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Altaie, Asmaa ; Hadis, Mohammed; Wilson, Victoria ; German, Matthew ; Nattress, Brian; Wood, David; Palin, William

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An evaluation of the efficacy of LED light curing units in primary and secondary dental settings in the UK

Asmaa Altaie[a], Mohammed Hadis[b], Victoria Wilson[c], Matthew German[c], Brian Nattress[a], David Wood[d] and William Palin[b]

[a] Restorative Dentistry Department, School of Dentistry, University of Leeds, Leeds, UK

[b] Biomaterials Unit, School of Dentistry, College of Medical and Dental Sciences, University of Birmingham, UK

[c] School of Dental Sciences, Translational and Clinical Research Institute, Faculty of Medical Sciences, Newcastle University, Newcastle upon Tyne,UK

[d] Division of Oral Biology, School of Dentistry, University of Leeds, Leeds, UK

Corresponding author

Dr Asmaa Altaie

Restorative Dentistry Department, School of Dentistry, Worsley Building, University of Leeds, LS2 9LU, Leeds, UK

A.Altaie@leeds.ac.uk

Abstract

Objective
This study aimed to evaluate the irradiance and the quality of LED light curing units (LCUs) in primary and secondary clinics in the UK and to assess the effect of damage, contamination, use of protective sleeves and light tip to target distance on the irradiance and performance of LCUs.

Methods
The irradiance (mW/cm^2) of 26 LED LCU's from general dental practices and 207 LED LCUs from two dental hospitals was measured using a digital radiometer (Blue Phase II, Ivoclar-Vivadent, Amherst, NY). Ten LED light guide tips (Satelec mini, Acteon, Merignac, France) were selected to evaluate the effect of chipping, contamination (tip debris), use of protective sleeves and tip to sensor distance on irradiance (mW/cm^2) using a MARC™ Resin Calibrator (Blue Light Analytics, Halifax, Canada). Homogeneity of the light output was evaluated using a laser beam profiler (SP620; Ophir-Spiricon, Longan, USA). Statistical analysis was conducted using one-way ANOVA with post hoc Tukey (p<0.05) and linear regression with stepwise correlation tests.

Results
Thirty-three percent of the LCUs delivered irradiance output less than 500mW/cm^2. The condition of the light curing tips was poor with 16% contaminated with resin debris, 26% damaged and 10% both contaminated and damaged. The irradiance output was significantly reduced in contaminated (62%), chipped (50%) light curing tips and when using protective sleeves (24%) (p<0.05). Irradiance was also reduced when increasing the distance with 25% and 34% reduction at 7 mm and 10 mm respectively (p<0.05).

Conclusion
There remains a lack of awareness of the need for regular monitoring and maintenance of dental LCUs. Damaged and contaminated light curing tips, use of protective sleeves and increasing the distance from the restoration significantly reduced the irradiance output and the performance of the LCUs.

Clinical relevance statement
Clinicians should regularly monitor and maintain their light curing units to ensure optimum light curing process. It is also essential to appreciate the various factors that reduce the performance of the LCU.

Keywords: Light curing units, Irradiance, Beam homogeneity, Resin composites

Introduction

The introduction of light cured dental resins led to a revolution in modern dental practice. Consequently, the dental light curing unit (LCU) has become an integral piece of equipment in every dental practice. However, the lack of knowledge amongst dental practitioners concerning the factors affecting the performance of LCUs raises a major concern as the use of resin based materials has significantly risen worldwide. It was reported that approximately 800 composite restorations were placed worldwide in 2015 [1], of which 80% were posterior composite restorations exceeding the use of amalgam restorations in several countries [2–4]. This increase is expected to continue following the Minamata convention and the calls for a phase down in the use of mercury containing products which has placed resin composites as the most suitable alternative to amalgam as a direct restorative material [5].

Current resin composite formulations exhibit enhanced mechanical and physical properties allowing them to be used as a posterior restorative. However, the average life span of composite restorations remains just under 10 years, after which clinical intervention may be required [6]. Recurrent caries and restoration fracture remain as the primary reasons of clinical failures of composite restorations [7,8]. Inadequate polymerisation of resin composites has a major impact on the mechanical and physical properties of the material, including reduced bond strength to the tooth, bulk fractures, increased wear and increased amount of residual monomers within the resin [9–13]. Therefore, a major contributing factor to the early failures of resin composite restorations might be related to limited polymerisation and sub-optimal curing of the material. Whilst it was reported that an irradiance of 400 mW/cm² was the minimum that must be delivered for effective polymerisation of most resin-based composites when appropriate curing times were used [14], most dental composite manufacturers recommend delivering a minimum of 500 mW/cm^2 for a duration of 40 seconds for optimum curing and many recommend shorter curing times if irradiance is higher, e.g. >1000 mW/cm^2 for 10 seconds. Such arbitrary values may provide some margin for error, however, if the absolute irradiance output is unknown, there would exist a greater risk of sub-optimally cured materials. Additionally, there has been an increase in the popularity of bulk-fill composite materials which are claimed to enable restorations build up in thicker increments of 4-6 mm [15]. The composition of bulk-fill composites varies dependent on the type and amount of filler content and the photoinitiator systems used, therefore adequate curing is essential to achieve adequate polymerization and the desired mechanical properties of these materials [16–18].

LCUs containing light emitting diodes (LED) are the most commonly used in dental practice [19] as they exhibit specific spectral output to closely match CQ absorption without the need for optical filters [20,21]. LED LCUs have several advantages because they are ergonomic, lightweight, battery operated and present greater efficiency compared with quartz tungsten halogen (QTH) LCUs due to the non-filtered irradiation [21,22]. Furthermore, LED light sources can provide much longer working life compared to QTH and plasma-arc (PAC) light sources [23]. Therefore, nowadays there is a general definite trend toward using LED LCUs only. The first generation of LED LCUs contained arrays of multiple individual LED emitters that generated low irradiance output and required prolonged curing times [21,23]. The second generation of LED lights evolved to incorporate small surface-mounted LEDs instead of discrete LED multiple arrays [22]. Following this innovation, the irradiance output was significantly increased [24] resulting in less exposure time being required to adequately photocure restorations [25,26].

More recently, alternative photoinitiators to camphorquinone (CQ) such as phenyl propanedione (PPD), Benzil (BZ) and Norrish Type I photoinitiator systems such as mono- (Lucirin TPO) and bi-(Irgacure 819) acylphosphine oxides have been introduced [27,28]. These have been used in an attempt to increase the curing efficiency and the depth of polymerisation in so-called ‘bulk fill’ resin composites [16]. Additionally, most of these photoinitiators are less pigmented and can therefore be used in bleached shades of resin composites overcoming the yellowing effect of CQ when used solely. However, these alternative photoinitiators require shorter wavelengths of light at or below 410 nm. Consequently, the third generation of LED lights were introduced by incorporating multiple LED chips generating distinct wavelength bands (~380-500 nm, LCU dependent) [22]. These LCUs are considered broad-spectrum lights and sometimes they are referred to as “polywave” LCUs. Polywave lights are proposed to effectively photopolymerise all dental resin-based restorative materials that contain a variety of photoinitiators. Therefore, clinicians should be aware weather the restorative materials used contain alternative photoinitaors which will require a polywave LCU rather than assuming that all LED LCUs are suitable.

To achieve optimal photopolymerisation of resin based materials, clinicians should aim to deliver sufficient radiant exposure at the correct wavelength(s) of light according to the intrinsic characteristics of the material (thickness, shade, photosenstisters, etc). Many clinicians do not understand proper use of a dental LCU or the critical factors for optimising the material properties of light cured resin composites [29–31]. Several studies have shown that LCUs used in dental practices are poorly maintained and deliver inadequate light output [32–37]. Additionally, most clinicians did not know the irradiance and wavelength of their LCU and were unaware that LCUs with low irradiance output were unable to adequately cure the resin based restorations used routinely [30,35].

Evaluating the condition of the light guide is a key factor in optimising light curing, as the regular and frequent use of LCUs in most dental practices leads to damage and resin contamination, which result in a reduced power output [38,39]. Furthermore, various clinical factors have been shown to influence the irradiance of the light such as increasing the distance from the restoration [40]. It was reported that some LCUs deliver only 25% or less of the irradiance measured at the tip when the distance is increased by 8 mm [12,41,42]. Further, the use of protective sleeves to minimise potential cross infection from the LCU tip is reported to reduce the irradiance by 40% [43,44]. An additional clinically relevant factor to consider is the beam homogeneity of the LCUs, which can be evaluated using the beam profiling technique that is commonly used to examine lasers and other light sources [45]. It was reported that many LCUs do not have a uniform light beam across the tip with “hot spots” of high irradiance and areas of significantly reduced irradiance across the tip [46]. The impact of light guide properties and other clinical factors varies between different LCUs and is dependent upon individual design and optics of the light guide. Therefore, it is important to evaluate the effect of these factors on the performance of commonly used and newly introduced LED LCUs.

Although several studies have evaluated LCUs in various dental settings, to our knowledge no studies have been published to date evaluating the irradiance and the condition of LCUs used in UK primary and secondary dental settings. Therefore, the aims of this study were (1) to evaluate the irradiance and the condition of LCUs in both primary and secondary dental care units in the UK and (2) to evaluate common clinical and light guide factors that may influence the light output and the performance of contemporary LED based LCUs.

Materials and Methods

Light curing units (n=233) were evaluated in the first part of this study; Leeds Dental Institute (n=102) and Newcastle Dental Hospital (n=105) as secondary care units and general dental practices in West Yorkshire (n=26) as primary care units. Various LCU brands were used with light curing tip diameter ranging from 7.5 to 12 mm, details of the lights tested are shown in Table 1.

Table 1: Summary of all LCUs tested in this study

Light curing unit	Manufacturer	Number	Light guide diameter
Satelec mini LED	Acteon, Merignac, France	158	7.5 mm
SmartLite	Dentsply, DE, USA	20	12 mm
Woodpecker LED H	Woodpecker, China	13	8 mm
Dentsply QHL75	Dentsply, DE, USA	8	10 mm
Satelec BlueRay	Acteon, Merignac, France	5	6 mm
BA Optima 10	BA international Northampton, UK	5	8 mm
Henry Schein LED	Henry Schein Inc., NY, USA	3	8 mm
Coltoux LED	Coltene, NJ, USA	4	12 mm
Demi Plus	Kerr Corporation, CT, USA	3	8 mm
Demi Ultra	Kerr Corporation, CT, USA	2	11 mm
C02-C LED	Premium plus, Hong Kong	2	10 mm
Flashlite 1401	Den-Mat Holdings LLC CA, USA	2	12 mm
Sliverlight LED	GC Corporation, Tokyo, Japan	2	8 mm
Translux wave LED	Kulzer GmbH Hanau, Germany	1	8 mm
GC D-Light Duo	GC Corporation Tokyo, Japan	1	8 mm
DentMate LED	DENTMATE, New Taipei City, Taiwan	1	8 mm
Radii LED	SDI, Bayswater, Australia	1	8 mm

VRN VAFU LED	VRN, China	1	8 mm
SEASKY	Skysea, China	1	8 mm

The light output irradiance (mW/cm^2) was measured for each LCU using a Blue Phase II (BPII) digital radiometer (Ivoclar-Vivadent, Amherst, NY). The BPII calculates the light irradiance based on the measured power (mW) when the light tip diameter is entered into the meter software and has a minimum detection threshold of 20mW/cm^2. The BPII radiometer contains a large sensor area, which enables measurement of the radiant power up to a 13 mm diameter tip size. Higher accuracy of the BPII compared with other commercial radiometers has been reported previously and an accuracy of ±10% compared to a laboratory-grade meter [47] has been reported. For each unit tested three separate measurements of 20 seconds duration were taken and the mean reading was recorded. The LCU type and the size of the fibre optic tip was recorded for each unit using the BPII integrated template to determine the diameter of circular light probes. The appearance of the light curing tip was also evaluated and observations of chipping and debris noted. The readings were recorded by a single investigator and recordings of light irradiance below a threshold of 500 mW/cm^2 were considered unsatisfactory. The output intensity (mW/cm^2) of all the examined lights were categorised into three groups: (i) <200 mW/cm^2, (ii) 200-500 mW/cm^2, and (iii) >500 mW/cm^2.

Based on investigator visual examination, ten Satelec mini LED light guides (Acteon, Merignac, France) were selected to evaluate the effect of chipping, contamination and tip-debris on the overall light output (mW/cm^2) using a MARC™ Resin Calibrator (Blue Light Analytics, Halifax, Canada). The MARC™ Resin Calibrator was fixed to an optical board and a universal joint and clamps were used to allow accurate and concentric positioning of the tip and sensor. The exposure time was set to 20 seconds and energy level of 16J/cm^2 for all LCUs [14,48]. The irradiance of the damaged and contaminated LCU curing tips were measured using the same light source (Satelec mini LED) of known output with a clean and undamaged (control) tip. LCUs with debris on the fibreoptic tip surface were selected based on residue of up to 50% over the surface of the tip, which were identified after investigator visual examination. Measurements were taken normal to the sensor surface at 0 mm distance (n=3).

To evaluate the effect of the protective sleeves on LCU output, a light protective sleeve (WRAPAROUND, UnoDent, Essex, England) was placed on the LCU (Figure 1) with new light curing tip and irradiance values were recorded (n=10). To evaluate the effect of distance of the light from the restoration, the LCU with a new light guide tip was mounted securely on the optical bench and placed perpendicular to the sensor surface on the MARC™ Resin Calibrator, three readings were taken at 1 mm intervals from 0 to 10 mm from the sensor surface, the mean reading at each individual distance was then recoded.

Figure 1: Satelec mini LED (Acteon, Merignac, France) with a light protective sleeve (WRAPAROUND, UnoDent, Essex, England) over the tip.

The homogeneity of the light beams was evaluated using a laser beam profiler (Ophir Spiricon, SP620, Israel) and analysed in Beamgage 6.3 (Ophir-Spiricon, Longan, USA) [46,49]. The laser beam profiler has a high resolution CCD sensor (4.4 μm square pixels) that takes images of the light output and the power received within each pixel. A 50 mm CCTV lens (Ophir, Spiricon) was attached to a camera and was focused directly onto the tip of the light source. Following a linear calibration to correct pixel dimension due to the magnification by the lens, saturation of the CCD sensor was controlled using 1) neutral density filters (OD 2 and 1, Ophir Spiricon) stacked above the lens, 2) the aperture on the 50 mm lens, and 3) the integration time within BeamGage software. Subsequently, an ambient light correction was performed using the built-in UlltraCal function within BeamGage. Pixel response was then calibrated using previously determined power values measured using a photodiode power meter

(PD300, Ophir Spiricon). For each LCU, the distance between the camera and the light guide tip was fixed. The beam profile images were then analysed using Ophir-Spiricon software and displayed on a computer screen as color-coded image of the beam irradiance distribution across the emitting surface.

Three light curing devices that represented “2nd generation” LCUs: single diode, one waveband emission; Satelec mini LED (Acteon, Merignac, France), Elipar S10 (3M Oral Care, St. Paul, MN, USA) and Woodpecker LED (Woodpecker, China) and one “3rd generation LED light: double diode, multi-waveband emission; BluePhase Style (Ivoclar-Vivadent, Amherst, NY) were selected to evaluate the variability of the beam light homogeneity amongst different LCU brands. Selected LCUs with chipped and contaminated light curing guides were also evaluated using the laser beam profiler. To demonstrate the clinical implications of beam light homogeneity, scaled beam profile images were superimposed over a tooth preparation to demonstrate the radiant power received over various regions within a typical cavity preparation.

Statistical analysis was conducted using SPSS 21. Data was analysed for normality using Shapiro-Wilk Test and comparisons were made using One-Way ANOVA and post hoc Tukey tests (p=0.05). Linear regression with stepwise correlation were also used to analyse the correlation between the light output and the presence of tip debris, chipping, the effect of increasing the distance from the target and the effect of using protective sleeves.

Results

Data showed that 33% of the tested lights showed irradiance output below 500mW/cm^2 which was considered unacceptable, details shown in Table 2. The condition of the light curing guides was also poor with only 48% identified to be in good condition, Table 3.

Table 2: **The irradiance output (mW/cm2) of the light curing units tested in Leeds Dental Hospital, Newcastle Dental Hospital and General Dental Practices**

Irradiance output (mW/cm^2)	Number of LCUs
< 200	3 (1%)
200-400	30 (13%)
400-500	44 (19%)
> 500	156 (67%)

Table 3: **The condition of the light curing tip guides tested.**

Condition of the LCU guide	Number of LCUs
Debris buildup	38 (16%)
Damaged	60 (26%)
Debris buildup and Damaged	24 (10%)
Good	111 (48%)

Data showed that all variables tested had a highly significant impact on the irradiance output emitted from the LED LCUs, these variables were as follows;

Light guide factors: Effect of debris build, chipping and use of protective sleeve

Resin debris build up ($r^2 = 0.95$, $p < 0.05$)

Chipping of the light curing tip ($r^2 = 0.96$, $p < 0.05$)

Use of protective sleeve ($r^2 = 0.82$, $p < 0.05$)

Data showed that using a light curing tip with resin debris buildup resulted in a significant reduction in the irradiance output by an average of 62% ($p<0.05$). Similarly, the use of a chipped tip or using protective sleeves resulted in a reduction of the irradiance output by 50% and 24% ($p<0.05$) respectively. Details are shown in Table 4 including the reported irradiance values and the impact on the light performance.

Table 4: The mean irradiance values (mW/cm2) and the performance (%) of the same LCU source (Satelec mini LED, Acteon, Merignac, France) when used with new light guide tips, with debris build up, chipped tips and when used with protective sleeves.

Group	Mean (Std)	Performance (%)
New tip	1072 (13.03)	100
Debris buildup	410 (12.24)	38
Chipping	540 (7.07)	50
Protective sleeve	810 (0.1)	76

Operator factors: Effect of distance

Distance from the sensor target ($r^2 = 0.98$, $p < 0.05$)

Increasing the distance of the light guide tip from the sensor target also resulted in a reduction in the irradiance output; the irradiance was reduced by 25% at 7 mm and 34% at 10 mm (p<0.05). Figure 2 and Figure 3 show the effect of increasing the distance from the target on the overall irradiance output and the time required to reach an energy level of 16J/cm^2 required to cure resin composites.

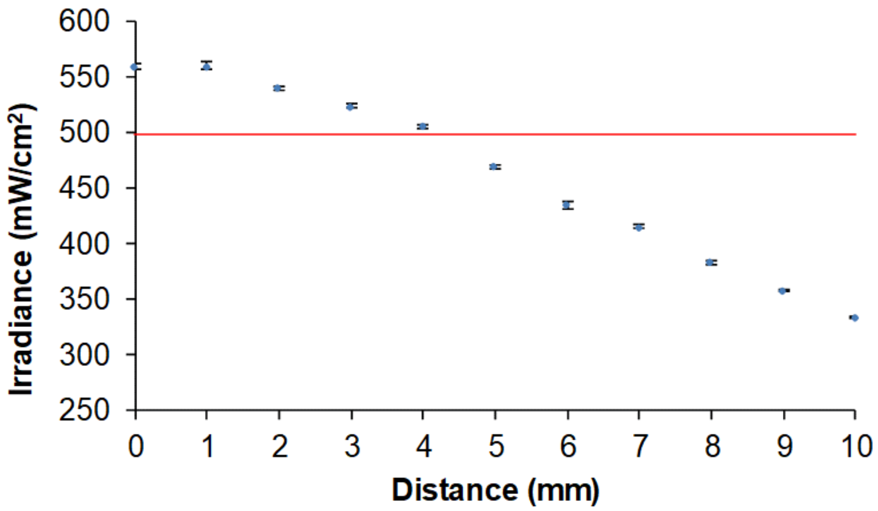

Figure 2: Effect of increasing the distance between light guide tip and the sensor target on the irradiance output using Satelec mini LED (Acteon, Merignac, France). The red line represents the manufacturers recommended irradiance of 500mW/cm^2.

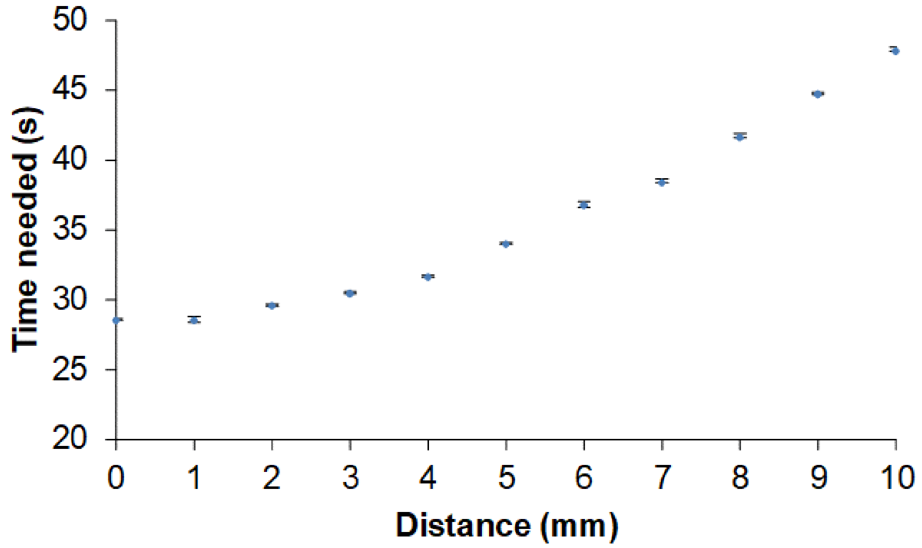

Figure 3: The effect of increasing the distance on the time required to reach 16J/cm^2 recommended to cure resin composites using Satelec mini LED (Acteon, Merignac, France).

Figure 4 demonstrates the clinically relevant distances for example the distance between the cusp tip and the base of a posterior interproximal box which may exceed 7 mm [48,50] and its effect on the light output and performance.

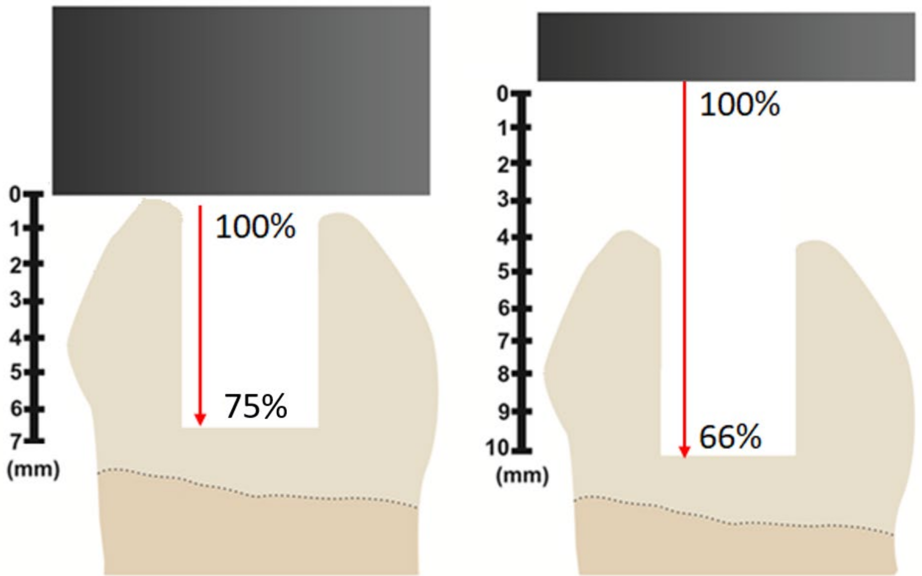

Figure 4: The effect of increasing the distance of the light tip on the irradiance output using Satelec mini LED (Acteon, Merignac, France). The light irradiance performance is reduced to 75% at 7 mm and 66% at 10 mm.

Beam light uniformity

The light output uniformity across the emitting tip and the irradiance distribution from four representative lights tested in this study are shown in Figure 5. The beam profiles show differences in the beam diameters amongst different lights and inhomogeneous irradiance distribution with presence of “hot spots” (indicated by the colour scales on the right of each beam profile image).

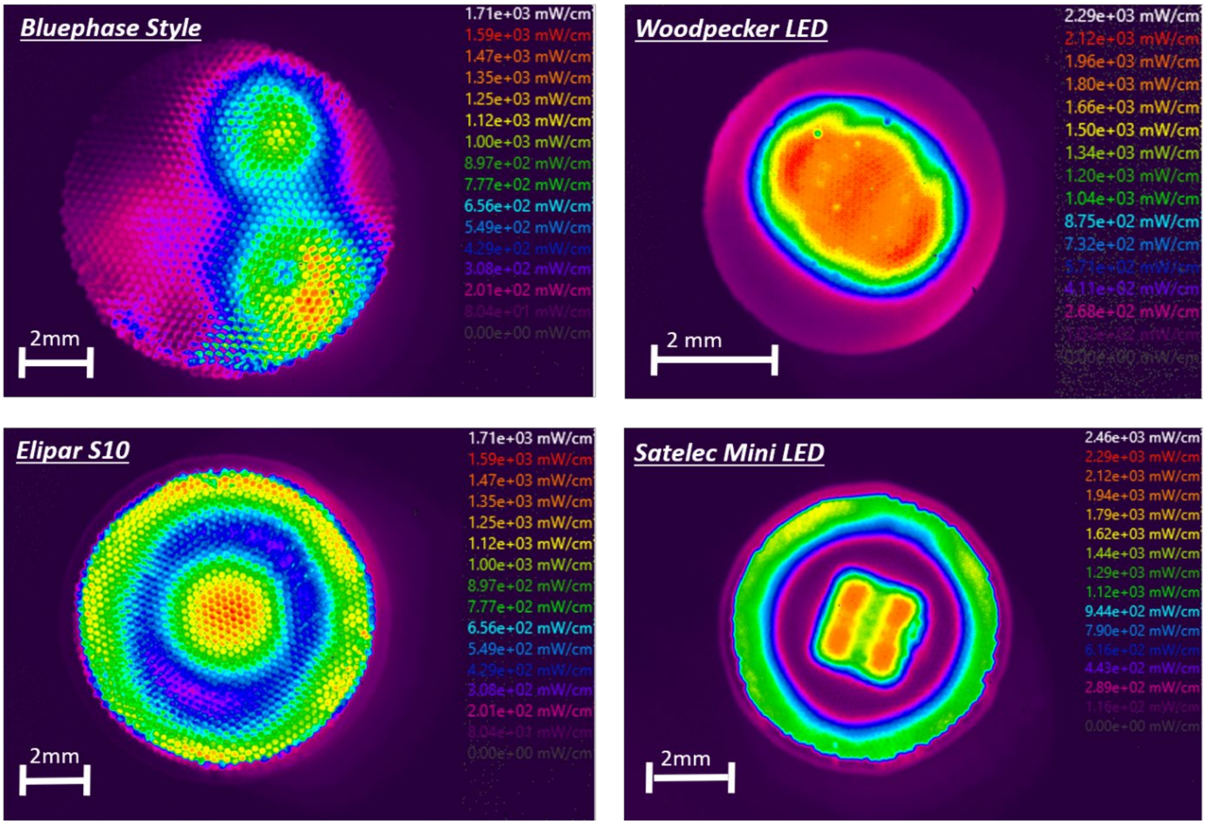

Figure 5: Beam profile images of four LED units showing the differences in the beam diameter and the beam heterogeneity across the tips.

Figure 6 shows examples of beam profile images comparing the effect of contamination and damage on the irradiance output.

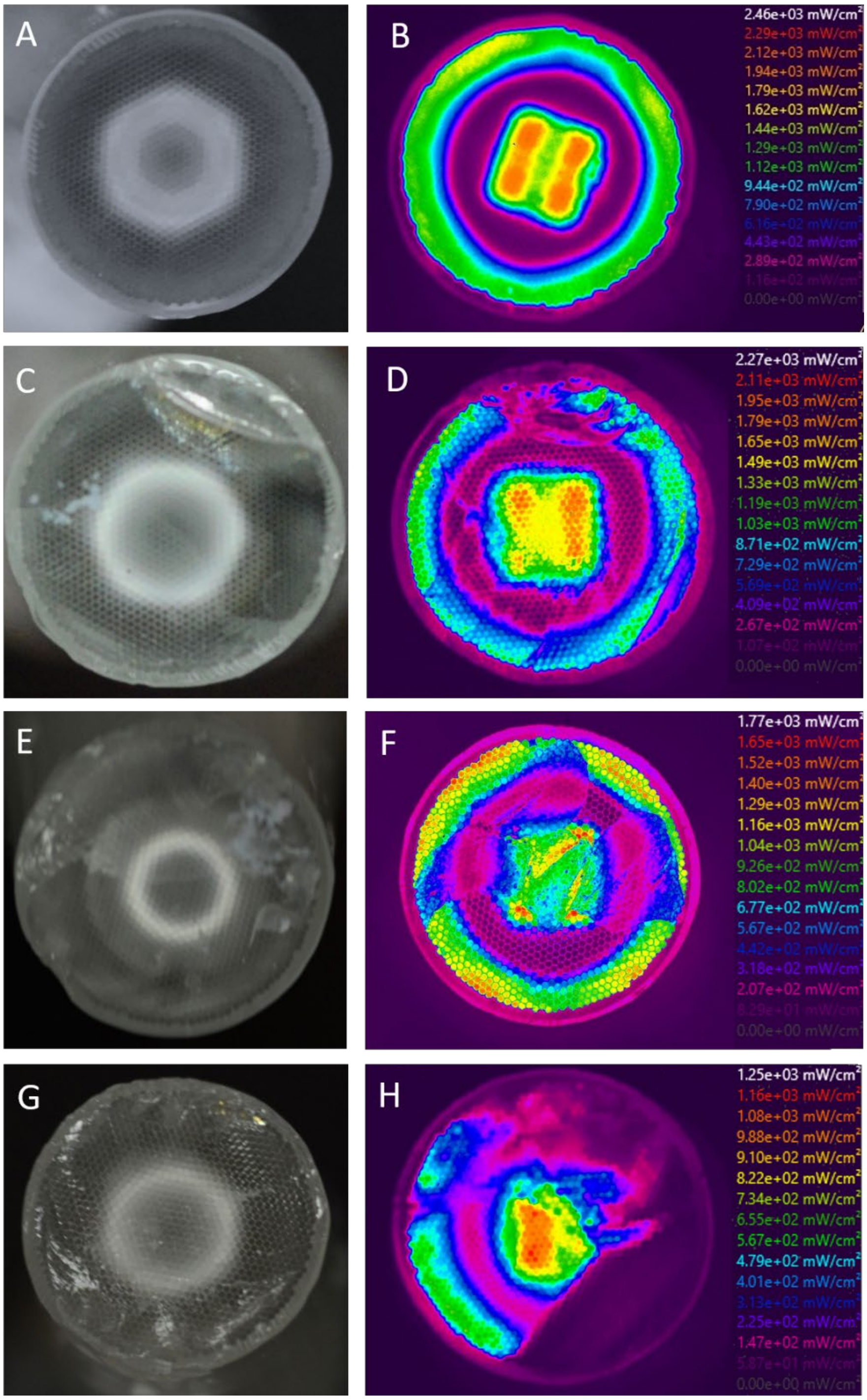

Figure 6: Examples Satelec mini LED (Acteon, Merignac, France) LCU fibre optic tips and their corresponding beam profile images. (A,B) representative control showing clean tip with unaffected beam profile distribution albeit with central hot spots of high irradiance output. (C,D) representative images of chipped light guide tips showing compromised beam profiles where irradiance has significantly decreased in areas of chipping and damage. (E,F) representative beam profile images of light guide tip with resin build up covering the surface

resulting in significantly reduced irradiance in areas of resin build up. (G,H) severely damaged light guide tip with large cold area in the corresponding beam profile image.

Discussion

The dental light curing unit (LCU) is an essential piece of equipment in every dental practice. However, proper use and maintenance of LCUs is not very well understood and often underappreciated amongst most operators. This study showed that 33% of the LED LCUs across primary and secondary dental settings were considered not to comply with the minimum recommended light irradiance required to optimally cure resin composites using a convenient exposure time (~40s). Most dental composite manufacturers recommend delivering a minimum of 500 mW/cm^2 for a duration of 40 seconds for optimum curing and many recommend shorter curing times if irradiance is higher, e.g. >1000 mW/cm^2 for 10 seconds. It has been previously reported that delivering 400mW/cm^2 for 60 seconds is required to adequately cure a 1.5 to 2 mm thickness resin composite [14,51]. Consequently, when the irradiance is multiplied by exposure time a sufficient radiant exposure of 16-24 J/cm^2 is often quoted.. It is possible to compensate for lower irradiance by prolonging the exposure time [15], however this not recommended by the manufacturers due to increased risks of overheating the pulp. The findings of this study are in agreement with other studies evaluating QTH and LED LCUs in dental practices which have shown that most curing lights are poorly maintained and deliver inadequate light irradiance for optimum curing process [32–37]. This study also found that there was a general lack of awareness of the type and the irradiance output of the LCUs which are already in use. Practitioners were also unaware that a large number of LCUs were unable to deliver a sufficient light output to adequately cure resin composite restorations. Despite their routine use most operators were simply using any LCU for 20 seconds without further knowledge on the wavelength and irradiance requirements. Additionally, there was a general lack of awareness of the impact of various clinical factors and the light guide factors on the efficiency and the performance of the LCUs.

This study investigated the effect of contamination of the light guide tip with debris, damage, increasing the distance and using protective sleeves on the irradiance output and the performance of LCUs. Data showed that all aforementioned factors have significant impact on the overall light output and the performance and should be taken into consideration when the LCU is used. Data showed that presence of debris build up and damage of the light curing tip resulted in reducing the irradiance output by 62% and 50% respectively.

The effect of increasing the distance from the restoration was also evaluated in this study. It might be assumed that this falls under the inverse square law however this does not always occur. The inverse law is applicable on a point source of radiation emitting 360° in space, whereas the emission from the light curing unit does not act as a point source. The light emitted from dental LCUs varies depending on the design and the optics within the unit. The findings of this study showed significantly lower irradiance values reached by the surface when the distance of the light source from that surface increases. The total irradiance output for Satelec mini LED (Acteon, Merignac, France) was reduced by 25% and 34% at 7 mm and 10 mm respectively. Previous studies also reported that some curing lights deliver only 25% or less of the irradiance measured at the tip when the distance is increased by 8 mm [12,45,50,52]. Therefore, operators should take into consideration the clinically relevant distances that may affect the irradiance output delivered to the restoration especially in a Class II cavity box where the distance between the cusp tip and the base of the box may exceed 7 mm [52]. Furthermore, it is important to ensure that the LCU is emitting sufficient light to compensate for the reduction over the distance and to consider increasing the exposure times for the initial increments.

The effect of barriers including use of protective sleeves was also evaluated. Data showed that the use of protective sleeve reduces the overall output by 24%. It was previously reported that when some commercial barriers are used, the light output can be reduced by up to 40% [44,53,54]. Therefore, it is important to emphasise that when a barrier is used, it should fit tightly over the light tip and not obstruct the light output (Figure 7) in order to minimise the refraction that occurs when light passes through different mediums and the impact on the light output. Additionally, it is recommended that the light output from the LCU should be recorded with the barrier over the tip when they are routinely used. Having a tightly fitted barrier not only will be a good infection control measure, it will also prevent debris build up on the LCU tip which also impact on the irradiance output. It was suggested that clear, plastic food wrap can be an inexpensive and effective infection control barrier with minimal effect on light output

[44,53].

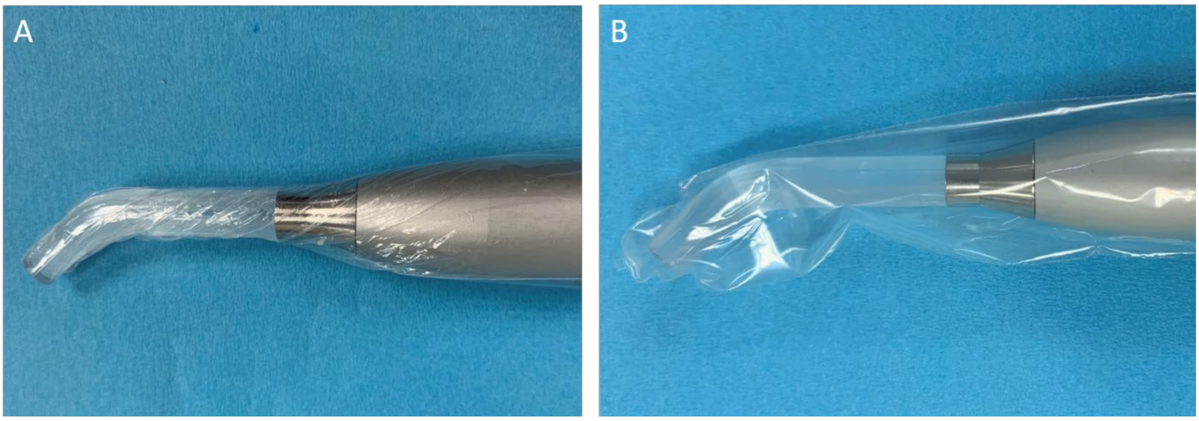

Figure 7: The light protective sleeve is (A) fitted tightly over the light tip whereas (B) shows less ideal fit which impede on the light output.

Several studies have shown that the light output from many LCUs is not uniform and the irradiance homogeneity depends on the design of the curing light and optical arrangement [55–58]. In this study, beam profiles were not uniform with “hot spots” of high irradiance and “cold spots” of lower irradiance values. Therefore, using a single irradiance value does not describe the irradiance across the entire light tip. Consequently, manufacturers should provide the beam profile of their LCUs. The clinical relevance of the beam profiles is highlighted by overlaying the irradiance beam images on a cavity preparation, Figure 8.

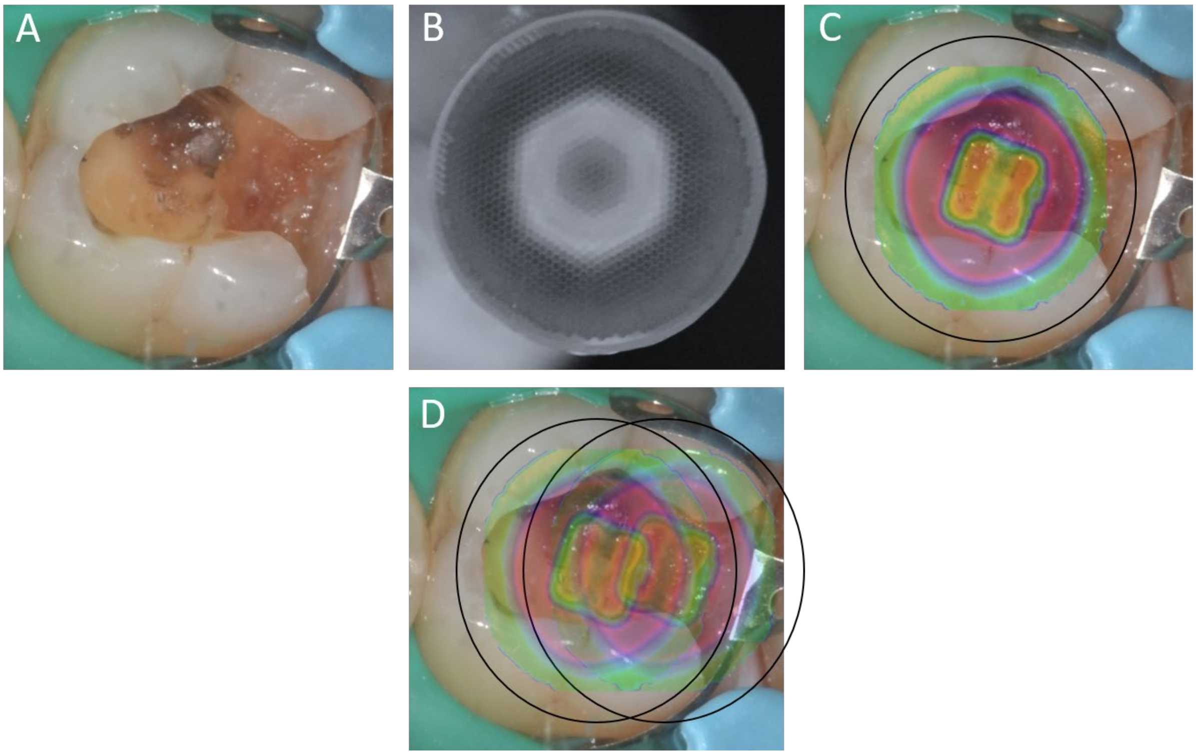

Figure 8: : (A-C) images showing molar tooth preparation, Satelec mini LED (Acteon, Merignac, France) light curing tip with 7 mm diameter and its corresponding beam profile image superimposed on the cavity preparation. This shows that the light beam does not cover the entire cavity and will require multiple exposures to cover the entire restoration as shown in (D).

This shows that some locations in the cavity may receive different amounts of light depending on effective light tip size and the homogeneity of the light output. It also shows that the size of the light curing tip may not necessarily reflect on the *actual* active tip emitting sufficient irradiance output. Consequently, the light received at the proximal boxes from some LCUs may be inadequate for optimal curing if used for one exposure cycle. Therefore, multiple exposure cycles maybe required especially if a small tip is used to cover the entire restoration, Figure 8.

The condition of the light curing tip can degrade overtime due to debris build up or simply damage that may occur with regular use and autoclave procedures [38]. Additionally, clinical barriers are often present such as matrix bands and tooth position which limit the access of the light curing tip to the intended restoration. It is also important to appreciate that these factors are usually combined such as distance of the light from the restoration and the use of protective sleeve which would act together resulting in a significant reduction in the overall light output. Consequently, composite restorations could be under-cured and prone to early failure due to decreased bond strength, bulk fractures and increased wear [9,10,12].

Regular monitoring and maintenance protocols for LCUs should be in place in every clinic. This should include regular evaluation of the irradiance output and careful evaluation of the light curing tips for debris build up and damage. Handheld dental radiometers are widely available and can be used to monitor the light output, even if only as a relative measurement of performance with continued use. However, several studies have reported their inaccuracy in measuring absolute irradiance [59–62]. The sensor area of most commercial dental radiometers is usually smaller than the LCU tip diameter which therefore provides inaccurate values. However a recently introduced dental radiometer, the BluePhase II from Ivoclar-Vivadent (Schaan, Liechtenstein), used in this study, was able to measure the irradiance of up to a 13 mm diameter tip due to its large sensor area. It was reported that the accuracy of Blue Phase II is comparable to laboratory grade spectrophotometer providing the most accurate data compared to other commercial dental radiometers [47].

It is also important to appreciate the role of education and training on the use of LCUs. It was reported that there is up to a tenfold difference in the ability of different operators to deliver adequate light exposure even when the same light source is used [63,64]. Operator variability can be minimised and improved techniques can be employed if users are trained on how to use the curing lights using a device such as the MARC patient simulator (Blue Light Analytics, Halifax,Canada). Training on this device allows operators to learn how to correctly position the light and the patient to improve access to the restoration for effective curing process. The MARC patient simulator has been shown to be effective in teaching appropriate light curing technique by providing direct feedback to the operator on how much irradiance is delivered and highlights operator factors that results in suboptimal curing process [65–68].

On the basis of this study, in order to help improve the use of LCU’s it is encouraged to follow the below recommendations:

- Have a protocol in place for regular monitoring and maintenance of LCUs to meet the manufacturers’ specifications.
- Inspect and clean the LCU before use to ensure that it is free of defects and debris.

- Use infection control barriers that fit tightly over the light tip without impeding the light output.
- Follow the light exposure times and increment thickness recommended by the resin composite material manufacturer.
- Position the light tip as close as possible (but without touching the uncured resin composite material to avoid debris) and parallel to the surface of the resin composite being cured.
- Stabilise and maintain the tip of the LCU over the resin composite throughout the exposure.
- Further light exposure cycles may be required when there is limited access, barriers present, curing larger restorations and when using protective.
- Ensure eye protection by using appropriate blue blocking filters.

Following the findings of this study, LCUs which were found to be of poor quality and have low irradiance output were immediately removed from the clinics and replaced. Furthermore, local protocols were put in place within both dental hospitals to regularly check and evaluate the LCUs in use. LCUs were then followed up to ensure sufficient output and are currently regularly monitored and audited. General Dental Practices were also made aware of the findings and further measures were taken to ensure that their lights are able deliver sufficient light output and were advised with a suitable maintenance and monitoring protocol.

Conclusions

This study showed that there is lack of protocols for regular monitoring and maintenance of LCUs used in primary and secondary care. Thirty-three percent of the LCUs delivered irradiance output less that 500mW/cm^2. The condition of the light curing tips was also poor with 16% contaminated with resin debris, 26% damaged and 10% both contaminated and damaged. Using damaged and contaminated light curing tips, protective sleeves and increasing the distance from the restoration significantly reduce the irradiance output and the performance of the LCU.

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