Review Article

Assessing Dental Light-curing Units' Output Using Radiometers: A Narrative Review

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ABSTRACT

Introduction: This review aimed to describe dental radiometers and discuss their effectiveness compared to other light-testing devices. **Materials and Methods:** The search for light-curing units (LCUs), radiometers, and other light-measuring tools available on the market was accomplished on data found on PubMed, Wikipedia, and Google. **Results:** LCUs are prone to deterioration due to several reasons such as the light's limited life span, the worsening of the LCU's filters, light guide, and light tip end; consequently, decreased photopolymerization and insufficient resin conversion may occur. A regular light output assessment is highly recommended in dental daily practice as well as before any new LCU purchase to make sure the light features meet the factory specifications delivered by the manufacturer and they remained stable through time. **Discussion:** Irradiance values reported by radiometers do not match accurately with those delivered by laboratory power meters. Therefore, dental practitioners as well as dental students are advised to control regularly every LCU by using the same handheld radiometer.

Keywords: *Irradiance, light filters, light guide, photopolymerization*

Introduction

In recent years, aesthetic restorations became very popular. Therefore, tooth-colored resin-based composites (RBCs) were widely used. Photopolymerization effectiveness has a great impact in achieving high degree of conversion of the resin and consequently successful and long-lasting direct restorations.

Recently, light-emitting diode (LED) lights became the most utilized among other light-curing units (LCUs) for they produce more light with less heat.[1,2] Blue light wavelength ranges between 380 and 550 nm,[1] but spectral radiant power can widely vary between different brands of LCUs. The use of dental radiometers to assess the light irradiance could be helpful for dental practitioners to control their LCUs and ensure optimal light curing and for dental students to choose an appropriate LCU.

This article highlights on dental radiometers, their composition, indications, and limitations compared to similar testing devices.

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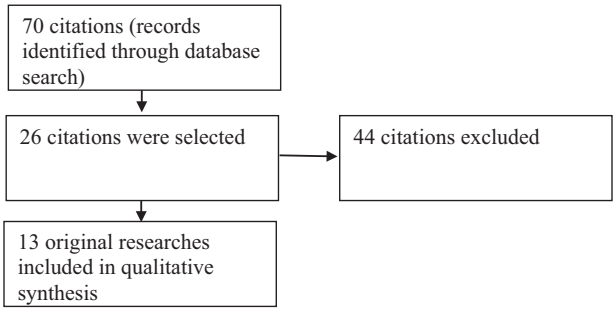
Materials and Methods

Study identification and selection

Data extraction was accomplished according to a PRISMA form by answering the 17-item checklist of PRISMA-P and following the PICO elements strategy:



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P (Problem): Dental LCUs' irradiance requires regular assessment
I (Intervention): Using handheld radiometers as irradiance-measuring device
C (Comparison): Other testing tools such as laboratory-grade meters and checkMARC system
O, Halifax- Canada (Outcome of interest): Maintaining minimal accepted irradiance to optimize resin conversion

An electronic search for specific keywords, such as radiant power, LCUs, light guide, light tip end, light filters, dual and multiple peak LCUs, spectral mismatch, handheld radiometers, laboratory-grade meters, and spectrometers, was carried out from the first of July till the end of August 2019, on the three websites: Google, PubMed, and Wikipedia. An additional hand search for main variables such as photoinitiators, light wavelengths, irradiance, handheld radiometers, and LED LCUs was accomplished. Search simplifications were made regarding the other LCUs. Duplicate articles were eliminated. Articles published between 2003 and 2019 were selected. Titles were first screened, followed by abstracts and then full texts were studied.

Inclusion and exclusion criteria

Articles were assessed according to inclusion criteria, which comprised studies conducted on dental LED light-curing devices and light-testing devices, especially those describing handheld radiometers, and exclusion criteria, which comprised all publications not available in electronic full texts or not in English.

Data extraction

Two reviewers carried out the search. Cross references, manual queries, and assessing risk of bias were resolved by the third reviewer.

Risk of bias

Quality of selected articles was assessed by following the *Cochrane Handbook* guidelines. Criteria for judgment were: Are reports free of selective reporting?

Reports with low risk of bias are those with a specified and available protocol.

Reports with high risk of bias are those with one or more reported primary outcomes that were not prespecified or specified incompletely.

Reports with uncertain risk of bias are those with insufficient information to permit judgment.

Seventy citations were retrieved from the initial electronic search; 26 citations, with low or uncertain risk of bias, were finally selected, of which 13 were original researches, 8 were review articles, and 5 were scientific documentations. Three original researches were conducted in Jordan, Malaysia, and Norway. The sample size was mentioned in the 13 selected original researches. Data were recorded under following headings: study title, aim of the study, study authors, and results, and were presented in Table 1.

Discussion

Overview on light-curing units

Quartz tungsten halogen (QTH) LCUs were popular in the recent past. The life span of QTH light devices is 50–100 h according to their filter's deterioration.[3,14] They emit light in the wavelength range of 410–500 nm with an irradiance of 300–1000 mW/cm^2.[14]

Plasma arc units are designed to emit light from glowing plasma. This later is a combination of several ionized molecules. The emitted light has high output intensity within a narrow range of wavelength around 470 nm. Therefore, the required curing time with plasma units could be three times less than that with QTH units.[14] This type of LCU did not have a great success, and therefore was gradually discontinued.

LED units followed and easily replaced QTH units due to their narrow wavelength spectrum of 450–486 nm and their life expectancy exceeding thousands of hours with less heat generation.[3,4] LED LCUs could be either corded or cordless;[1] they may have different designs such as gun style or pen style, and light source may be delivered either by the tip or by light guides.[5] Several LED unit designs are shown in Figure 1.

In the last few years, QTH and plasma light units were no longer produced. LED technologies were leading and evolving until new generations emerged into the market with higher energy and reduced curing time [Table 2].

A photoinitiator is a compound that undergoes a photoreaction on absorbing light and initiates a free radical addition polymerization of the resin monomers. So, it can transform the physical energy of light into chemical energy of free radicals.[15] Photoinitiators are integrated within the RBCs' composition to induce the conversion of resin monomers into polymers. Camphorquinone (CQ) used to dominate over all other photoinitiators. One major drawback of CQ is that it induces a yellowish shade in cured composites due to its yellow diketone compound, so other photo initiators, such as diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide (TPO) and phenyl propanedione (PPD), are

Table 1: Citations' recorded data

Serial number	Study title	Aim of the study	Author	Number of individuals	Results
1	Light-curing units used in dentistry: factors associated with heat development-potential risk for patients	To investigate how heat development in the pulp chamber and coronal surface of natural teeth is associated with (1) irradiance, (2) time, (3) distance, and (4) radiant exposure	Mouhat *et al.*, 2017[1]	Three different LED-LCUs were used	Increased exposure time seems to be the factor most likely to cause tissue damage
2	Comparison of halogen, plasma, and LED curing units	Plasma arc and blue light-emitting diodes (LEDs), in comparison with a conventional tungsten-halogen LCU	Nomoto *et al.*, 2004[2]	One plasma arc, one LED, and one QTH LCUs	The temperature increases were 15°C–60°C for plasma arc units, around 15°C for a conventional halogen unit and under 10°C for LED units
3	Assessing the irradiance delivered from light-curing units in private dental offices in Jordan	To examine the irradiance from LCUs used in dental offices in Jordan	Maghaireh *et al.*, 2013[3]	295 LCUs in Jordan	The irradiance from many of the units in this study was less than 300 mW/cm^2, which may affect the quality of resin-RBC restorations
4	Evaluation of light-curing units used in dental clinics at a university in Malaysia	To evaluate the efficiency of all LCUs used in dental clinics of a university in Malaysia	Lee *et al.*, 2018[4]	88 LCUs in Malaysia	Cordless LED LCU showed better performance than corded ones
5	An evaluation of the light output from 22 contemporary light curing units	This study measured the radiant power (mW), irradiance (mW/cm^2) and emission spectra (mW/cm^2/nm) of 22 new, or almost new, LCUs	Soares *et al.*, 2017[5]	22 new LCUs	The emission spectrum from the various monowave LED LCUs varied greatly. The multi-peak LCUs delivered similar emission spectra to both sensors
6	Effect of emitted wavelength and light guide type on irradiance discrepancies in handheld curing radiometers	To determine any discrepancies in the outputs of five commercial dental radiometers using a laboratory-grade spectroradiometer	Kamayema *et al.*, 2013[6]	Five commercial radiometers and 12 LCUs	These results cast doubt on the accuracy of commercially available dental radiometers
7	Accuracy of irradiance and power of light-curing units measured with handheld or laboratory grade radiometers	This study measured irradiance and power of four commercial dental LCUs	Giannini *et al.*, 2019[7]	Four LCUs, two handheld radiometers, and three lab instruments	The handheld radiometers used by practitioners (analog or digital) show a wide range of irradiance values and may show lower outcomes compared to laboratory-based instruments
8	The effect of distance from light source on light intensity from light curing lights	To investigate how light intensity changes as the distance increases from the tip of the light guide	Felix and Price, 2003[8]	Ten LCUs	It is not possible to predict light intensity at 10 mm from measurements made at 0 mm
9	Ability of four dental radiometers to measure the light output from nine curing lights	To evaluate the accuracy of four dental radiometers when measuring the output from nine LCUs	Shimokawa *et al.*, 2016[9]	Nine LCUs, four radiometers, one lab power meter	Of the dental radiometers, only the Bluephase Meter II could measure power
10	Irradiance uniformity and distribution from dental light curing units	This study examined the irradiance uniformity and distribution from a variety of LCUs as well as the effect of different light guides	Price *et al.*, 2010[10]	Five LCUs each with two different light guides	Irradiance values calculated using conventional methods do not validly characterize the distribution of the irradiance delivered from dental LCUs

Table 1:Continue

Serial number	Study title	Aim of the study	Author	Number of individuals	Results
11	Characterizing the output settings of dental curing lights	What electromagnetic radiation (light) is emitted from the LCU and what is received by the resin	Harlow *et al.*, 2016[11]	Two QTH and four LED LCUs	A single irradiance value derived from a dental radiometer or from a laboratory grade power meter cannot adequately describe the output from the LCU
12	Intra- and inter-brand accuracy of four dental radiometers	This study measured the accuracy and precision of four commercial dental radiometers. The intra-brand accuracy was also determined	Price *et al.*, 2012[12]	Fourteen LCUs, four radiometers, and two lab power meters	Dental radiometers should not be used when either the irradiance or energy delivered needs to be accurately known
13	Accuracy of LED and halogen radiometers using different light sources	To determine the accuracy of commercially available, handheld LED and halogen-based radiometers	Roberts *et al.*, 2006[13]	One LED, one QTH LCU with five light guides each, and three radiometers	In general, both handheld radiometer types showed significantly different irradiance readings compared with the control meter

introduced as good alternatives for whiter shades of RBCs.[16,17] TPO and PPD are both activated with shorter wavelengths than CQ[16] [Table 3].

Light is measured by its wavelength in nanometers. One wavelength is the distance between identical points also called waves that determine light's color. The received number of photons at the appropriate wavelength is critical to ensure adequate resin conversion.[7] Polymerization is initiated when LCUs activate the photo initiators within the RBCs.[16,17] Optimal photoinitiator activation occurs when its peak absorbance matches the LCU's wavelength.[16]

LCU irradiance (mW/cm^2) is defined as the radiant power (mW) over the emitting light tip area (cm^2),[7,8] and it is considered as a key factor to induce more carbon–carbon double bonds through time.[3] Insufficient light irradiance may be responsible for several postoperative complications such as marginal leakage, discoloration, and subsequent decays; thus inducing restoration failure. On the contrary, high irradiance could also induce soft tissue and pulp damage, especially in deep cavities.[4] Radiant exposure also called "light dose" may also have great impact on the extent of resin conversion. It is nothing but the product of irradiance and exposure time (mJ/cm^2). Approximately 8–50 J/cm^2 are required to efficiently cure a layer of composite.[18] Price *et al.*,[19] in guidelines for successful light curing, stated that an irradiance value of 300–400 mW/cm^2 is the minimal requirement to efficiently cure RBCs. LCU's irradiance may change, eventually drop, over time due to several factors. Away from those related to the light guide or the LED chip, debris that adhere to the light tip may decrease the emitted light irradiance. These debris often consist of cured bonding agents or composite materials that could be easily whipped off with a gauze or by immersing the contaminated tip in a mass of uncured composite. When light is activating, the freshly polymerized composite will adhere the debris pulling them off. This protocol could be repeated several times to clean off totally the contaminated tip.[7]

Some RBCs may incorporate several photoinitiators, thus inducing a spectral mismatch between the LCU and the RBC. Dual-peak LCUs were innovated to resolve the spectral mismatch problem by emitting first a light spectrum of 460 nm to activate CQ and a second peak of 400 nm to activate either TPO or PPD.[17]

In other words, a lack of photopolymerization may be induced by the following:

- Insufficient light irradiance
- Insufficient exposure time

Figure 1: Different LED units' styles and light guides' designs

Table 2: Features of quartz tungsten halogen, plasma, and light-emitting diode units[2,14]

LCU type	Wavelength range (nm)	Generated heat (for the same exposure time) (°C)	Curing time (for the same depth of cure) (s)
QTH	410–500	15	20
Plasma	Around 470	15–60	6–9
LED	450–486	10 (except for high intensities LED units)	40–60

Table 3: Absorption spectrum of the commonly used photoinitiators[6,17]

Photoinitiator	Spectrum wavelength	Light range
CQ	430–490 nm	Blue
TPO	380–425 nm	Violet
PPD	350–490 nm	Violet

- An eventual lack of compatibility between the RBC's photoinitiator and the LCU's spectral wavelength[3]

Definition, types, and composition of handheld radiometers

Dental radiometers are able to convert light into electric current, which is quantified by either an analog or a digital display.[7] The two types of handheld radiometers (digital and analog) are shown in Figure 2.[9]

A conventional radiometer is composed of a case with an entrance port, diffusers, filters, a detector, and a display to read values. The latter, as previously mentioned, could be either digital or analog;[8] digital displays, although look accurate, do not deliver 100% precise results.[20] Figure 3 shows the main components of a handheld radiometer.[20]

The port, from which light penetrates, has major impact on how many light photons would reach the detector. Often, these ports are small windows ranging from 6 to 12 mm of diameter.[8] So, by moving the light tip away from the port, the practitioner will notice a large fluctuation of irradiance values.[20]

Two main factors may influence the accuracy of the test at this point: First, the calculated irradiance does not take into consideration light nonuniformity at the tip of the LCU that mainly occurs when adding several LED wavelengths within the same light unit also called dual- or multiple-peak LCUs.[5]

Second, when testing irradiance, the light tip is positioned at 0 mm distance. Knowing that rarely the light tip may be in contact with RBCs, the calculated value could not report a clinical setting.[8,20]

Diffusers are integrated before the detector to equally distribute the entering light, but they can also block some of beam's inhomogeneity.[20]

Filters (that could be numerous in some devices) are responsible for reducing selectively the intensity of lights with specific wavelengths. The number and types of filters differ from one radiometer to another.[20] Therefore, a LED light is accurately tested with a radiometer that does not filter out its spectral wavelength, and the irradiance of the same LCU may vary when tested with several radiometers.

The detector (or photodiode) is where the light hits last. It has smaller size than the port, and it is not

Figure 2: Two types of dental radiometers, three brands on the left are digital and one on the right is analog

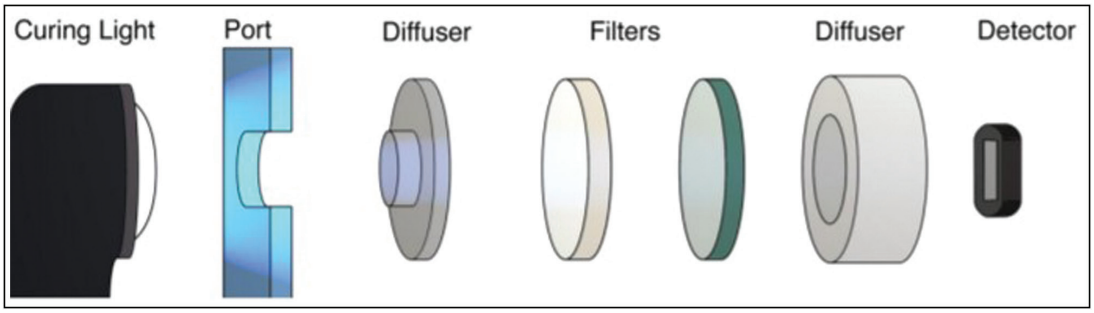

Figure 3: Composition of a typical handheld radiometer

equally sensitive to all wavelengths as well. It only tests a portion of the emitted light and then it predicts the total irradiance from this value. This also affects negatively the accuracy of radiometers' measurements. Consequently, the detector is more sensitive to single-peak LED units in opposition to other broadband lights as violet light band is less detected (typically filtered) by a simple radiometer.[10,20]

Handheld radiometers, integrating spheres, checkMARC spectrometer, and laboratory power meter instruments

Handheld radiometers, as previously mentioned, are calibrated by the manufacturer according to a specific wavelength,[6,7] so the structures of the conversion of light into electric current differ between radiometers.[6,21] Consequently, when comparing LCU's performances and when testing multiple-peak LCUs, conventional radiometers do not deliver accurate and reliable results.[7,11,12,22] For regular LCU control, conventional radiometers are still recommended while keeping the LCU's light guide in the same position and the light tip in a flat angle with regard to the radiometer's entrance port.[7]

Relevant LCU features such as radiant power (mW), the effect of distance on the irradiance, and the

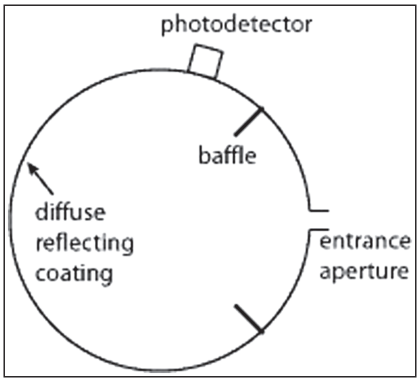

Figure 4: Integrating sphere design

emission spectrum across the light tip are not described by handheld radiometers.[5] An integrating sphere consist of a hollow and performed sphere with an internal white reflective coating allowing accurate measurements of optical signals. Integrating spheres measure LCU's power intensities (mW) as an absolute value, then irradiance may be calculated individually by dividing the power over the light tip diameter. Although accurate (±5%), integrated spheres may provide false results in terms of irradiance due to the big influence of the squared denominator (cm^2); in addition, the sphere's

Table 4: Indications and limitations of three light-curing units testing tools

LCU testing device	Indications	Limitations
Handheld radiometers	Monitor the same LCU over time	-Inaccurate to test multiple peak LCUs -Inaccurate when comparing several LCUs
Laboratory-grade meters	-Assessing radiant power -Comparing several LCUs -Testing radiometers' efficiencies	Not used in dental daily practice
checkMARC system	Reliable results when measuring light irradiance	Only available as a deliverable service

high cost may be a disadvantage for many dentists.[23] Figure 4 describes an integrating sphere dynamics.

A new Canadian LCU testing service was recently introduced, aiming to provide a more accurate LCU output assessment than conventional handheld radiometers.[24,25] checkMARC (Bluelight Analytics Inc., Halifax NS B3L 4G4, Canada) consists of a portable spectrometer, knowing that spectrometers are similar to radiometers by measuring a specific wavelength range but they differ by using an optical grating and multiple sensors to break down the incoming energy into different wavelengths, thus delivering more accurate results than radiometers. checkMARC has a wider port diameter (approximately 16 mm) and a Teflon diffuser window. It measures wavelengths ranging from 300 to 700 nm,[25] and can deliver several values such as irradiance (mW/cm^2), radiant power (J/cm^2), and spectral emission (nm).[5] Results are displayed with a web-linked software.[25] This innovation is still a service delivered on clinical appointment visit.[25]

Laboratory-grade meters, also called photometers, can measure any electromagnetic radiation ranging between infrared and ultraviolet and passing through visible light, by converting light into an electric current. Light passes through a filter or a monochromator before any measurement or analysis. Photometers could be set on different modes such as irradiance, scattering of light, and reflection of light,[26] and several types are available such as system with an integrating sphere connected to a spectrometer (Labsphere, Sutton, New Hampshire, to USB 2000, Ocean Optics, Dunedin, Florida) or a system with a thermopile sensor (PowerMax PM-10; Coherent, Santa Clara, California).[7] When testing LCUs with lab-grade meters, the tip should be kept close but never in contact with the tip sensor.[7] In many papers, researchers considered laboratory power meter results as control group[5,6,9,13] for assessing accurately light outputs.

This review's main findings are summarized in Table 3 by comparing efficiencies of three LCUs testing tools in delivering accurate results [Table 4].

No conflicting findings could be reported regarding the indications and limitations of the mentioned LCUs' testing devices.

Limitations of study might exist since LCUs testing devices, such as handheld radiometers and laboratory-grade meters, were compared to an LCU testing service as checkMARC system, and since few references were found regarding integrating spheres' applications.

Conclusion

Although LCU manufacturers often provide detailed information concerning the radiant power (mW) and irradiance, a periodic LCU check is highly recommended as time, frequent usage, and disinfecting light guides, may all decrease LCUs' performance and reduce their light outputs.

LCUs' routine examination is necessary to monitor any change in the light output intensity over time. Therefore, a new dental radiometer easily handled, calibrated by the practitioner, and capable to measure the beam features of any type of LCUs is a must in dental daily practice.

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Nil.

Conflicts of interest

There are no conflicts of interest.

Author contributions

As per ICMJE guidelines, the three authors involved in this study contributed in: Dr Cendrella Assaf: study conception, data collection, data analysis and writing. Dr Jean Claude Fahd: data acquisition and interpretation, and manuscript editing. Pr Joseph Sabbagh: data analysis and interpretation, and manuscript editing. The three authors have approved this final version of the manuscript for publication.

Data availability statement

Data that support the findings of this study will be available from the Dr. Cendrella Assaf, E-mail: cendrellassaf@yahoo.fr

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