International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

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Assessment of radiant exitance of light-curing units used in Dental Clinics in Benghazi, Libya

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International Journal of Science and Research Archive, 2025, 15(02), 538-548

Publication history: Received on 21 March 2025; revised on 09 May 2025; accepted on 11 May 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.15.2.1395

Abstract

Aim: To evaluate the radiant exitance (RE) of light-curing units (LCUs) used in dental clinics and educational centers in Benghazi, Libya, and assess dentists' knowledge of LCU usage.

Materials and Methods: RE measurements of 180 LCUs from various dental clinics in Benghazi were obtained using a handheld dental radiometer. Data collected included: I) Device specifications (type [quartz-tungsten-halogen (QTH) or light-emitting diode (LED)], manufacturer, model, and version; II) Usage and maintenance history (clinical age, date of last use, and type of last maintenance of the LCU, III) Clinical practice parameters (exposure time per resin composite increment, tip size, presence of residual cured resin composite on the tips, and radiometer availability). Three measurements per LCU were taken, and the average was recorded as the RE value. The acceptable RE range was set between 300-1200 mW/cm^2. Data were analyzed using SPSS with descriptive statistics.

Results: LED LCUs were the most frequently used in the dental clinics (179, 99.4%), with only one QTH unit (0.6%). Woodpecker cordless models were the most common. Mean RE was 930.86 mW/cm^2 (SD: 633; range: 0–3125 mW/cm^2). Out of the 180 LCUs, 111 (61.7%) fell within the acceptable RE range, while 20 (11.1%) delivered insufficient RE (<300 mW/cm^2) and 49 (27.2%) exceeded the upper limit (>1200 mW/cm^2). Dentists exhibited limited knowledge of LCU functionality.

Conclusions: Within the study's limitations, the following conclusions were drawn: a) Great variations in RE performance among LCUs with clinically significant outliers, b) Majority were LED LCUs and operating within the acceptable RE range; c) The predominant LCU brand showed deficiencies in RE efficiency. Dentists' knowledge regarding LCU functionality maintenance was limited.

Keywords: Radiant exitance (RE); Light-curing unit (LCU); LED; QTH; Dental radiometer; Resin composite.

1. Introduction

Modern resin-based composites (RBCs) depend completely on the use of light curing units (LCUs) for photo-polymerization. Those LCUs are available in four types: quartz-tungsten-halogen (QTH), light-emitting diode (LED), plasma arc curing lamps (PACLs), and argon-ion laser lamps (ALLs) [1]. However, LED and QTH are the most commonly used LCUs by dental practitioners. The clinical efficiency of these LCUs plays an important role in attaining the most favorable photo-polymerization and outcomes of RBC restorations [2]. Furthermore, there is no doubt that the photo-polymerization of RBC is a critical step in the restorative process that gives the resin composite material the greatest physical and mechanical properties to perform its functions. However, it is always taken for granted by practitioners [3]. In addition, lack of proper photo-polymerization can lead to several unfavorable impacts on the clinical achievement

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of light-activated RBC such as; postoperative sensitivity [4], recurrent caries, excessive wear, bulk fracture [5,6], greater water absorption, and cytotoxicity of the resin [7].

Photo-polymerization of light-cured RBCs is influenced by several intrinsic and extrinsic factors. Intrinsic factors pertain to a material formulation including filler content, co-monomer ratio, and composition [2]. While extrinsic factors are related to irradiation parameters, light-curing unit characteristics, temperature, curing modes, and light-guide tip positioning [2]. Among extrinsic factors is the radiant exitance (RE) of curing light [2]. RE of curing light is defined as "the power emitted by the light source divided by the area of the light tip that emits light and expressed in units of mW/cm^2" [8]. The RE plays a critical role in photo-polymerization [2]. Together with the emission spectrum and irradiation time, RE determines the LCU's efficiency and significantly affects the physicochemical properties of RBCs [2].

Several factors compromise the quality of cured RBCs, with the light-curing unit (LCU) aging being a critical concern. As LCUs age, their radiant exitance (RE) progressively declines and that cannot be detected with the naked eye and is not always compensated by increasing irradiation time [9]. The use of LCUs with insufficient and degraded RE introduces significant risks, including Inadequate polymerization of the RBC, and reducing restoration longevity, as well as compromised integrity of adjacent dental tissues [1].

Another issue is the surface hardness of the RBC. Notably, surface hardness alone is an unreliable indicator of curing efficacy. While superficially hardened RBCs may suggest successful polymerization, insufficient RE can lead to the "soggy bottom phenomenon" [8]. A condition where the restoration's base remains uncured despite a rigid surface [8]. Consequently, clinicians using low-RE LCUs cannot visually assess subsurface curing completeness [9]. Therefore, the radiometer is needed to evaluate the radiant exitance of LCU to determine the need for LCU maintenance, repair, or replacement [10].

To our knowledge, there has been no research have been conducted regarding this issue in Benghazi dental clinics before, therefore it is of importance to investigate and assess the radiant exitance of LCUs used by dentists in the daily practice in various dental clinics. The study aimed to evaluate the radiant exitance (RE) of light-curing units (LCUs) used in dental clinics and educational centers in Benghazi, Libya, and assess dentists' knowledge of LCU usage.

2. Materials and Methods

2.1. Study design

This cross-sectional descriptive study was conducted to evaluate the radiant exitance of various light-curing units (LCUs) used by general practitioners and specialists across governmental and private dental clinics in Benghazi, Libya during the year 2022. Dental clinics were selected via cluster randomization ensuring proportional representation from all city regions (East, West, North, and South). The methodology was adapted from established methodological approaches in previous studies [11-13].

The ethical approval for this study was obtained from the Research Ethics Committee at the Faculty of Dentistry, University of Benghazi, Libya (approval No.: 016/2020), with additional approval obtained from the Libyan Authority for Scientific Research. Furthermore, permission to access these dental clinics was secured from the Libyan Ministry of Health in Benghazi. To ensure the confidentiality of participating individuals and the dental clinics, no personal identifiers were collected. Participants and dental clinics retained the right to withdraw from the study at any time without consequences. Verbal consent was obtained from the dental clinic director(s) after explaining the purpose and methodology. All individuals present during the measurements process were informed of potential blue light hazards and instructed to wear protective eyewear or avoid direct exposure to the curing light.

2.1.1. Study Population and Selection Criteria

The study included light-curing units (LCUs) from the following categories of dental clinics in Benghazi. Governmental and Private dental clinics. Dental clinics affiliated with private and governmental dental faculties and educational centres, willing to participate in the study. Dental clinics participated in the study must offer light-cured RBC restorations to the patients. All functional LCUs present in participating dental clinics were included in the study and evaluated. Dental clinics that refused to participate in the study, or that do not use LCUs in their clinics and Non-functional LCUs were excluded.

2.2. Light Curing Units Data Collection

A standardized data collection form was used to record detailed information about each LCU, including: I) Device specifications such as Type (LED/QTH), Manufacturer, Model, and version. II) Usage and maintenance history: such as Clinical age of the LCU, Date of last use, Date and type of last maintenance performed. III) Clinical practice parameters: included exposure time per resin composite increment, size of the light-curing tip, and availability of a radiometer in the clinic. The form was designed to collect information and systematically capture all relevant operational and maintenance characteristics of the LCUs while maintaining consistency in data collection across all study regions.

2.3. Radiant Exitance Measuring Procedure

Prior to radiant exitance (RE) measurements, all light-curing units (LCUs) included in the study underwent thorough visual and physical inspection. This examination assessed: the presence of cured RBC remnants on LCU tips, Cracks or fractures in the light-guide tips, and any disposable barriers (e.g., plastic cover sleeves) that could interfere with RE measurements, which were removed for more precise readings. Following the inspection, each LCU was wiped with a piece of cotton containing 96% medical alcohol (Star Magic, Turkey) to ensure disinfection, then photographed for documentation, and the composite remnant cleaned if any. For eye protection and safety, the principal investigator and all present personnel wore protective eyewear during measurements.

Following visual inspection and preparation, each LCU was switched on and operated for a brief warm-up period to ensure optimal power output [13]. Three consecutive radiant exitance (RE) measurements were then recorded for every LCU using a calibrated handheld dental radiometer (LM-1, Woodpecker, China). A single investigator practiced using the radiometer and performed all the measurements for standardization. The radiometer operation protocol was established through training at the Department of Conservative Dentistry and Endodontics, Faculty of Dentistry, University of Benghazi. The average of the three measurements was taken as a final RE value [13]. RE values were categorized into four ranges based on manufacturer specifications: <300 mW/cm^2, 300-799 mW/cm^2, 800-1200 mW/cm^2, and >1200 mW/cm^2. Radiant exitance of <300 mW/ cm^2 and >1200 mW/cm^2 is considered non-acceptable. While RE of 300-799 mW/cm^2 and 800-1200 mW/cm^2 is considered acceptable.

After completing RE measurements, the principal investigator delivered these outcomes to all participating clinics as part of knowledge translation and facilitate practice improvements: i) Verbal feedback to each practitioner regarding their LCU's radiant exitance (RE) values and performance. ii) Personalized recommendations for LCU repair or replacement based on physical inspection and RE measurements. iii) Written recommendations and guidelines on proper LCU use, maintenance protocols, and optimal light-curing techniques.

2.4. Statistical analysis

The Statistical Package for the Social Sciences (SPSS) version 21 was used to analyze the data. Descriptive statistics, including mean, standard deviation, minimum, and maximum values, were calculated to summarize the radiant exitance (RE) measurements obtained from the different light-curing units (LCUs).

3. Results

3.1. Results of the Light Curing Unit Data Collection

A total of 180 LCUs from 52 dental clinics were examined and evaluated. Data and information about the LCUs revealed the following findings:

I) Device specification: Results of the LCU type and prevalence revealed that the Light emitting diode (LED) LCUs were the most commonly used, accounting for 179 units (99.4 percent), and only one LCU (0.6 percent) was quartz tungsten halogen (QTH).

The most frequently used brand in the dental clinics in Benghazi was found to be the Woodpecker, though its units consistently exhibited insufficient RE. It was also found that Unknown brands had the highest number of LCUs with low (non-acceptable) RE values. Woodpecker LCUs had the highest number of LCUs exceeding the upper RE limit (non-acceptably high) RE. The majority of the LCUs with acceptable RE were from unknown brands. Table (1) presents the detailed brands and manufacturer data for the evaluated LCUs.

Table 1 Brands, manufacturers, and radiant exitance (RE) of evaluated light-curing units (LCUs)

Brand name	**Radiant exitance (mW/cm²)**				**Total**
	<300	300-799	800-1200	>1200	
3M ESPE	0	0	1	6	7
Acteon satelec	1	1	0	1	3
Appledental	0	2	1	0	3
COXO	1	2	3	1	7
DABI ATLANTE	0	1	0	0	1
Denjoy	0	2	0	0	2
Eighteeth	0	1	2	3	6
FANTA	0	0	0	1	1
Gladen	0	2	2	0	4
Gnatus	0	1	0	4	5
GREELOY	1	1	0	0	2
Ivoclar vivadent	0	2	0	0	2
JINWO PHANTOM	0	1	0	0	1
Kerr	0	0	1	0	1
Roson	2	10	0	0	12
Runyes	0	1	0	0	1
SDI	0	6	3	0	9
Shnajgian	1	0	0	0	1
Unbranded/Unknown origin	9	22	7	0	38
Verona	0	3	3	0	6
Woodpecker	4	11	9	25	49
Yearmoon	1	5	4	8	18
Zzlinker	0	1	0	0	1
Total	20	75	36	49	180

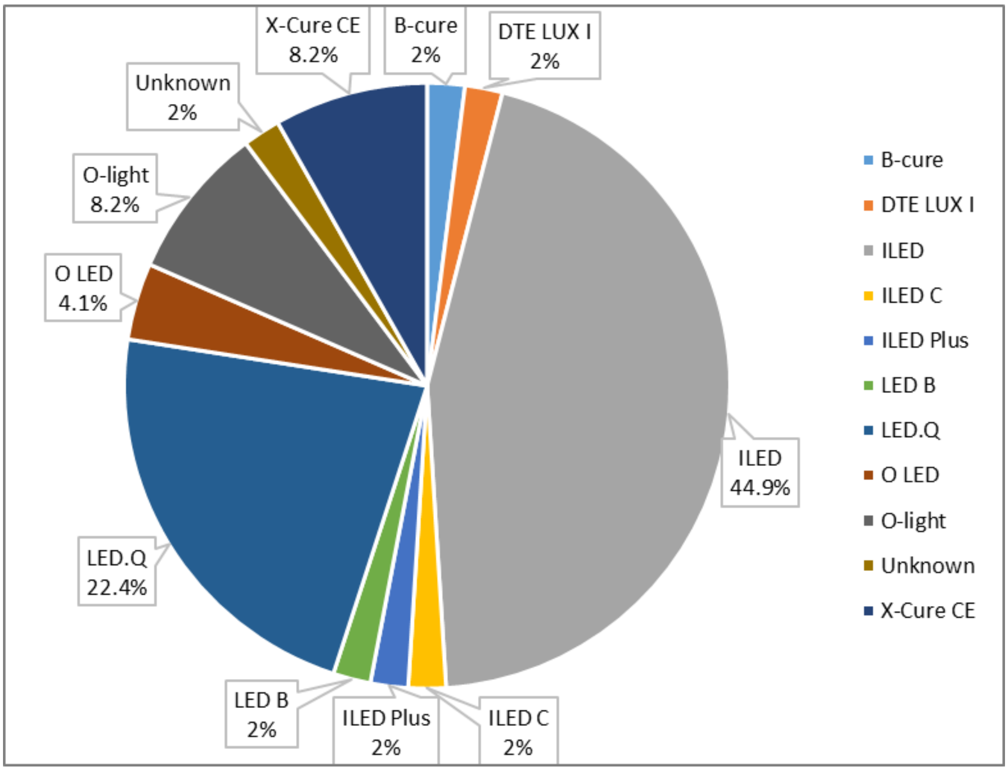

Figure 1 Models and percentage of Woodpecker LCUs**.**

The most commonly used Woodpecker LCU model was the ILED (44.9%). The least frequently used models were B-cure, DTE LUX I, ILED C, ILED Plus, LED B, and unbranded/unknown origin each accounting for 2% of the total. Figure 1 summarizes the distribution and percentage of woodpecker LCU models used by dentists in daily practice. The cordless (portable) LED LCUs were the most prevalent version, accounting for 137 units (76.5%), followed by built-in (dental chair-attached) LED LCUs with 40 units (22.3%). Corded LCUs were the least common configuration, representing only 2 units (1.1%).

II) Usage and maintenance history of LCUs revealed that: the recently maintained LCUs, within the last three months were 4 LCUs (2.22 %), while the LCUs maintained 3-9 months ago were 3 LCUs (1.67 %). New units requiring no maintenance were 4 LCUs (2.22 %). The LCUs with unknown or undocumented maintenance status accounted for 169 (93.89%). Type of LCUs maintenance included; light guide replacement of 2 LCUs (1.11 %), battery replacement of 1 LCU (0.55 %), and power switch repair of 4 LCUs (2.22 %). Regarding the usage frequency: Recent use (within days) accounted for 167 units (92.78 %), intermediate use (within weeks) 12 LCUs (6.67 %), and long-term unused (months), 1 LCU (0.55 %).

III) Clinical practice parameters: There were resin composite remnants on tips of 38 (21.11 %) LCUs. The tip size was not documented by users. The mean clinical age of LCUs was 116,286.85 seconds (± 149102.02 seconds), Ranging from 960 to 748,800 seconds. Regarding the radiometer availability in dental clinics; No clinics had external radiometers available. It has been found that built-in radiometers were observed in 4 LCUs (2.22%), and built-in radiometers in 9 (5%) LCUs' charging bases.

Regarding the Light Guide Condition: A total of 126 (70 %) LCUs with intact light guide, 8 (4.44 %) LCUs had a chipped light guide tip, 37 (20.56 %) LCUs had a fractured light guide tip at varying levels, 4 (2.22 %) LCUs with fractured external part of the light guide, 2 (1.11 %) LCU with missing light guide, and 3 (1.67 %) LCUs had a fractured plastic cover (Figures 2).

Figure 2 The Light Guide Conditions: I) Chipped light guide tip. II) & III) Fractured light guide tip at varying levels. IV) Fractured external part of the light guide. V) Missing light guide. VI) Fractured plastic cover

3.2. Results of Radiant Exitance Measurement

The mean radiant exitance (RE) of the 180 evaluated LCUs was 930.86 ±633 mW/cm^2. The RE values ranged from zero mW/cm^2 (recorded in Woodpecker, Acteon, and unknown brand LCUs) to 3125 mW/cm^2 (measured in Woodpecker O LED LCU). These findings highlight significant variability in LCU performance and RE values across dental clinics in Benghazi. A total of 20 out of 180 LCUs (11.1 %) delivered RE of less than 300 mW/cm^2, and 49 LCUs (27.2 %) delivered RE values higher than 1200 mW/cm^2. 75 LCUs (41.7%) delivered RE fell within 300-799 mW/cm^2, and 36 LCUs (20.0%) had RE of 800-1200 mW/cm^2. Table (2) summarizes the frequency distribution of LCUs across these RE categories.

Table 2 Frequency distribution and radiant exitance (RE) categories of evaluated light-curing units (LCUs)

RE (mW/cm^2)	Frequency	Percent (%)
<300	20	11.1
300-799	75	41.7
800-1200	36	20.0
>1200	49	27.2
Total	180	100.0

4. Discussion

In the current study; an assessment of the radiant exitance (RE) of 180 LCUs used by dentists in various dental clinics in Benghazi city was performed. The term "radiant exitance" (RE) was employed because it accurately describes the power emitted from an LCU tip [14]. Kirkpatrick [15] defined "radiant exitance" (also referred to as "radiant emittance" [16]; as the radiant power/flux emitted from a surface (e.g., a curing light). Alternatively, radiant exitance is equivalent to irradiance at zero distance, such as when the light tip or exit window is in direct contact with the resin composite surface. Evaluation of RE is important because it influences the mechanical and physical properties of RBCs. Although several tools are available to measure RE, most are impractical for regular use by dentists in clinical practice (e.g.

spectrophotometer, integrated sphere, …etc). In the current study, radiant exitance (RE) was measured using a calibrated hand-held dental radiometer, a device that was a widely adopted method due to its simplicity and practicality in daily practice.

Concerning the device specifications; The results found that the majority (99.4%) of the LCUs were LED LCUs and only one LCU (0.6%) was a quartz-tungsten-halogen (QTH) device. This predominance of LED LCUs can be attributed to their advantages over QTH units, including being powered by long-life batteries, lower heat generation, and durable diodes [17]. The LED units also showed minimal output degradation over their lifetime, do not need cooling, and consume less energy than QTH [18, 19]. Additionally, the spectral output of LED units aligns with the maximal absorption peak of camphorquinone (CQ) (450-490 nm), the most commonly utilized photo-initiator in RBCs [20]. In contrast, QTH LCUs have several disadvantages such as excessive heat production which is the major drawback, and low efficiency. Furthermore, the degeneration of filters, reflectors, and bulbs over time are common disadvantage of QTH. This can lead to reduced output and compromise the photo-polymerization efficacy [17].

Results also revealed that the most common LCU brand practically used in dental clinics was the Woodpecker (Woodpecker Medical Instrument, Guilin, China). This preference could be attributed to the brand's reasonable cost, availability in the local market, high RE, and short curing time (reducing chairside time) as claimed by the manufacturer. This finding was also reported by Omidi et al [12].

A notable finding was that the second most frequently used LCUs were unbranded or unknown origin. These unknown LCUs exhibited the lowest RE values. Likely because they were budget devices purchased from unauthorized distributors. Compared to established brands, these unbranded LCUs were significantly cheaper, which may explain their use by some practitioners. However, such devices are neither regulated nor tested for efficacy and safety. Using uncertified LCUs is ethically and clinically concerning, comparable to conducting an in-vivo study without obtaining patient consent. This practice may also reflect limited knowledge among some dentists regarding LCU standards and the principles of photo-polymerization.

Another key finding was that the most frequently used woodpecker model was the ILED unit. According to the manufacturer, this LCU can deliver a high constant intensity of up to 2300 mW/cm^2 with an extremely short curing time (1 second). This rapid curing capability may explain its popularity among practitioners seeking to minimize chairside time. However, such high radiant exitance (RE) delivered in such a short exposure time is clinically inadvisable. A very rapid curing can compromise the polymerization quality of resin-based composites (RBCs) due to insufficient time for proper monomer conversion. Furthermore, excessive RE levels may jeopardize pulp vitality and cause thermal damage to surrounding soft tissues. The study also revealed that cordless (portable) LED LCUs were the predominant version in clinical use. This preference likely arises from their practical advantages, including lightweight construction and enhanced portability [17].

Regarding the maintenance status, the majority of LCUs (93.89%) had undocumented maintenance histories, indicating a lack of awareness and poor knowledge among dental practitioners about the importance of regular LCU maintenance. Among the few units that did undergo maintenance (6.11%), power switch failure was the most common reason, accounting for 2.22% of cases. This finding aligns with Omidi et al. [12], who reported that power switch failures represented 3.3% of maintenance cases in their study. The study also documented LCUs with damaged components, including chipped or fractured light guide tips, plastic covers, and exit windows, highlighting negligence in device maintenance. Previous research has emphasized the critical importance of replacing filters, lamps, and fiber optic light guides to maintain optimal radiant exitance (RE). Miyazaki et al. [21] reported that replacing fiber optic light guides could increase light intensity by up to 46.2%, suggesting that failure to replace worn components may contribute to reduced RE in some LCUs.

The mean clinical age of the examined LCUs fell within the expected shelf life of LED LCUs. However the clinical age of the LCU can significantly affect its performance. Over time, the RE of the light is reduced as the device ages. This inverse relationship between RE and LCU age has been supported by previous studies, including those by Barghi et al. [22] and Omidi et al. [12].

Concerning the clinical parameters; the most common exposure time for each increment of RBCs among dentists was 20 seconds. This finding aligns with previous studies by Barghi et al [22] and Martin [23], who reported that many practitioners use a 20-second curing period for 2 mm-thick composite resin increments. However, this exposure time may be insufficient in certain clinical conditions, such as increased LCU tip-to-composite distance, greater increment thickness, or reduced radiant exitance, potentially compromising the depth of cure [24]. Current recommendations advise using an LCU with a radiant exitance (RE) exceeding 400 mW/cm^2, a 2 mm composite increment, and an exposure time of 40–60 seconds [25,26]. In contrast, manufacturers typically recommend 20–40 seconds, with longer times for darker shades [27].

A common principle proposed by several researchers was that the curing time must be doubled when the light intensity supplied by the manufacturer is reduced to half. This is allowed only when the irradiance levels fall within the marginal range (400–850 mW/cm^2) [25]. These LCUs' RE might be considered acceptable, merely after extra curing time is utilized [27]. However, Lindberg et al [24] suggest that 20 seconds may suffice for a 2 mm increment, while 40 seconds could extend the curing depth to 3.5 mm. Although absolute cure depths vary by material, correlations between exposure time, LCU performance, and light-guide distance are generally consistent across studies [24].

The data revealed that dentists in the investigated clinics had limited awareness of LCU tip size; an issue that should not be overlooked. Clinically, it is crucial to recognize that LCUs with small curing tips require overlapping exposures to ensure complete coverage of the restoration surface, particularly in mesial-occlusal-distal (MOD) restorations [28]. Conversely, LCUs with larger tip diameters can efficiently cover the surface without overlapping exposures, reducing chairside time [28]. Additionally, larger tip diameters generally provide greater radiant exitance (RE), further enhancing curing efficiency [11]. A further observation was the presence of cured RBC remnants on LCU tips, which can directly reduce RE. Madhusudhana et al [27] reported a significant decline in RE due to composite resin buildup on curing tips. These remnants partially block light output, leading to diminished curing performance.

The radiometer deficiency in the surveyed clinics may be attributed to a lack of awareness about LCU maintenance protocols and the importance of regularly monitoring radiant exposure (RE). In addition, while some LCUs have built-in radiometers either in the charger base or the device itself, none of the practitioners recognized this feature. A likely reason is that dentists often overlook the instruction manuals of LCU devices. The current study revealed a significant knowledge gap among dentists practicing in the investigated clinics regarding the components, properties, usage, maintenance, and safety protocols of LCUs. This deficiency may adversely affect the clinical performance of composite resin restorations.

4.1. Radiant Exitance Categorization and Performance

The mean radiant exitance (RE) of the evaluated LCUs was 930.86 mW/cm^2, which falls within the acceptable range (300–1200 mW/cm^2). However, substantial variability was observed (SD: 633 mW/cm^2; range: 0–3125 mW/cm^2). These findings align with Alquria et al [13], who reported a mean RE of 826.4 mW/cm^2 for tested LCUs. In contrast, earlier studies documented significantly lower mean RE values (255.8–526 mW/cm^2) [9,11,29, 30,31]. This discrepancy likely results from the predominant use of quartz-tungsten-halogen (QTH) LCUs in those studies, which typically exhibit lower RE values compared to modern LED-based LCUs. The latter is the focus of the current investigation. The high standard deviation in our data may reflect variability in; Device factors such as manufacturer, brand, model, generation, and quality. Clinical factors such as age, usage patterns, maintenance status, and tip condition (e.g., damaged tips reduced RE by up to 30%).

In the current study, the RE values were divided into four categories; < 300 mW/cm^2, 300-799 mW/cm^2, 800-1200 mW/cm^2, and >1200 mW/cm^2. The minimal acceptable RE value (300 mW/cm^2) aligns with established literature [12, 13] and complies with ANSI/ADA Specifications No. 48-1 (2004) and No. 48-2 (2010), which mandate ≥300 mW/cm^2 in the 400-515 nm wavelength range for effective resin polymerization [32]. The maximum acceptable RE value (1200 mW/cm$^{2)}$ was in agreement with Nassar et al [33]. RE of >1200 mW/cm^2 was considered unacceptable due to the risk of thermal injury to the pulp and adjacent soft tissues particularly with a thin residual dentin bridge and compromised polymerization efficacy even with reduced exposure times [34].

Rationale for Radiant Exitance Categorization: In the current study, RE categorization was based on ANSI/ADA standards while incorporating the manufacturer's recommendations for the radiometer used. This approach is further supported by evidence regarding thermal risks associated with LCUs [34]. In contrast, most previous studies categorized RE values solely based on empirical results without established upper limits: Maghaireh et al [11] used three arbitrary categories: <300 mW/cm^2, 300-400 mW/cm^2, and >400 mW/cm^2. and Hao et al [9] employed a binary classification: <300 mW/cm^2 and ≥300 mW/cm^2.

Radiant Exitance Performance; Results revealed that over one-third of LCUs (38.3%) produced non-acceptable RE values (either below or above the recommended range). The results revealed that the RE of 11.1 % of the LCUs fell below the minimum threshold value (RE <300 mW/cm^2) which was considered inadequate performance. This aligns with the findings by El-Mowafy et al [31] and Barghi et al [22], who found 12.1%, and 10.4% of LCUs (respectively) were less than acceptable RE value. Higher prevalence was reported by Maghaireh et al [11] (46.1%), Hao et al [9] (6%), and

Martin [23] (27%). This could be attributed to: studies reporting higher percentages predominantly evaluated QTH LCUs, which experience significant output degradation over time compared to more stable LED units.

On the other hand, the current study revealed that 27.2% of LCUs were higher than the maximum acceptable value (RE >1200 mW/cm²), which was considered excessive output. This finding is contrary to Nassar et al [33] who reported only 9.4% above this limit (1200 mW/cm²). This might be attributed to the prevalence of budget LCUs employing small tip diameters to compensate for inherently low RE, inadvertently creating localized high-intensity zones."

4.2. Clinical and operational implications

Dentists need education and training on LCU maintenance (e.g., tip cleaning, annual radiometer checks), and optimal curing protocols (e.g., longer exposure for thicker increments). Avoid the use of unregulated, low-quality LCUs through policy enforcement and monitoring. Periodic checks using radiometers to measure and record LCU output, ensuring consistent and effective device performance. Further research to investigate the long-term effects of high-RE LCUs on pulp vitality.

5. Conclusions

Within the limitation of this study, the following conclusions were drawn:

- Significant RE variability existed among LCUs with some clinically concerning outliers.
- LCUs used in the governmental and private dental clinics, faculties, and teaching centers, in Benghazi city were of great variations.
- The majority of the LCUs were LED based units operating within the acceptable RE range.
- The predominant LED units were the cordless Woodpecker brand.
- Dentists exhibited limited knowledge about LCU Functionality.
- Unregulated devices and poor maintenance practices compromise the quality of RBC restoration and adversely affect the pulpal and soft tissues.
- Prioritizing education, maintenance protocols, and policy enforcement would enhance restorative dentistry standards.

Compliance with ethical standards

Acknowledgments

The authors gratefully acknowledge all participating dentists from dental clinics in Benghazi, Libya, for their cooperation and invaluable contributions to this study. We also extend our sincere appreciation to the Libyan Authority for Scientific Research and the Ministry of Health in Benghazi for granting access to the dental clinics and facilitating this research.

Disclosure of conflict of interest

The authors (Hana I Blgasem and Naeima M Betamar) reported no conflicts of interest regarding the publication of this paper.

Statement of ethical approval

Ethical approval for this study was obtained from the Research Ethics Committee of the Faculty of Dentistry, University of Benghazi (Approval No.: 016/2020), the Libyan Authority for Scientific Research, and the Ministry of Health in Benghazi, Libya.

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