

## Scientific article

**Long-term quality management  
of third-generation LED light-  
curing units: A 10-year  
retrospective analysis**Accepted: February 11, 2026  
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**Keywords**

Light-curing unit, radiometer, resin-based composite, polymerization, quality management, dental offices

**Abstract**

The radiant exposure of light-curing units (LCU) is the most important parameter in resin-based composite polymerization. Ensuring the quality management of light-curing procedures in dental offices is thus vital. Therefore, this report retrospectively evaluated the performance, frequency, and reasons for service removal of all third-generation LED light-curing units used in one healthcare center over 10 years. The tip irradiance of LCUs (Bluephase G2, Ivoclar Vivadent) was monitored with a dental radiometer (Bluephase Meter, Ivoclar Vivadent) at 1–2-month intervals, regardless of the duration of use. Additional measurements were conducted after special incidents (e.g., accidental dropping). Measurements were documented in the dental practice management software. The date and reasons for additional measurements or removal were also recorded. In two-thirds of incidents, the LCU was accidentally dropped, and in approximately half of these cases, the LCU had to be replaced. The mean of all 554 irradiance measurements over 10 years was  $(1,375 \pm 68)$  mW/cm<sup>2</sup>, higher than the value specified by the LCU manufacturer. Even for LCUs with data available for the entire 10 years, no relevant loss of tip irradiance was detected. While this study was the first to demonstrate such performance stability of third-generation LED LCUs over 10 years, it should not lead to the complete abandonment of routine quality assurance procedures for this type of device due to unreported or unrecognized accidents.

## Introduction

Insufficient polymerization of resin-based composites (RBCs) results in lower physical properties (1-4), reduced color stability (5, 6), increased cytotoxicity due to higher residual monomer concentrations (2, 7, 8), increased bacterial colonization (9), and postoperative sensitivity (10).

The irradiance (11-14), the irradiation time (11, 12, 14), the probe tip distance (13, 14), the battery level of the light-curing unit (LCU) (15-17), the form of the cavity (18), the thickness of the increment (12, 13, 19), and the composition, the translucency, and the shade of the RBC (13, 20, 21) can affect polymerization.

In the context of quality management, the tip irradiance of the LCU is a key device-related parameter because reduced output is typically not apparent clinically and can only be detected by metrological controls (22). Polymerization is governed by radiant exposure, i.e., the product of LCU irradiance and exposure time; thus, once sufficient irradiance is available, irradiation time becomes the practical lever to achieve adequate radiant exposure and polymerization quality (23). However, as the present study evaluated LCU performance and long-term stability, tip irradiance represents the primary device-related parameter, whereas exposure time is operator-controlled and does not reflect LCU function. Therefore, if the irradiance is unnoticed inadequate due to a lack of control, optimizing the aforementioned parameters will not prevent poor polymerization.

Performance testing of LCUs is normally carried out with brand-new devices by the manufacturers (24). Field tests in dental offices represent a snapshot in time (24-29). Consequently, while one study has monitored LCU performance in a university hospital for 1–6 years (30), no such studies have been conducted in dental offices. The aim of this report was therefore to retrospectively assess the performance, frequency and reasons for decommissioning the LCUs used in one healthcare center over a 10-year period, i.e. the long-term quality management.

## Materials and methods

### *Data collection*

The pediatric department of the healthcare center, in which the measurements of the present report

were performed, has been using ten Bluephase G2 (BP 01 – BP 10) light-curing units (Ivoclar Vivadent AG, Schaan, Liechtenstein) with the parallel-walled 10 mm light probe over the past ten years (4/2014 – 3/2024). This LCU uses a broad-spectrum (multi-peak) LED technology to emit light across a range of wavelengths from approximately 385 to 515 nm. This includes both violet and blue spectra.

During the observation period, the tip irradiance of the High Power curing program (i.e.  $1,200 \pm 120$  mW/cm<sup>2</sup>) of the LCU was monitored with a dental radiometer (Bluephase Meter, Ivoclar Vivadent AG, Schaan, Liechtenstein) at intervals ranging from one month to a maximum of two months (according to the opening schedule), regardless of the duration of use. Additional measurements were conducted in case of special incidents (e.g. accidental dropping of the LCU). During these ten years, quality management, i.e. maintenance and tip irradiance measurements of the LCUs, were all managed by just one experienced dental assistant following the measurement recommendations of the radiometer user manual. Measurements were documented in the dental practice management software Charly XL (solution GmbH & Co. KG, Holzgerlingen, Germany). In addition, the date and reasons for additional measurements or the decommissioning of the LCUs were recorded.

### *Statistical analyses*

Statistical analyses were conducted with the software JMP 18.2 (JMP Statistical Discovery LLC, Raleigh, United States). Firstly, the Shapiro–Wilk test ( $p > 0.05$ ) was used to check if the data (mean  $\pm$  standard deviation) conformed to a normal distribution. To assess statistically significant differences between the test data, the Kruska-Wallis test followed by Dunn All Pairs for Joint Ranks test was performed at a significance level of  $\alpha = 0.05$ .

## Results

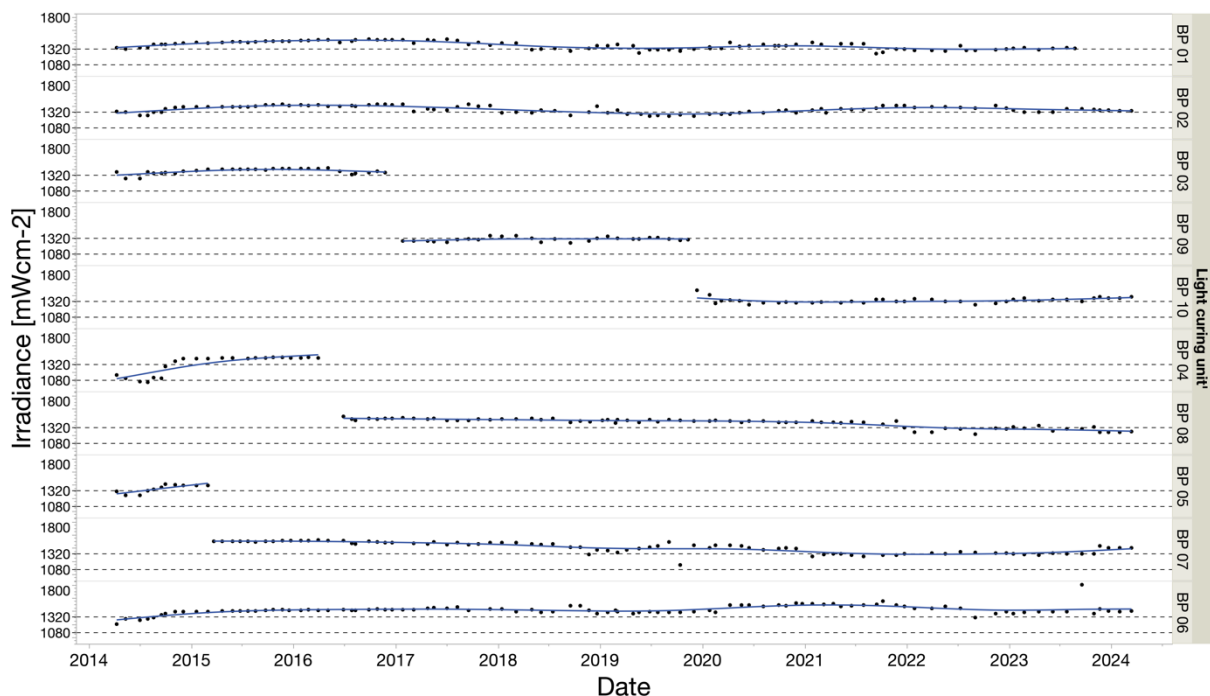
A total of ten LCUs (BP 01 – BP 10) were in use in the period of ten years (4/2014 - 3/2024). However, no more than six units were in service at the same time. During this period, there were 16 incidents that required additional irradiance measurements (Table 1).

**Table 1.** Overview of the light curing units in operation since 4/2014 and incidents that led to additional radiometer measurements and, if necessary, replacement of the handpiece or the light probe.

Bluephase G2 (Serial number)	Initial operation	Incidents	Consequence	Replacement
BP 01 (564896)	10.04.14	19.01.20 (dropped)	None	
		18.05.22 (dropped)	None	
		26.07.23 (dropped)	None	
		18.09.23 (dropped)	Display damaged / not repairable	None
BP 02 (580373)	10.04.14	18.03.21 (RBC doesn't cure)	None / measurement inconspicuous	
BP 03 (576124)	10.04.14	08.12.16 (dropped)	Display damaged / not repairable	Handpiece replaced (BP 09)
BP 09 (707587)	26.01.17	10.05.19 (dropped)	None / measurement inconspicuous	
		11.11.19 (dropped)	None / measurement inconspicuous	
		02.12.19 (dropped)	Display damaged / not repairable	Handpiece replaced (BP 10)
BP 10 (722519)	13.12.19	None		
BP 04 (580421)	10.04.14	18.09.14 (low intensity)		Light probe replaced
		11.04.16 (dropped)	Not repairable	Handpiece replaced (BP 08)
BP 08 (701287)	28.06.16	None		
BP 05 (575719)	10.04.14	06.03.15 (dropped)	None / measurement inconspicuous	
		09.03.15 (dropped)	Not repairable	Handpiece replaced (BP 07)
BP 07 (592000)	23.03.15	20.05.19 (Crack in the light probe)	None / measurement inconspicuous	
BP 06 (560438)	10.04.14	20.05.19 (Crack in the light probe)	None / measurement inconspicuous	
		23.12.20 (RBC doesn't cure)	None / measurement inconspicuous	

In 68.75 % of the mishaps, the LCU fell accidentally to the floor. However, in less than half of the cases (i.e. five cases), the handpiece, and therefore the LEDs, had to be replaced. In three of these cases, the display was irreversibly damaged. In the other two cases, customer service provided no further information about the cause of the replacement. In all cases requiring the replacement of the LCU

handpiece, the light probe and battery could still be used. In one case (6.25 %), the measured irradiances fell below the range of  $(1,200 \pm 120)$  mW/cm<sup>2</sup> specified by the manufacturer (Figure 1 and Table 1 – BP 04). In this case, the lamp itself was not defective and normal irradiance parameters were successfully achieved by replacing the light probe with a new one.



**Figure 1.** Overview of the tip irradiance measurements with a Bluephase Meter (Ivoclar Vivadent AG, Schaan, Liechtenstein) over a ten year period. The dashed area shows the performance of the  $(1,200 \pm 120)$  mW/cm<sup>2</sup> of the High Power curing program.

In two incidents (12.5 %), the RBC did not cure, with no irregularities in the subsequent irradiance measurement. Furthermore, other lots of the same RBC brand cured just fine, indicating a lot-specific manufacturing issue. In two other incidents, a little crack was detected in the light probe, which also had no effect on the irradiance measurement. In these four cases, no parts were replaced.

(1,375 ± 68) mW/cm<sup>2</sup> was the mean of all 554 irradiance measurements in ten years. Therefore, the mean value was higher than the value of (1,200 ± 120) mW/cm<sup>2</sup> specified by the manufacturer for the

curing program High Power. However, differences were found between the ten LCUs (Table 2). BP 06 had the highest mean irradiance with (1,414 ± 58) mW/cm<sup>2</sup> (n = 95), while BP 09 had the lowest with (1,295 ± 30) mW/cm<sup>2</sup> (n = 26). Nevertheless, all measurements were within, and in most cases above, the manufacturer specifications. Therefore, the differences were not considered as relevant (Figure 1). In addition, this retrospective 10-year analysis showed that even LCUs for which data are available for the entire period (i.e. BP 01, BP 02, BP 06), no relevant loss of tip irradiance could be detected.

**Table 2.** Tip irradiance of the LCUs expressed as mean ± standard deviation. No statistical differences (Dunn All Pairs for Joint Ranks test) were found between groups marked with the same letter. Additionally, the operating time, the number of tip irradiance measurements taken during that time, and the resulting measurement frequency are shown.

Bluephase G2	Tip irradiance [mW/cm <sup>2</sup> ]	Operating time [month]	Irradiance measurements	Measurement frequency [month]
BP 01	1,367 ± 58 <sup>A,B</sup>	113	91	1.2
BP 02	1,352 ± 52 <sup>A,C</sup>	120	94	1.3
BP 03	1,371 ± 41 <sup>A,B,C,D,E</sup>	31	30	1.0
BP 04	1,398 ± 34 <sup>A,B,D,E</sup>	24	16	1.5
BP 05	1,342 ± 62 <sup>A,B,C,E,F</sup>	11	11	1.0
BP 06	1,414 ± 58 <sup>D</sup>	120	95	1.3
BP 07	1,407 ± 84 <sup>D,E</sup>	107	82	1.3
BP 08	1,381 ± 69 <sup>B,D,E</sup>	92	71	1.3
BP 09	1,295 ± 30 <sup>F</sup>	34	26	1.3
BP 10	1,325 ± 42 <sup>C,F</sup>	51	38	1.3

## Discussion

The light curing guidelines for practitioners (31) recommend regular monitoring and recording of the LCU irradiance. In contrast, various studies conducted between 1998 and 2021 have shown that between 50 % and 90 % of the dental offices surveyed have never audited the performance of their units (24, 25, 32-35). Most of the offices did not have access to a radiometer, but even some offices that were equipped with a radiometer did not perform any monitoring (32, 34).

Laboratory-grade radiometers are the gold standard for scientific studies. However, their cost and difficult handling make them unsuitable for routine measurements in dental offices. As new dental radiometers have been introduced over the past decades, there have been numerous publications comparing the accuracy of these devices to laboratory-grade radiometers (36-49). The important information for practitioners from these studies is that the measured irradiance values can vary between different brands and even between LCUs of the same brand compared to the laboratory control. Therefore, the main use of a dental radiometer is to monitor the irradiance of an LCU over a period of time to detect changes, but not necessarily to

measure absolute irradiance values (40, 42, 45). As a result, the fact that all measurements in this research report were above the manufacturer specifications must be interpreted with caution, even though Gianini et al. were able to show that the Bluephase Meter used in this report and its successor, the Bluephase Meter II, were closest to the values measured with laboratory equipment (46). Ultimately, it comes down to trusting that only LCUs that meet the manufacturer specifications will be supplied. Dental offices can only document that the measured irradiance values have not changed significantly since the LCU was put into service.

In addition, Price et al. found that the corresponding brands of dental radiometers and LCUs from one company provide the most accurate results (40). For this reason, the dental radiometer used in the healthcare center of the present research report was not replaced during the study period of ten years. No other brands of LCUs were purchased as replacement, although others were offered or recommended by suppliers. Furthermore, the restriction to a single type of LCU has further advantages in terms of quality management. The time and effort required for training staff or exchanging LCUs and their documentation is reduced. Device use errors are also reduced when either LCUs are

moved or staff switch from one dental treatment room to the next.

This research report is the first to demonstrate the performance stability of third-generation LED LCUs over a 10-year period. The gradual loss of light output from LCU BP 04 (Figure 1), resulting in the replacement of the light probe, shows that despite the noteworthy stability of LED LCUs, regular monitoring should not be neglected. A common reason for the loss of tip irradiance can be the build-up of RBC remnants on the light probe of the LCU. Studies examining the condition of the light probe tip in dental offices found contamination rates of 35-80 % (24, 29, 32, 50-52). Only one study showed no loss of light output despite contamination of the tip (52). Therefore, for quality assurance purposes, a cling film is pulled tightly over the tip of the light probe in the healthcare center where the measurements presented were performed and fixed with the eye protection filter of the LCU to prevent contamination of the tip. No differences were found when measuring tip irradiance with or without cling film (data not shown), which is in agreement with Scott et al. (53). Soares et al. showed a 5-8 % reduction in light output measured with a laboratory-grade radiometer for correctly applied barriers, whereas wrinkled barriers showed a 14-26 % reduction (54). Mitton et al. found that cling film was not effective in preventing cross-contamination due to microscopic holes (32). Since the use of rubber dam is also standard in the pediatric department of the healthcare center, wipe disinfection of the light probe is sufficient to prevent cross contamination. In addition, repeated autoclaving cycles can reduce the ability of the light probe to transmit light (55).

During these ten years of monitoring, dropping the LCU on the floor was the most common incident that led to additional LCU irradiance measurements (Table 1). In about half of these cases, the hand-piece had to be replaced. Furthermore, even if there is a corporate culture that allows and encourages open reporting of errors or incidents, it is possible that damage to an LCU that is not visible externally may not be reported by the clinical team handling the device. Therefore, as a benchmark for decision making, the establishment of regular monitoring protocols is also essential in these cases.

The limitations of this research report are threefold: First, it is a single-center study. Second, due to the aforementioned benefits of quality management, only one brand of LCU was operational during the

observation period. Nevertheless, the stability of this third-generation LED LCU, which is being demonstrated in the present report for the first time over a ten-year period, should also apply to other brands based on the known technical properties of LEDs. Finally, calibrating a dental radiometer is beyond the capabilities of dental offices. The radiometer used does not provide a user calibration/recalibration procedure, so no formal calibration was performed during the 10-year period. Consequently, measurement drift cannot be completely excluded. Nevertheless, the present report assessed longitudinal consistency through repeated monitoring of the LCUs over the 10-year period. The observed trends support stable radiometer performance over time (Figure 1). To ensure consistent comparability across timepoints, all study data were collected using the same radiometer.

## Conclusions

Although this study is the first to demonstrate such performance stability of third-generation LED LCUs, such as the Bluphase G2, over a 10-year period, this finding should not lead to the complete abandonment of routine quality assurance procedures for this type of device. Furthermore, such benchmark measurements are valuable for detecting unexpected changes in the LCU performance or unreported or unrecognized accidents.

## Acknowledgements

The authors deny any possible conflict of interest related to this study.

## Zusammenfassung

### Einleitung

Eine unzureichende Polymerisation von Kompositen kann deren mechanische Eigenschaften, Farbstabilität und Biokompatibilität beeinträchtigen. Darüber hinaus kann sie die bakterielle Besiedlung sowie postoperative Empfindlichkeiten erhöhen. Die Polymerisation wird durch verschiedene Faktoren beeinflusst, darunter die Belichtungszeit, der Sondenabstand, die Schichtdicke und die Kompositeigenschaften. Der kritischste Parameter ist jedoch die Bestrahlungsstärke. Selbst die Optimierung aller anderen Parameter kann eine unzureichende Polymerisation nicht verhindern, wenn die Bestrahlungsstärke unzureichend ist.

Leistungstests der Hersteller werden in der Regel mit brandneuen Geräten durchgeführt. Praxistests in Zahnarztpraxen hingegen stellen nur eine Momentaufnahme dar. Bislang hat nur eine Studie die Leistung von Polymerisationslampen über einen Zeitraum von einem bis sechs Jahren beobachtet. Ziel dieses Berichts war es daher, die Leistung, Häufigkeit und Gründe für die Außerbetriebnahme der über einen Zeitraum von zehn Jahren in einem Gesundheitszentrum eingesetzten Lampen, d.h. deren Qualitätsmanagement, retrospektiv zu bewerten.

### Material und Methoden

Zehn identische Polymerisationslampen wurden von April 2014 bis März 2024 unter Verwendung gemäß den Herstellerangaben überwacht. Das Qualitätsmanagement wurde von derselben geschulten Zahnarzthelferin durchgeführt. Die Bestrahlungsstärke des High-Power-Programms wurde alle ein bis zwei Monate mit einem Bluephase-Meter-Radiometer gemessen. Zusätzliche Messungen wurden nach Zwischenfällen, wie beispielsweise dem versehentlichen Herunterfallen, durchgeführt. Alle Messungen und Zwischenfälle wurden in der Praxisverwaltungssoftware dokumentiert.

Die statistischen Analysen wurden mit JMP 18.2 durchgeführt. Mit dem Shapiro-Wilk-Test wurde eine Normalverteilung überprüft. Anschließend wurden zur Bewertung der Gruppenunterschiede der Kruskal-Wallis-Test gefolgt vom Dunn-Post-hoc-Test ( $\alpha = 0.05$ ) verwendet.

### Resultate

Über einen Zeitraum von zehn Jahren wurden zehn Polymerisationslampen verwendet, wobei maximal sechs gleichzeitig in Betrieb waren. Sechzehn Zwischenfälle erforderten außerplanmäßige Belichtungsstärkenkontrollen, meist aufgrund von versehentlichem Herunterfallen (68.75 %). Allerdings führten weniger als die Hälfte dieser Zwischenfälle zu irreparablen Schäden, die einen Austausch des Handstücks erforderlich machten.

In einem Fall wurde ein Rückgang der Bestrahlungsstärke unter den zulässigen Bereich auf eine defekte Lichtsonde zurückgeführt. Fälle von unvollständiger Aushärtung oder geringfügigen Rissen in der Sonde standen nicht im Zusammenhang mit abnormalen Bestrahlungsstärkewerten und erforderten keinen Austausch von Teilen.

Von den 554 gemessenen Bestrahlungsstärken lag der Mittelwert bei  $(1,375 \pm 68)$  mW/cm<sup>2</sup>, und damit über der Herstellerspezifikation. Obwohl zwischen den Geräten Unterschiede festgestellt wurden, blieben alle Werte inner- oder oberhalb der Spezifikation. Bemerkenswert ist, dass selbst Lampen, die während des gesamten Zeitraums in Betrieb waren, keinen signifikanten Leistungsabfall aufwiesen.

### Diskussion

Trotz bestehender Richtlinien, die eine routinemäßige Überwachung der Bestrahlungsstärke empfehlen, führen viele Zahnarztpraxen keine routinemäßigen Messungen durch – selbst dann nicht, wenn ein Radiometer verfügbar ist. Im Gegensatz zu Laborradiometern eignen sich zahnärztliche Radiometer eher zur Verfolgung relativer Veränderungen als zur Bestimmung der absoluten Bestrahlungsstärke. Das in dieser Studie verwendete Bluephase-Meter-Messgerät hat jedoch bereits zuvor eine gute Übereinstimmung mit Laborgeräten gezeigt. Messungen von Lampen mit einem Radiometer desselben Herstellers scheinen genauer zu sein.

In diesem Bericht wird die Langzeitstabilität von LED-Lampen der dritten Generation demonstriert. Während der zehnjährigen Untersuchung war das Herunterfallen der häufigste Vorfall. Selbst in einer Unternehmenskultur, die die offene Meldung von Fehlern oder Vorfällen zulässt und fördert, ist es möglich, dass äußerlich nicht sichtbare Schäden von den Zahnarzthelferinnen nicht gemeldet werden. Daher sind regelmäßige Überwachungsprotokolle unerlässlich.

## Résumé

### Introduction

Une polymérisation insuffisante des composites peut nuire à leurs propriétés mécaniques, à la stabilité de leur couleur et à leur biocompatibilité. Elle peut également favoriser la colonisation bactérienne et augmenter la sensibilité postopératoire. Ce processus est influencé par divers facteurs, tels que le temps d'exposition, la distance de la sonde, l'épaisseur de la couche et les propriétés du composite. Cependant, le paramètre le plus important est l'intensité du rayonnement. L'optimisation de tous les autres paramètres ne peut pas empêcher une polymérisation insuffisante si l'intensité du rayonnement est insuffisante.

Les tests de performance réalisés par les fabricants sont généralement effectués avec des appareils neufs. Les tests pratiques réalisés dans les cabinets dentaires ne constituent quant à eux qu'un instantané. À ce jour, une seule étude a observé les performances des lampes sur une période d'un à six ans. L'objectif de ce rapport était donc d'évaluer rétrospectivement les performances, la fréquence et les raisons de la mise hors service des lampes utilisées dans un centre de santé sur une période de dix ans, c'est-à-dire leur gestion de la qualité.

### Matériels et méthodes

Dix lampes à polymériser identiques ont été surveillées d'avril 2014 à mars 2024, conformément aux instructions du fabricant. La gestion de la qualité a été assurée par la même assistante dentaire qualifiée. L'intensité d'irradiation du programme haute puissance a été mesurée tous les uns à deux mois à l'aide d'un radiomètre Bluephase Meter. Des mesures supplémentaires ont été effectuées après des incidents, tels que des chutes accidentelles. Toutes les mesures et tous les incidents ont été consignés dans le logiciel de gestion du cabinet.

Les analyses statistiques ont été réalisées à l'aide du logiciel JMP 18.2. La distribution normale a été vérifiée à l'aide du test de Shapiro-Wilk. Le test de Kruskal-Wallis, suivi du test post-hoc de Dunn ( $\alpha = 0.05$ ), a ensuite été utilisé pour évaluer les différences entre les groupes.

### Résultats

Sur une période de dix ans, dix lampes à polymériser ont été utilisées, avec un maximum de six en service simultanément. Seize incidents ont nécessité des contrôles imprévus de l'intensité du rayonnement, principalement à cause de chutes accidentelles (68.75 %). Cependant, moins de la moitié de ces incidents ont entraîné des dommages irréparables nécessitant le remplacement de la pièce à main.

Dans un cas, une baisse de l'intensité d'irradiation en deçà de la plage autorisée a été attribuée à une sonde lumineuse défectueuse. Les cas de polymérisation incomplète ou de fissures mineures dans la sonde n'étaient pas liés à des valeurs d'intensité d'irradiation anormales et n'ont pas nécessité le remplacement de pièces.

Sur les 554 mesures d'intensité d'irradiation effectuées, la valeur moyenne était de  $(1,375 \pm 68)$  mW/cm<sup>2</sup>, soit supérieure aux spécifications du fabricant. Bien que des différences aient été constatées entre les appareils, toutes les valeurs sont restées supérieures aux spécifications. Il est à noter que même les lampes ayant fonctionné pendant toute la période n'ont pas présenté de baisse de puissance significative.

### Discussion

Malgré l'existence de directives recommandant une surveillance régulière de l'intensité d'irradiation, de nombreux cabinets dentaires ne procèdent pas à des mesures régulières, même lorsqu'un radiomètre est à leur disposition. Contrairement aux radiomètres de laboratoire, les radiomètres dentaires sont mieux adaptés au suivi des variations relatives qu'à la mesure de l'intensité d'irradiation absolue. Cependant, l'appareil de mesure Bluephase Meter utilisé dans cette étude a déjà démontré une bonne concordance avec les appareils de laboratoire. Les mesures effectuées sur des lampes à l'aide d'un radiomètre du même fabricant semblent plus précises.

Cette étude démontre la stabilité à long terme des lampes LED de troisième génération. Au cours de l'étude menée sur dix ans, la chute était l'incident le plus fréquent. Même dans une culture d'entreprise qui encourage le signalement ouvert des erreurs ou des incidents, il est possible que des dommages non visibles à l'œil nu ne soient pas signalés par les assistantes dentaires. C'est pourquoi des routines de surveillance régulières sont indispensables.

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