999, Roberts 2006, Sulaiman 2010, Price 2012, Marovic 2013, Kameyama 2013, Shortall 2021) The LCU irradiance (mW/cm^2) is defined as the emitted power divided by the emitting light tip area. In general, for calculating irradiance, most traditional chairside handheld radiometers do not take into consideration the different areas of the LCU tips. The entrance port for measuring light outputs on the radiometer is typically smaller than most of the light tips. (Shimokawa 2016) Additionally, most handheld radiometers contain diffusers that homogenize the entrance beam rather than capture the true nature of beam inhomogeneity across a light tip. The calculated irradiance may not take into account the non-uniformity of the light at the LCU tip that may occur with multi-spectrum LCUs that emit light at different wavelengths. (Shortall 2015) Multi-spectrum LCUs were introduced to emit light in two or more wavelengths to activate more than one photoinitiator. Camphorquinone is the most common photoinitiator in our composite systems and is sensitive to light in the blue wavelengths, most often centered near 470nm. Some manufacturers use other photoinitiators, such as trimethylbenzoyl-diphenylphosphine oxide (TPO), which is less yellow in color and more efficient than camphorquinone. These initiators are usually sensitive to ultraviolet or violet light or wavelengths between 380 and 410 nm. (Bortolotto 2016) As shown in Figure 2, the multi-spectrum LCUs (Bluephase G4, Style, and 20i) emit light in both the violet (390–420 nm) and blue wavelengths (420-500 nm). The remaining LCUs had a single-spectrum emission only in the blue wavelengths (420-520 nm) of light.

In this study, significant differences were found in the LCU's irradiance between the 5 meters and in the percent irradiance change from CheckUP with the other 4 meters; therefore, the null hypotheses were rejected.

The Bluephase Meter I reportedly utilizes a linear strip sensor to estimate the light tip diameter, and then an integrated microprocessor calculates the irradiance. (Shortall, 2021) However, in this study, the linear regression analysis demonstrated that the irradiances of the LCUs had a relatively lower correlation between the Bluephase Meter I radiometer and the integrating sphere (r^2=0.387) or the thermopile (r^2=0.189). The Bluephase Meter I radiometer also had the greatest absolute percent change from the CheckUP (21.5 ± 16.1%).

The Bluephase Meter II is a handheld radiometer that reportedly measures the radiant power in milliWatts and then calculates the irradiance after the light tip diameter is manually entered into the meter software. (Giannini 2019) Linear regression analysis demonstrated that the irradiances of the LCUs had a relatively moderate correlation between the Bluephase Meter II radiometer and the integrating sphere (r^2=0.493) or the thermopile (r^2=0.585). Also, the Bluephase Meter II had an absolute percent change from the CheckUp (13.1 ± 7.1%) that was less than the Bluephase Meter I (21.5 ± 16.1%) but not statistically significantly different. A study by Shimokawa et al. compared the accuracy of four chairside dental radiometers to a thermopile when measuring the light output from nine LED LCUs. Of the tested chairside radiometers, the Bluephase Meter II provided the most accurate data when compared to the calculated irradiance values from the thermopile. (Shimokawa 2016) The larger sensor area in the Bluephase Meter II may have contributed to its greater accuracy compared to the Bluephase Meter I. (Shortall 2021). However, a study by Giannini et al. found that when the measurement scale on the back of the Bluephase Meter II was used to determine the tip diameter, the accuracy of the reported irradiance was significantly reduced. (Giannini 2019) The scale only measures the external tip diameter ranging from 6 to 12mm to the nearest 1mm and not the active optical diameter, as was done in this study. (Shortall 2021)

Linear regression analysis demonstrated that the irradiances of the LCUs correlated the best between the CheckUP and the integrating sphere (r^2=0.980) or the thermopile (r^2=0.933) compared to the other meters. Additionally, the lowest percent change from the CheckUP occurred with the thermopile (7.0 ± 3.6%) and integrating sphere (7.2 ± 2.0%). The thermopile and integrating sphere can measure any electromagnetic radiation ranging between infrared and ultraviolet and passing through visible light and are considered the gold standards when assessing radiant power from LCUs. (Assaf 2020) Their ability to capture all the wavelengths of light emitted from the multi-spectrum LCUs evaluated in this study may have contributed to their greater accuracy when compared with the chairside radiometers. However, the high cost of the laboratory equipment makes them impractical for use by dental practitioners. (Assaf 2020) The wireless, handheld, chairside spectrometer system, CheckUP, has a large sensor that can collect all of the light emitted when an LCU is tested, similar to the laboratory-grade thermopile and integrating sphere. CheckUp reportedly uses a machine-learning algorithm, which is trained by thousands of measurements taken with an integrating sphere and spectrometer system. According to the company, the algorithm compares and adjusts for different LCU characteristics so that each test result has a higher level of accuracy. (CheckUP, BlueLight Analytics website) It is important that clinicians monitor the performance of their LCUs using a reliable chairside system to determine if the light output has significantly changed and if so, then appropriate actions can be taken to compensate for the loss.

Conclusions

The new chairside spectrometer system (CheckUP) provided the best correlation and the lowest overall percent deviation in irradiance from the integrating sphere and the thermopile compared to other radiometers tested.

Disclaimer: The views expressed are those of the authors and do not reflect the official views or policy of the Uniformed Services University, Department of Defense, or its Components. The authors do not have any financial interest in the companies whose materials are discussed in this abstract. BlueLight Analytics (Halifax, Canada) loaned the CheckUP unit used in this study as part of a Material Transfer Agreement with the US Air Force.

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