Novel chairside spectrometer-trained system for measuring the irradiance of light-curing units

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The purpose of this study was to compare the performances of 5 different instruments in measuring the irradiance of light-curing units (LCUs). A novel spectrometer-trained radiometer (CheckUp), 2 conventional chairside radiometers (Bluephase Meter I and Bluephase Meter II), and 2 devices considered to be gold standards for measuring irradiance (an integrating sphere spectrometer and a thermopile sensor) were used to evaluate 7 LCUs. The irradiance of each LCU was measured 10 times with each meter. Data were analyzed using linear regression analysis and a 1-way analysis of variance with Tukey post hoc test ($\alpha = 0.05$). The mean irradiance values of the LCUs differed significantly depending on which meter was used for measurement ($P < 0.05$). Bivariate regression analysis demonstrated that the highest correlations in the irradiance values were found between the CheckUp meter and both the integrating sphere ($r^2 = 0.980$) and the thermopile ($r^2 = 0.933$). The absolute mean (SD) percentage deviation between irradiance measured by the CheckUp instrument and irradiance measured by the other meters was 7.2% (2.0%) for the integrating sphere, 7.0% (3.6%) for the thermopile, 21.5% (16.1%) for Bluephase Meter I, and 13.1% (7.1%) for Bluephase Meter II. Compared with the 2 conventional chairside radiometers, the CheckUp meter provided the highest correlation with and lowest absolute percentage deviation from the irradiance measured by the gold standard spectrometers.

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With the wide variety of light-curing units (LCUs) and composite resin restorative materials available today, it is important for practitioners to understand the factors related to photopolymerization in order to provide adequate light exposure for restorations. The photopolymerization of composite resin is affected by factors related to both the composite resin material and the light. Material-related factors include the shade, translucency, type, and concentration of photoinitiators; and size, load, and distribution of filler particles.[1] Light-related factors include intensity, exposure time, spectral distribution, and light dispersion.[2,3] The primary purpose of LCUs is to initiate the polymerization process by energizing 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 and pliable product into a solid material with physical properties desirable for long-term success as a dental restorative material.[4]

Repetitive use of LCUs results in routine wear, tear, and damage, which can be caused by chemical disinfectants, light-guide autoclaving, accidental dropping, and/or adherence of the restorative material to the light guide of the LCU.[5] Periodic assessment of the LCU's irradiance by the dental practitioner is highly recommended to make sure the light features meet the manufacturer's specifications and remain stable over time, as insufficient light irradiance may be responsible for increased marginal leakage, discoloration, recurrent caries, and/or postoperative sensitivity.[2,6,7] The American Dental Association recommends that practitioners regularly monitor the irradiance of LCUs to ensure that they meet the manufacturer's specifications and functions.[8]

The integrating sphere spectrometer and the thermopile are considered the gold standard instruments for testing the output of a dental LCU.[9] Due to the high cost and impracticality of using either of these devices in a dental office, conscientious dental practitioners have utilized various handheld radiometers as an alternative. However, multiple studies have reported that such devices have questionable accuracy and reliability.[10-16] In addition, currently available dental handheld radiometers have other shortcomings: they cannot be user calibrated; they have a fixed sensor aperture size; they do not account for different optic areas when calculating irradiance; they do not provide insight into the wavelengths at which light energy is delivered; and most contain diffusers that homogenize the entrance beam rather than capture the true nature of the beam's inhomogeneity across the light tip.[9,13,17]

BlueLight Analytics recently introduced CheckUp, an integrated wireless handheld spectrometer-trained radiometer. CheckUp is a unique LCU measurement instrument connected to a cloud-based neural network trained with National

Table 1. Specifications[a] and optic area[b] of the light-curing units evaluated in the study.

Unit	Multispectral	Irradiance, mW/cm²	Optic area, cm²
Bluephase G4	Yes	1200	0.636
Bluephase Style	Yes	1100	0.622
Bluephase 20i	Yes	1200 (high); 2000 (turbo)	0.430
Demi Ultra	No	1100-1330	0.490
Paradigm	No	1200	0.622
SmartLite Pro (Cure tip)	No	1250	0.785
S.P.E.C. 3	No	1600 (high); 3000-3500 (3K)	0.407

[a]Spectra and irradiance reported by the device manufacturer.

[b]Active optic area measured with a digital micrometer.

Institute of Standards and Technology–traceable measurement standards.[18,19] It is designed to measure irradiance and provide customized curing times based on the LCU used and the photosensitive composite material selected. CheckUp features a 17-mm-diameter uniform active light collection port and a 28 × 28-mm array sensor. Its aperture is large enough to capture all of the light exiting the LCU tip. The device transfers the readings via Bluetooth to a proprietary application. The dental practitioner is also able to use the application to select specific composite resins and shades utilized in the clinic. The CheckUp application determines the irradiance based on the spectrometer results and calculates an appropriate curing time for the particular combination of composite resin and light.[19]

To the best of the authors' knowledge, no research has been published evaluating the accuracy of the CheckUp system. The aim of this research was to compare the performances of 5 different instruments in measuring the irradiance of 7 LCUs. The study evaluated the CheckUp radiometer, 2 conventional chairside radiometers, an integrating sphere spectrometer, and a thermopile sensor. Both the integrating sphere and the thermopile sensor are considered to be gold standard instruments for measuring power output from LCUs.[9] The null hypotheses were that there would be no statistically significant difference among the irradiance values measured with the 5 meters and no statistically significant difference in the absolute mean percentage deviations between irradiance measured by the CheckUp and irradiance measured by the other 4 meters.

Methods

Five different meters were used to evaluate 7 contemporary LED LCUs representative of the different commercially available devices: Bluephase G4 (Ivoclar Vivadent), Bluephase Style (Ivoclar Vivadent), Bluephase 20i (Ivoclar Vivadent), Demi Ultra (Kerr), Paradigm (3M), SmartLite Pro with Cure tip (Dentsply Sirona), and S.P.E.C. 3 (Coltene). The surface area of each LCU tip was calculated by measuring the diameter of the active optic area to the nearest 0.1 mm using a digital micrometer (Table 1).

The meters used for the evaluation were a thermopile sensor (PM10, Coherent), a laboratory-grade integrating sphere (Labsphere) linked to a calibrated spectrometer (Flame-T-VIS-NIR, Ocean Insight), a spectrometer-trained radiometer (CheckUp), and 2 conventional chairside radiometers (Bluephase Meter I, Ivoclar Vivadent; Bluephase Meter II, Ivoclar Vivadent). The LCUs were held in place during the power measurements with a fixed vise grip retaining device (model 301, PanaVise). The irradiance of each LCU was measured 10 times with each meter. Irradiance was expressed in milliwatts per square centimeter.

A thermopile sensor (PM10) was connected to a laptop computer via a 4-channel interface (Pulsar-4 7Z01201, Ophir Optronics), and a rigid stand was used to hold the light tip of each LCU as close as possible to, but not in contact with, the sensor. Power measurements were recorded with the thermopile's proprietary software (StarLab version 3.0, Ophir Optronics) and then divided by the active optic area of the LCU to calculate the irradiance.

A laboratory-grade integrating sphere (Labsphere) with a 19-mm entrance port linked to a calibrated spectrometer (Flame-T-VIS-NIR) was used to evaluate the power of each LCU. The optic-to-entrance distance was set to 0 mm. Software was used to integrate each LCU's power spectrum from 350 to 550 nm (SpectraSuite version 1.6.0_11, Ocean Insight). This limited spectrum range fully covers the wavelength ranges emitted by the LCUs. Each measured power value was then divided by the active optic area of the LCU to calculate the irradiance.

Two chairside handheld radiometers (Bluephase Meter I and Bluephase Meter II) were each used to measure the irradiance of each LCU at a light source-to-sensor distance of 0 mm. For the Bluephase Meter II, the measured diameter of the light tip was entered into the radiometer, and the unit calculated the irradiance.

For measurement with the CheckUp radiometer, the tip of the LCU was placed on the light collection area of the radiometer at an optic-to-sensor distance of 0 mm, and the output was uploaded to the CheckUp application on an iOS-based phone (iPhone 11, Apple) via Bluetooth. The active area of each LCU tip and the mode, power, and time were analyzed, and the software computed the average irradiance.

The emission spectra of the LCUs were recorded using the sensor of a spectrophotometer (Marc Light Collector, Bluelight Analytics).

The Pearson correlation was used to evaluate the relationships of LCU irradiance values measured with the different instruments. One-way analysis of variance (ANOVA) with Tukey post hoc test ($\alpha = 0.05$) was used to analyze the effect of the instrument on the measured irradiance of each of the 7 LCUs and to evaluate the percentage deviation between irradiance measured with the CheckUp radiometer and the irradiance measured with the other 4 instruments (SPSS, version 20, IBM).

Chart. Emission spectra of the light-curing units recorded with the spectrophotometer.

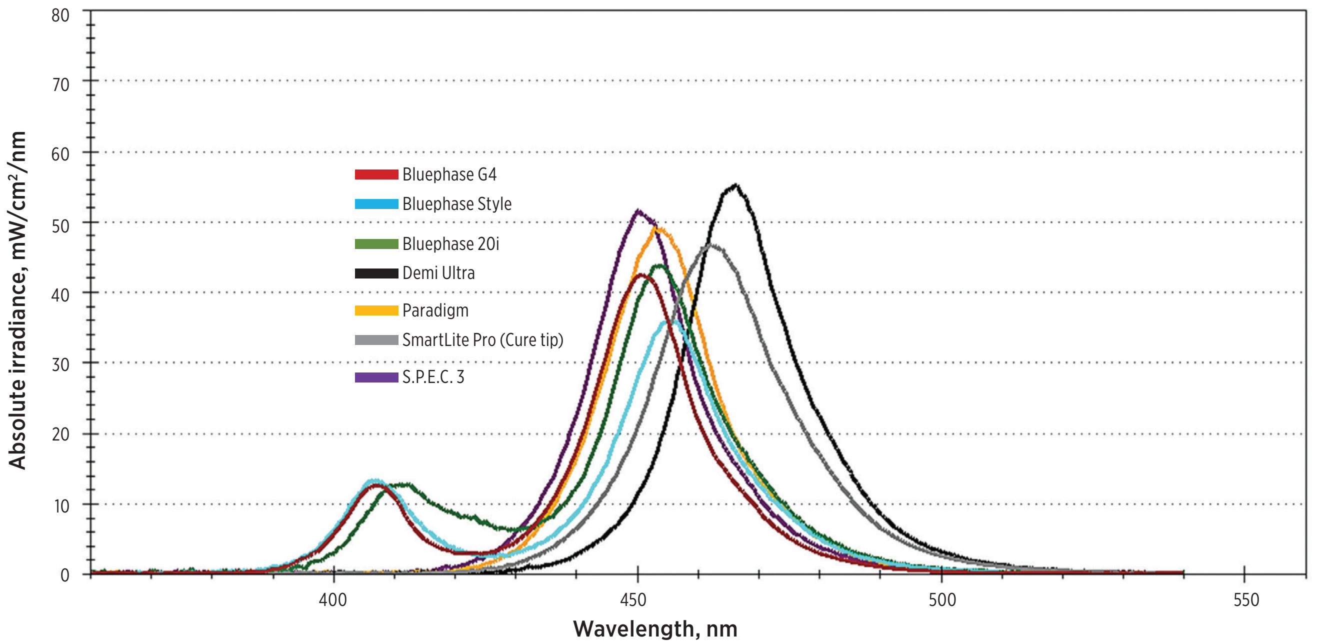

Table 2. Mean (SD) irradiance of light-curing units, mW/cm² (n = 10 measurements per unit per instrument).

Unit	Thermopile	Integrating sphere	Radiometers		
			CheckUp	BM I	BM II
Bluephase G4	1049 (10)[a]	1056 (13)[a]	1111 (11)[b]	1135 (14)[c]	1357 (11)[d]
Bluephase Style	965 (14)[b]	978 (6)[b]	1047 (8)[c]	914 (37)[a]	1234 (7)[d]
Bluephase 20i	1224 (25)[b]	1231 (11)[b]	1339 (7)[d]	1130 (19)[a]	1255 (15)[c]
Demi Ultra	1413 (63)[d]	1225 (57)[b]	1359 (8)[c]	711 (19)[a]	1495 (15)[e]
Paradigm	1040 (9)[b]	1091 (6)[c]	1173 (5)[d]	935 (25)[a]	1303 (13)[e]
SmartLite Pro (Cure tip)	1105 (26)[b]	1119 (7)[b]	1234 (7)[c]	750 (16)[a]	1485 (20)[d]
S.P.E.C. 3	1619 (37)[cd]	1563 (28)[b]	1640 (12)[d]	1424 (68)[a]	1577 (13)[bc]

Abbreviations: BM I, Bluephase Meter I; BM II, Bluephase Meter II.
Means followed by the same superscript letter are not significantly different ($P > 0.05$; Tukey test).

Results

The emission spectra of the 7 LCUs are displayed in the Chart. Table 2 shows the mean irradiance of the 7 LCUs as measured by the different instruments. The mean irradiance values of the LCUs differed significantly depending on which meter was used for measurement ($P < 0.05$). Bivariate regression analysis demonstrated that the highest correlations in the irradiance values were between the CheckUp meter and both the integrating sphere ($r^2 = 0.980$) and the thermopile ($r^2 = 0.933$). More moderate correlations were found between the Bluephase Meter II and the integrating sphere ($r^2 = 0.493$) and the Bluephase Meter II and the thermopile ($r^2 = 0.585$). The lowest correlations were determined to be between the Bluephase Meter I and the gold standard devices (integrating sphere, $r^2 = 0.387$; thermopile, $r^2 = 0.189$).

The lowest absolute mean (SD) percentage deviations between the CheckUp and the other devices occurred with the thermopile, at 7.0% (3.6%), and the integrating sphere, at 7.2% (2.0%), which were not significantly different from each other (Table 3). The greatest absolute mean (SD) percentage deviation in irradiance values from the CheckUp instrument occurred with the Bluephase Meter I, at 21.5% (16.1%), which was significantly greater than the absolute mean deviation of the integrating sphere ($P = 0.032$) and thermopile ($P = 0.029$) but not significantly different ($P = 0.73$) from that of the Bluephase Meter II, at 13.1% (7.1%).

Table 3. Percentage deviation between CheckUp and the other instruments in the measured irradiance of light-curing units.

Unit	Thermopile	Integrating sphere	Radiometer	
			BM I	BM II
Bluephase G4	−5.6	−4.9	2.2	22.2
Bluephase Style	−7.8	−6.6	−12.7	17.9
Bluephase 20i	−8.6	−8.1	−15.6	−6.2
Demi Ultra	4.0	−9.8	−47.7	10.0
Paradigm	−11.3	−7.0	−20.3	11.1
SmartLite Pro (Cure tip)	−10.3	−9.3	−39.2	20.3
S.P.E.C. 3	−1.3	−4.7	−13.2	−3.9
Absolute mean (SD)	7.0 (3.6)[a]	7.2 (2.0)[a]	21.5 (16.1)[b]	13.1 (7.1)[ab]

Means followed by the same superscript letter are not significantly different ($P > 0.05$; Tukey test).

Discussion

The physical and chemical properties of resin-based composite dental restorations are greatly influenced by the performance of the LCU. Routine monitoring and testing of LCUs to ensure the expected power output is crucial for clinical success. Three radiometers (Bluephase Meter I, Bluephase Meter II, and CheckUp) were tested in the present study, and the irradiance measurements of the CheckUp spectrometer-trained radiometer were the most similar to those of the integrating sphere and the thermopile sensor, which are considered to be gold standard devices for assessing radiant power from LCUs.[9] The present results therefore support the accuracy of the CheckUp system.

The CheckUp reportedly uses a machine-learning algorithm trained by thousands of measurements taken with an integrating sphere and spectrometer system. According to the manufacturer, the algorithm compares and adjusts for different LCU characteristics so that each test result has a higher level of accuracy.[19]

In addition to providing accurate irradiance measurements, the CheckUp also provides custom recommendations for curing times and LCU settings based on the LCU model and composite type. This information could be critical if multiple photoinitiators are present in the composite material. Camphorquinone is the most common photoinitiator in dental composite systems and is sensitive to blue light wavelengths, which form a gaussian curve and peak near 470 nm. Some manufacturers use other photoinitiators in addition to camphorquinone, such as trimethylbenzoyl diphenylphosphine oxide, which is less yellow and more efficient than camphorquinone. These initiators are usually sensitive to ultraviolet or violet light, both of which have wavelengths between 380 and 410 nm.[20] Multispectral LCUs emit light in 2 or more wavelengths, providing a broad spectrum of energies in an effort to activate a wide range of photoinitiators. Multispectral LCUs (eg, Bluephase G4, Style, and 20i) emit light in both the violet (390 to 420 nm) and blue (420 to 500 nm) wavelengths.

The present study found significant differences in LCU irradiance measurements found by the 5 meters tested as well as in the percentage deviation between the irradiance measured by CheckUP and that measured by 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 an integrated microprocessor to calculate the irradiance.[16] However, the linear regression analysis in the present study demonstrated that the irradiance measured by the Bluephase Meter I had the lowest correlation with that measured by the integrating sphere ($r^2 = 0.387$) and the thermopile ($r^2 = 0.189$). The Bluephase Meter I radiometer also had the greatest absolute mean (SD) percentage deviation from the CheckUp findings (21.5% [16.1%]).

The Bluephase Meter II radiometer measures the radiant power in milliwatts and then calculates the irradiance after the diameter of the light tip is manually entered into the unit.[6] Linear regression analysis demonstrated that the irradiance measured by the Bluephase Meter II had moderate correlations with those found by the integrating sphere ($r^2 = 0.493$) and the thermopile ($r^2 = 0.585$). The absolute mean (SD) percentage deviation from the CheckUp (13.1% [7.1%]) was less than that of the Bluephase Meter I, but not statistically significantly different. A study by Shimokawa et al compared the accuracy of 4 chairside dental radiometers to that of a thermopile for measuring the light output from 9 LED LCUs, and the Bluephase Meter II provided the most accurate data when benchmarked against the irradiance values measured by the thermopile.[9] The larger sensor area of the Bluephase Meter II may have contributed to its greater accuracy compared to the Bluephase Meter I.[16] However, a study by Giannini et al found that the accuracy of the reported irradiance was significantly reduced when the measurement scale on the back of the Bluephase Meter II was used to determine the tip diameter.[6] This scale only measures the external tip diameter (ranging from 6 to 12 mm, to the nearest 1 mm) and not the active optic diameter, which was used in the present study.[16]

Limitations of the present study include the use of only 7 LCUs and 2 types of radiometers. In addition, future studies should evaluate the capabilities of the CheckUp device for determining the recommended curing times and LCU settings based on the LCU model and composite type.

Conclusion

It is important for clinicians to monitor the performance of LCUs with a reliable chairside system to determine if the light output has significantly changed so they can take appropriate actions to ensure the best outcomes for patients. Compared with the conventional radiometers, the CheckUp system provided the greatest correlation with and the lowest overall percentage deviation from the gold standard devices (integrating sphere and thermopile).

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Conflicts of interest

None reported.

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Disclaimer

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