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ORIGINAL RESEARCH

Evaluation of Radiant Power of the Light Curing Units Used in Clinics at Governmental and Privates Dental Faculties

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Background: To evaluate the radiant power of the light cure units (LCUs) in relation to their type, radiant exitance, number of years in clinical use, and condition of LCUs tips in governmental and public clinics in Dental Faculties in Sana'a City.

Materials and Methods: LCUs were collected from different colleges at Sanaa City, Yemen, then LCU data as type, clinical age (<1 year, between 1–5 and > 5-years), tip condition was visually inspected for damage and adhering debris, and the radiant exitance values of the tested LCUs. Radiant exitance values were subcategorized into three groups: <400, 400–850, and >850 mW/cm², labeled as inadequate, marginal, and adequate radiant exitances, respectively. A Woodpecker radiometer was used with a mode lasting of 20 seconds was used with each LCU. Descriptive statistics of the different parameters were evaluated with SPSS version 25. One-way ANOVA and Mann–Whitney tests were performed to determine the mean difference between the groups with a significance value of < 0.05 was considered.

Results: Two hundred twenty-three LCUs were surveyed, and the majority were Light–emitting diode (LED). Forty-nine (21.9%), 117 (52.4%), 57 (25.6%) recorded lesser than, 400–850, and more than 850 mW/cm², respectively. Radiant exitances of < year-old units were found to be higher than those of units used for > 5 years with significant differences (p=0.001). The ANOVA test showed significant differences between the radiant exitance with clinical age and LCU tip conditions and a strong correlation p > 0.050.

Conclusion: LED curing lights were the most used in the tested Dental Faculties. More than half of the used LCU offered sufficient radiant exitance. Clinical age, the presence or absence of composite buildups, and damage to curing tips showed significantly affect radiant exitance values.

Keywords: dental light cure, radiant exitance, contaminated tip, radiometer

Background

Historically, 1970s was the first time that dental light-activated resin-based composites were introduced in restorative dentistry. More efforts have been made in order to improve the properties and clinical performance of resin restoration.[1] Then dental curing units (CUs) and light-activated resin have been improved.[2] CU produces radiant exitance yielded over the output area of the curing tip with its units in milliwatts per square centimeter (mW/cm²).[3,4] The majority of CUs have a light source and a relatively short, rigid light guide made of fused optical fibers.[5]

In dentistry, light sources are available in four types of dental curing lights: quartz-tungsten-halogen (QTH), plasma-arc (PAC), argon-ion laser (AIL), and light-emitting diode (LED). Currently, LED units have replaced QTHs and have become the most popular CUs in dentistry.[3,6] They were first used in the 1990s.[7] The newest LEDs have a radiant exitance between 1000

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and 2400 mW/cm².[6] There are forms of continuous curing modes, and most commonly used of which is uniform continuous curing with light of moderate radiant exitance that is applied for a period of time.[5,6,8]

LCUs may transfer adequate radiant exitance when new, but the radiant exitance will decrease over time of usage.[3] QTH lamps have a limited effective lifetime (100 hours); the longer they are used, the more degradation is caused by high temperatures in the light bulb, reflector, and filter, resulting in a lower radiant exitance and effectiveness in curing.[9] While LEDs have the potential to last for thousands of hours, they can be damaged rapidly if subjected to a high-current density in an attempt to deliver a high radiant exitance. This can cause overheating of the LED chip and yellowing of the epoxy around the LED, resulting in a reduced radiant exitance.[6]

Obviously, LCU is used to activate polymerization of composite resin, sufficient curing depends on several factors related to LCU, such as the light intensity, duration of exposure time, wavelength, condition of the light guide, location, and orientation of the unit tip.[4,10,11]

The ISO 4049 standard requires a light intensity of 300 mW/cm² and a wavelength bandwidth of 400–500 nm, with a minimum cure depth of 1.5 mm.[12,13] In this context, Almeida et al, reported that a light intensity of 400 mW/cm² is the minimum, and it must be delivered for effective polymerization of most resin-based composites for a maximal increment thickness of 2 mm when suitable curing times are used.[14] Thus, it is important to select the proper CU since improper curing of the materials will result in material clinical failures such as sensitivity, de-bonding problems, secondary caries, and restoration failure.[4,10,15] On the contrary, high light intensity could also induce soft tissue and pulp damage, especially in deep cavities.[4]

Dental radiometers are devices used to measure the radiant exitance at its tip in milliwatts per centimeter squared (mW/cm2), which is discharged by LCUs that convert light into electric current, which is quantified by a digital screen.[16,17] It is composed of a case with an entrance port, diffusers, filters, a detector, and a display to read values.[16] These are lightweight, handheld, and simplified chair-side versions of sophisticated laboratory equipment used to measure the radiant exitance of curing lights. Also, they have ensuring that your cure intensity is accurate every time.[17,18]

Sufficient polymerization is required for the restorative material to declare excellent mechanical, physical, and clinical properties to ensure the long-term success of restoration initiatives.[7,19] A group of studies were conducted worldwide using different types of radiometers to check the radiant exitance of the used LCU either in dental colleges or private clinics. The majority of results documented that the LCUs used in their studies recorded an acceptable, adequate, and as being within the required range.[18,20–26] Other studies concluded an inverse relationship between the clinical age of LCUs,[12,18,27] the presence of uncleaned with remaining adhesive and resin materials stick on the LCU tip and the radiant exitance of LCUs.[22,28]

No previous study was conducted in different dental colleges in Sanaa city. Thus, this study aimed to evaluate the LCUs in relation to the type, radiant exitance, the number of years in clinical use, and condition of the LCUs tips in governmental and private clinics in Dental Faculties in Sana'a City.

Methodology

Study Design and Colleges Selection

This descriptive cross-sectional study was carried out at 10 of Sana'a's governmental and private Dental Colleges. The selection of those colleges depended on the presence of students at clinical phase and students at the higher levels within their colleges. A non-probability design was used to collect samples for this study.

Inclusion and Exclusion Criteria

The present study included all LCUs used in dental clinics at the selected governmental and private Dental Colleges in Sana'a City, irrespective of the LCU type. LCUs that were not effective in composite resin polymerization, non-functional units, and other units that were under maintenance or repair were excluded from this study.

Measurements of Radiant Power

The included parameters were assessed and evaluated as follows;

The type of the LCUs were classified as LED or QTH. The collected and selected LCUs devices that are routinely used during daily practice in the selected colleges and used by general practitioners, dental students, and interns in the selected colleges were evaluated.

The clinical age of the LCUs were collected from laboratories and clinical head nurses and categorized into three groups (< one year, between one and Five, and > five years).

The clinical condition of the LCU tip devices were visually inspected for damage and/or resin, adhesive contaminants and recorded as "Yes or present" or "No or not presented" (Figure 1). This was done under magnification X 10 using a magnification lens.

To calculate the radiant exitance, the tip of the device is held in a perpendicular position with intimate contact with the LCU. First activation of LCU or turned on the device by pressing the power button, the cure mode and time were selected and adjusted using the mode and control buttons to make the LCU ready for usage. The curing mode is then obtained from lists of the several curing programs, which was a standard continuous setting with maximum light output. After that, the time button was pressed to adjust the curing time; 20 seconds was specified to capture the full intensity, and the intensity was read out on a digital display and recorded in mW/cm².

The radiometer was powered on by inserting and adapting its batteries, then turned on by pressing the power button on the side radiometer to start the measurement on a flat surface. Then, by positioning the tip of the unit at a 0 mm distance on the detector window's center while taking care to keep the tip in contact with the device at the center at 90 angles.

For radiant exitance measurements, each measurement of each LCU device was recorded three times as the 1st, 2nd, 3rd reading, then the averages were taken as done in many earlier studies.[18,20–24,28] They divided into three groups and graded as (insufficient intensity that cannot be compensated even by increasing the light time), (marginal intensity at which additional curing was needed), and (sufficient intensity where further curing time would not be necessary) and represented as <400 mW/cm², between 400 and 850 mW/cm², and >850 mW/cm².

Adjusting the Radiometer Device

In this study, a digital radiometer device, Woodpecker Curing Light Power Meter (LM-1) (Woodpecker, China) was used to measure the radiant exitance from each LCU. This device is calibrated according to manufacturers, ensuring that it delivers high-precision measurements. It is characterized by its small size, handheld design, and ease of use, which allows it to be handled easily between clinics. Also, it has a detector window that records radiant exitance and is compatible with most light guides and lens caps of various sizes. Unlike other radiometers that require manual calibration, this model always automatically adjusts to all LCU types and lens diameters. This resulted in elimination of the possibility of user errors and ensuring maximum accuracy. Its digital display shows the intensity in milliwatts per

Figure 1 Digital Radiometer Device with tip condition statues.

square centimeter (mW/cm²), giving instant readings, with a visible number for easy reading. It was calibrated to detect the radiant exitance within a range of 0 to 3500 mW/cm². Also, it can detect a wide wavelength range of 400–3500 nm with ± 10% range is acceptable for their products, making it a useful device for various LCUs. Moreover, it is fully compatible with LED and QTH CUs, ensuring one-piece integration with your existing LCUs.

The manufacturer instructions were strictly followed as functions of a power switch, mode selection button, time adjustment button, switching on and off of the device, cleaning and disinfecting the unit, safety instruction in relation to dental staff and operator. To ensure that the radiometer provides accurate and reliable measurements, two curing lights with known intensities were used to estimate the radiometer's accuracy. Also, the radiometer was consistently checked against these light sources periodically and charged with new battery after every 5 measurements of LCUs. All the data was collected by a single researcher (S.A.A) in order to eliminate errors that might be caused by personal differences.

Data Analyzing

Following the evaluation of the curing unit, other information regarding the LCU as type, age, condition of the tip, and method to check the intensity of CUs, was also recorded, and entered on an Excel sheet data form. The data were evaluated with the assistance of SPSS version 25. Descriptive statistics as means and standard deviations with a significance threshold of 0.05, was used for statistical analysis. The influence of one significant factor, namely the age of the unit, on the radiant exitance was examined using a one-way ANOVA test, and Tukey's HSD test to determine the mean difference between the groups. The relationship between the clinical age and the level of output intensity of each curing unit was examined using the Pearson correlation coefficient. Radiant exitance values of LCUs with and without residue fractures were compared by year using Mann–Whitney *U*-test.

Results

Only 223 LCUs were evaluated in governmental and private clinics of the dental faculties in Sana'a city. Out of them LCUs 220 (98.7%) were LED type. LCU in relation to clinical age usage ranged from 3 months to 9 years. The clinical ages of the tested LCUs were 71 (31.8%), 131 (58.7), and 21 (9.4) for < than one year, between 1 and 5 years, and >5 years, respectively. The majority of LCUs do not have adhesion of composite resin as 148 (66.4%), while 75 (33.6) of the LCUs have residue fractures (Figure 2).

LCUs' with inadequate radiant exitance were 47 (21.1%) and 2 (0.9%) for LED and QTH units, whereas for marginal radiant exitance were 116 (52.0%) and one (0.4%) for LED and QTH units, while for LCUs that measured adequate

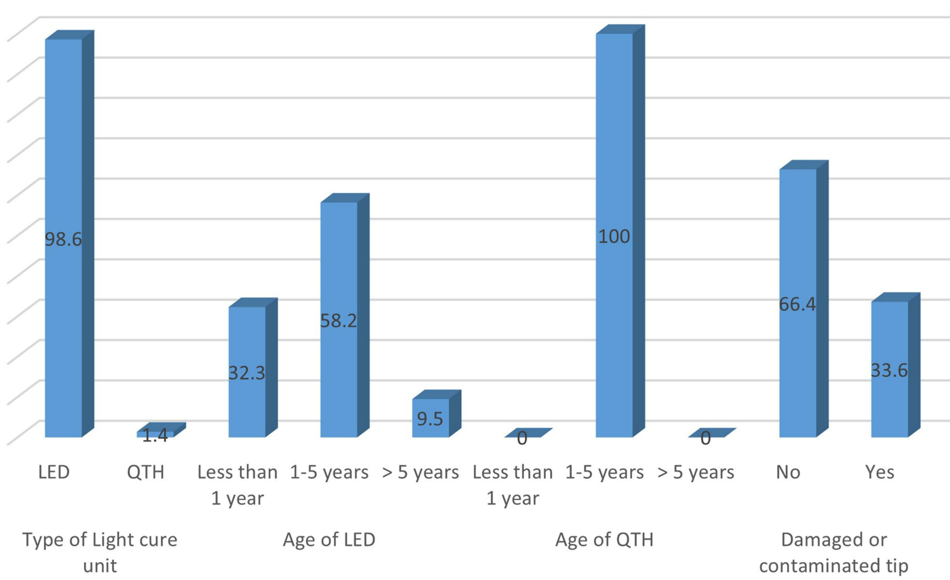

Figure 2 Characteristics of LCUs assessed in relation to type, clinical age, and tip condition.

radiant exitance were 57 (25.6%) for LED units. LCUs with a clinical age between 1 and 5 years were 100 (44.8%) and recording a radiant exitance between 400 and 850 mW/cm², while LCUs with lesser than 12-month age were 57 (25.6%) recording a radiant exitance above 850 mW/cm². The relationship between LCUs and radiant exitance, 47 (21.1%) residue fracture at the tip of the LCUs having inadequate radiant exitance and 101 (45.3%) residue fracture LCUs having marginal intensity between (400 and 850 mW/cm²). For conditioned LCU tips, there are 57 (25.6%) LCUs with adequate intensity, 16 (7.3%) LCUs with marginal intensity Figure 3.

One-Way ANOVA test was used to determine the mean difference between the groups. Table 1 results reveal that there are statistically significant differences in the LCUs' radiant exitance with age with $p = 0.001$. Furthermore, the Tukey's test show that there are differences in LCU radiant exitance between the groups of individuals aged < one year, one to five years, and five years and older (mean difference = 594.28 and 816.91, with $p = 0.001$, and 0.001). Additionally, there are differences in the radiant exitance of LCUs in the 1–5 year and > 5-year groups, with the 1–5-year LCUs being more intense than > 5-year LCUs (mean difference = 222.63, $p = 0.001$) Table 2.

The Pearson correlation test documented a statistically significant correlation relationship between the radiant exitance of LCUs and their age (= - 0.800, $p = 0.001$), the LCUs' radiant exitance is negatively, significantly, and strongly correlated with their clinical age. The Mann–Whitney U reveals that the new LCUs (<1 year) have differences in intensity ($p = 0.001$) based on their condition, and the well-conditioned LCUs (mean = 1165) have more intensity than the residue-fractured ones (mean = 792.5) Table 3. The same situation is observed for 1–5-year LCUs ($p = 0.001$), and the well-conditioned LCUs (mean = 719.4) have more radiant exitance than the residue-fractured ones (mean = 497.6). However, for old, aged LCUs (over 5 years), there are no differences in the intensity of LCUs ($p = 0.511$), and both good condition and residue fracture LCUs have the same radiant exitance (means of 275 and 297.6, respectively; inadequate radiant exitance less than 400 mW/cm²).

The Mann–Whitney *U*-test reveals that the new LCUs (<1 year) have significant differences in the radiant exitance ($p = 0.001$) based on their condition, and the well-conditioned LCUs (mean = 1165) have more radiant exitance than the residue-fractured ones (mean = 792.5). For 1–5-year LCUs ($p = 0.001$), and the well-conditioned LCUs (mean = 719.4) have more radiant exitance than the residue-fractured ones (mean = 497.6). However, for LCUs over 5 years, there are significant differences in the radiant

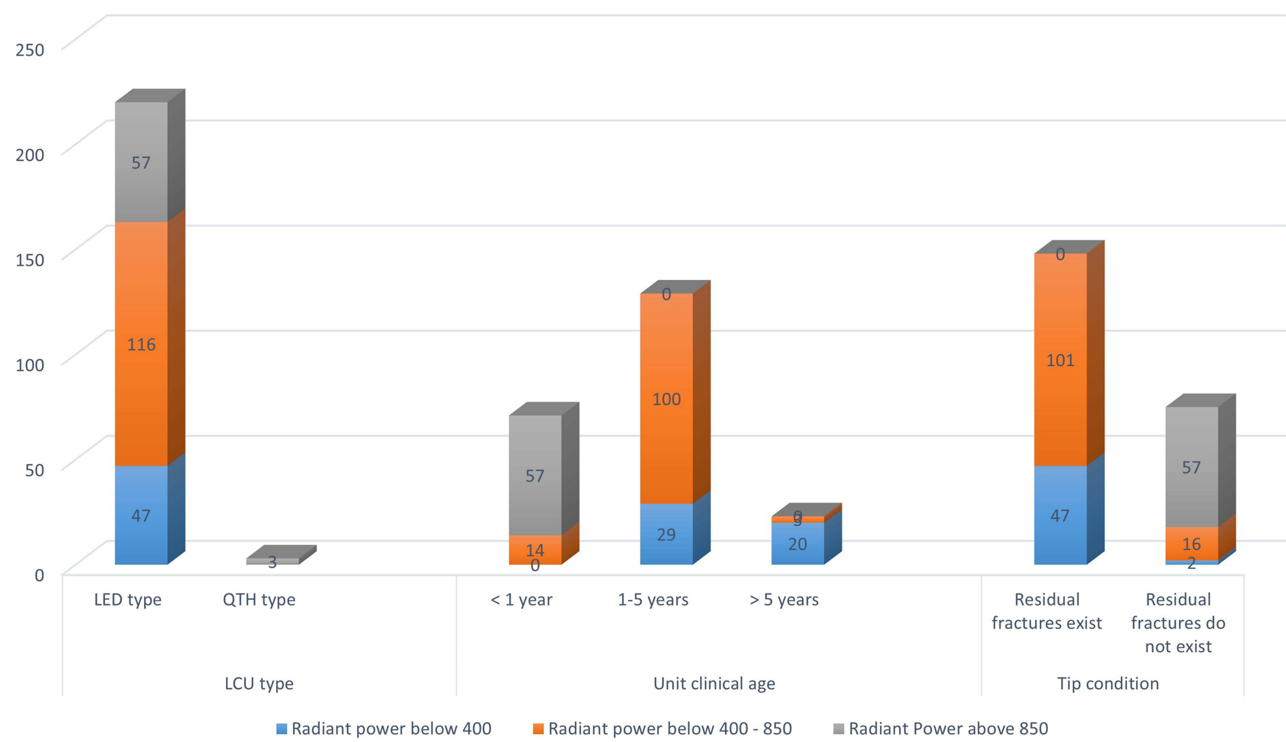

Figure 3 LCUs Distribution in relation to type and Intensity, clinical age, and tip condition.

Table 1 One Way ANOVA of LCUs Intensity mW/cm2 for the Number of Years in Used

	Sum of Squares	Df	Mean Square	F	Sig
Between Groups	20,051,372.7	2	10,025,686.4		0.000*
Within Groups	6,068,169.5	220	27,582.589	363.479	
Total	26,119,542.2	222			

Note: *Significant at the p 0.05.

Table 2 Comparison of Light Intensity Values mW/cm2 by Years (Tukey HSD Test)

Dependent Variable	Radiant exitance			
The number of years in used	Age	Mean Difference	Std. Error	Sig.
< 1 Year	1–5 Years > 5 Years	594.28* 816.91*	24.5 39.8	0.000* 0.000*
1–5 Years	> 5 Years	222.63*	37.6	0.000*

Note: *Significant at the p 0.05.

Table 3 Correlations, the Number of Years in Used and Radiant Power of LCUs

Parameter		Correlations	
		Age	**Radiant exitance**
Age	Pearson Correlation Sig. (2-tailed) N	1 223	−0.800**
Radiant power	Pearson Correlation Sig. (2-tailed) N	−0.800** 0.000 223	1 223

Note: **Correlation is significant at the 0.01 level (2-tailed).

Table 4 Radiant Exitance of CUs with Damaged or Contaminated Tips Were Compared with Undamaged, Non-Contaminated Tips by Years (Mann Whitney *U*-Test)

Age of LCU		Status of the tip	N	Mean	Standard Deviation	P - value
< 1 Year	Radiant exitance	Damaged/contaminated exist	10	792.5	37.6	0.000*
		Residues fractures do not exist	61	1165.0	206.3	
1–5 Years	Radiant exitance	Damaged/contaminated exist	117	497.6	115.6	0.000*
		Residues fractures do not exist	12	719.4	29.2	
> 5 Years	Radiant exitance	Damaged/contaminated exist	21	297.6	103.0	0.000*
		Residues fractures do not exist	2	275.0	35.4	

Note: *Significant at the p 0.05.

exitance of LCUs (p = 0.001), and without damaged or contaminated LCUs have more radiant exitance than the damaged or contaminated ones (means of 297.6, insufficient radiant exitance less than 400 mW/cm²) Table 4.

Discussion

The radiant exitance produced by a light curing unit is an important factor in dental treatment, and its monitoring must be done regularly in order to avoid insufficient curing and its effects on dental treatment.[21] Furthermore, the regular and frequent use of LCUs in most dental practices causes damage and resin contamination, which results in a lower power output; therefore, evaluating the state of the light guide is crucial to maximizing light curing.[29] Thus, this study assessed and measured the radiant exitance in relation to the LCU type, age, and condition of light tips at 10 of Sana'a's governmental and private dental colleges.

The results of the present study showed that LED LCUs are the main curing systems (98.7%) used in the tested faculties. Similar findings were recorded by Rabi and Arandi., Ashfaq et al.[28,30] But in contrast with a result study conducted in China by Hao et al, which may be due to the date of the conducted the survey.[31] Most worldwide dental clinics have shifted toward LED curing lights, because it does not generate heat during polymerization or transfer it to teeth, have faster polymerization periods, are cordless, portable, and ergonomic are further reasons why they have spread so quickly.[6,32]

The best way to calculate the radiant exitance of any type of LCU is to use Knoop's hardness test and infrared spectroscopy to measure the amount of carbon double bond conversion occurring during polymerization.[33] As these tests are expensive and difficult for the practitioner to perform regularly in the dental clinic, the use of radiometer devices has been suggested as a more efficacious method.[6] Several studies have shown the efficacy of radiometers for measuring the radiant exitance of curing units.[12,31,34]

LCUs are devices made specifically to polymerize dental materials that are sensitive to visible light. It is capable of producing and transmitting high-intensity blue light with a wavelength that oscillates between 400 and 500 nm.[9,30] In this study, the radiant exitance was measured using a digital radiometer called the LM-1, Woodpecker, China, which is intended for use with LED and QTH CUs and can measure the radiant exitance of LCUs between 0 and 3500 mW/cm² and has a wavelength range of 400–500 nm, as it was used earlier.[18,35] A light intensity of 400 mW/cm² is the minimum degree that must be delivered for effective polymerization of most resin composites for the maximal increment thickness of 2 mm when suitable curing times are used.[26,27,33] This is in agreement with values considered in the current study, an intensity of 400 mW/cm² and less was considered inadequate.

Overtime and frequent use of LCUs may result in reduction of the photopolymerization and inadequate resin full setting, as it was registered in the recorded values in this study. This in sufficient polymerization has a negative impact and reduction on the resin's physical, optical, and mechanical characteristics such as reduces wear resistance, increases microleakage, causes recurrent cavities, and exhibits color instability.[36]

Manufacturers' LCU devices stated that 20 to 40 seconds are needed curing time, with the condition that deeper colors should be cured for longer times. Many practitioners often follow a 20-second curing time for a 2-mm-thick increment of composite resin, as results recommended earlier.[18,26] Therefore, a common guideline was put out by several researchers: when the manufacturer's light intensity is cut in half, the curing time must be doubled; for example, 800 mW/cm² of light is the minimum intensity required to achieve adequate polymerization after 20 seconds, and 400 mW/cm² is the minimum intensity required to achieve adequate polymerization after 40 seconds of photo-activation on each composite layer to provide the required marginal energy (16 J/cm²). The intensity range of 400–850 mW/cm² was selected as the marginal intensity for this study. Furthermore, this study considers intensities above 850 mW/cm² adequate intensity, as recommended and suggested before.[23,25]

The present study showed that LCUs tested produced light intensity: 22.0%, 52.4%, and 25.6% measured inadequate intensity, marginal intensity, and adequate intensity, respectively. Similar results were found by Madhusudhana et al, who found that 18%, 57%, and 25% for the similar level of radiant exitances.[26] Also, Binalrimal et al, in Riyadh City's Dental Schools revealed that 12%, 50%, and 37% for the similar levels of intensity.[23] In contrast, Alqabbaa et al among private clinics found that 9.0%, 40.5%, and 50.5% for same level of radiant exitances, respectively.[25] This could be related to the regular maintenance in private clinics usually taking place during the grantee time of the equipment and devices. In comparison to our results, a considerable percentage of units had marginal intensity, a higher number of units had adequate intensity. It's probable that lack of maintenance is the problem.

The number of years in use of LCUs is negatively correlated with the radiant exitance, the length of usage of the units affects how much light is produced, and the radiant exitance reduces with each additional year of use.[12,18,35] Similar results were documented in the current analysis using the Pearson correlation test, which showed that older units, had a reduction in radiant exitance values with significance different (p 0.001) as shown in Table 3. Similar findings were obtained in studies carried out earlier in different types of clinics and countries.[26,27] LCUs, whether QTH or LED, may provide adequate radiant exitance while they are brand-new, but their radiant exitance will decrease over time, which may necessitate a routine examination to monitor any change in the radiant exitance over time.

LCUs are often used in dental clinics, but their use results in the adherence of composite residues and damage at the unit's tip, which lowers the radiant exitance.[3] The resin-based composite material and damage may significantly reduce the light's intensity since they partially reflect and block the light output.[27] By replacing the damaged tip with a new one, the LCUs' output was therefore significantly increased as 73%.[37] Also, after cleaning the LCU tips, with some units increasing by as much as 47%.[37,38] In order not to compromise the restorations, the integrity of the fiberglass of the curing light must be in good condition, and this is achieved through protective barriers and disinfection, in this way we also avoid cross-infection.

Rabi and Arandi reported the presence of composite, contaminated or damaged light tips was observed in 80.2% of the LCUs, while Eren and Tutkan reported that 52.9% of the units had residue and damage.[27,28] Our findings fall between the percentages of the two studies (66.4%) as Al-Senan et al, who found similar ratio of tips with composite accumulation and damage.[39]

Furthermore, a comparison of the radiant exitance values of LCUs with or without residue fractures by year is necessary in order to determine the effect of composite accumulation and damage on radiant exitance. The Mann–Whitney *U*-test, which was conducted to test the differences, shows a significant difference between LCUs that are < a year old and well-conditioned and have a higher intensity than those that have residue damage. A similar circumstance is seen with 1- to 5-year LCUs. It is probable that the resin composite material and damage may have a major negative impact on intensity, in contrast to the study by Eren and Tutkan, which did not detect a statistically significant difference.[27] This could be related to the age of the LCU as well as the thickness of the composite material used.

The curing light's tip should be checked and cleansed before each use to make sure it is free of defects and debris, and it should also be done after each use. For aged LCUs (> 5 years), the radiant exitance levels are the same intensity whether there are residual fractures or not (not statistically differences. It's probable that certain low-cost units could not show the original radiant exitance with repeated light applications and that the values gradually reduced over time.[40]

One of the drawbacks of this survey is that it does not include some colleges in other cities, also, it did not measure how damaged or composite build-ups affected the intensity of the LC. Therefore, it is unknown how cleaning the curing tips may affect the study's results. Second, since traditional radiometers have certain significant limitations: they can only provide a relative measure of irradiance and cannot consider wavelength, active diameter, or numerous light modes, as well as their measurements only reflect the maximum output, not the average.

Conclusion

Based on this cross-sectional clinical survey, the following conclusion can be drown;

Fifth (22%) of tested units did not produce adequate radiant exitance (less than 400 mW/cm² (inadequate to cure composite resin that is 2 mm in thickness). While half of them (52.5%) recorded outputs of 400 and 850 mW/cm² (acceptable with an additional 20 seconds of curing time), whereas 25.5% of LCUs reported outputs of more than 850 mW/cm² enough to cure composite resin with 2-mm-thick increments.

As LCUs aged or had the presence of debris or were damaged, their radiant exitance was significantly less than newer or less damaged LCUs.

A considerable number of the surveyed and evaluated LCUs were contaminated with remaining composite resin, remaining adhesive, and fractured tips. This strongly recommended the need for a program for routinely checking and maintaining the LCUs used in the tested colleges.

Data Sharing Statement

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors declare no conflicts of interest related to the study, including financial, personal, or other relationships that may influence the study or its interpretation.

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