



NEW PERSPECTIVE ARTICLE:

Changes in Irradiance and Polymerization Efficiency According to the Operating Cycle of Light-Curing Units

Cambios de irradiancia y eficiencia de polimerización según el ciclo operativo de lámparas de fotocurado

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ABSTRACT: Curing lights are indispensable devices in restorative dentistry, as they provide the necessary energy for resinous materials to achieve adequate mechanical, chemical, and physical properties. However, their performance depends not only on the irradiance reported by the manufacturer but also on the stability of the emission throughout usage cycles. Therefore, the objective of this study was to establish, based on current literature, how usage cycles modify the irradiance of curing lights and how this variation affects polymerization efficiency. The results showed that as the battery discharges or usage cycles accumulate, irradiance and dose decrease, leading to a reduction in the effective energy received by the restorative material and compromising the conversion rate, especially in wireless and low-cost lights. It is concluded that the stability of irradiance across cycles should be considered a critical factor for achieving adequate curing. Periodic monitoring of the lamps is a fundamental measure to preserve the quality and longevity of the restorations.

KEYWORDS: Photopolymerization; Composite resins; Irradiance; Light-curing units; Use cycles.

RESUMEN: Las lámparas de fotocurado son dispositivos indispensables en odontología restauradora, ya que aportan la energía necesaria para que los materiales resinosos alcancen propiedades mecánicas, químicas y físicas adecuadas. Sin embargo, su desempeño no depende solamente de la irradiancia informada por el fabricante, sino también de la estabilidad de la emisión a lo largo de los ciclos de uso. En ese sentido, el objetivo de este trabajo fue establecer, con base en la literatura actual, de qué forma los ciclos de uso modifican la irradiancia de las lámparas de fotocurado y cómo esta variación repercute en la eficiencia de la polimerización. Los resultados mostraron que, conforme avanza la descarga

de la batería o se acumulan los ciclos de uso, la irradiancia y la dosis disminuyen, lo que provoca una reducción de la energía efectiva recibida por el material restaurador y compromete el grado de conversión, especialmente en lámparas inalámbricas y de bajo costo. Se concluye que la estabilidad de la irradiancia a través de los ciclos debe considerarse un factor crítico para lograr un curado adecuado. El monitoreo periódico de las lámparas constituye una medida fundamental para preservar la calidad y la longevidad de las restauraciones.

PALABRAS CLAVE: Fotopolimerización; Resinas compuestas; Irradiancia; Lámparas de fotocurado; Ciclos de uso.

INTRODUCTION

Light-curing units provide the energy required for resin-based materials to achieve adequate mechanical, chemical, and physical properties, which is why they are considered indispensable tools in modern dentistry. Because of their clinical use, these devices must comply with standards established by national and international authorities, such as ISO 10650, which sets minimum irradiance values of 400 mW/cm² to ensure adequate performance (1).

Despite this, ensuring that these devices maintain a stable light output remains a clinically relevant challenge. Although several units available on the market report performance comparable to that of reference devices (2). This issue becomes even more important in cordless units, where the progressive reduction in total radiant energy may compromise the minimum energy required for adequate photopolymerization (1). Added to this are clinical and physical variables that modulate the energy actually received by the material, such as curing distance and the non-uniform distribution of the beam, so that a unit with unstable performance throughout successive cycles may translate that instability into an even greater reduction in curing efficiency under real clinical conditions (3,4).

Instability in light emission decreases the degree of cure and, consequently, compromises

restoration longevity (5). Evidence on the behavior of power, irradiance, and radiant exposure after multiple usage cycles is still limited (1). Therefore, the objective of this work is to argue, based on the available evidence, how usage cycles modify the irradiance of light-curing units and affect polymerization efficiency.

PHYSICAL PRINCIPLES OF DENTAL PHOTOCURING

Although irradiance and radiant exposure are sometimes used interchangeably in clinical practice, they describe two physically distinct quantities. Irradiance (I), expressed in mW/cm², is an instantaneous power density: it quantifies the rate at which light energy strikes a unit surface area at a given moment, and therefore characterizes the intensity of the light field at the tip of the device or on the surface of the resin. Meanwhile, radiant exposure or dose (D) expressed in J/cm², represents the total light energy accumulated per unit area during the exposure time. Both parameters are related through the exposure time (t), so clinically adequate radiant exposure can be achieved through high irradiance applied over a short interval or through lower irradiance over a longer interval, provided that the photoinitiator's absorption requirements, related to its absorption spectrum, are met. This distinction is essential because the degree of resin conversion depends on the radiant exposure received, not solely on the nominal irradiance declared by the manufacturer (3).

The irradiance integrated over the clinically useful emission range, or spectral irradiance, can be mathematically expressed as (6),

$$I = \int_{\lambda_1}^{\lambda_2} I_{\lambda} d\lambda,$$

where I represents the total irradiance, while I_{λ} corresponds to the irradiance contribution of wavelength λ of the beam within the emission range (λ_1, λ_2). According to the additional expression, it is not enough for the unit to emit light; this light must remain within the absorption range of the photoinitiators and remain stable during its use. Thus, a unit may continue to turn on yet lose curing effectiveness if its spectral emission decreases or shifts during use cycles. As the battery discharges, the lower driving current reduces the radiant power and the emission peak may shift, in some devices moving part of the light outside the useful absorption range of the photoinitiator (4,6).

The second relationship of greatest clinical interest is radiant exposure, or the energy per unit area received by the restorative material (6),

$$D = \int_{t_1}^{t_2} I(t) dt.$$

If irradiance remains approximately constant during the exposure interval, the previous expression can be simplified to (6,7),

$$D \approx I \times t.$$

This equation is fundamental for understanding the decline in curing efficiency. If I decreases during usage cycles, D also decreases, unless the exposure time t is increased enough to compensate for it. However, such compensation does

not always occur clinically, and when attempted empirically it may prolong the procedure, slow patient flow, and favor potentially harmful thermal increases in the dentin-pulp complex (6,8,9).

On the other hand, the loss of performance over the cycles can be expressed as a negative rate of change of the dose with respect to the number of use cycles (1,2,6),

$$\frac{\Delta D}{\Delta n} < 0.$$

Consequently, as the battery discharges due to increased device use (more cycles), the effective curing energy tends to decrease, leading to polymerization deficiencies. Therefore, the clinical focus should not be solely on the initial irradiance value, but rather on its stability across cycles.

EFFECT OF USAGE CYCLES ON CURING PERFORMANCE

Although this study focuses on usage cycles, it should be noted that the loss of efficiency also depends on the distance between the lamp and the restorative material, as well as the heterogeneity of the beam. A greater distance reduces the effective irradiance, while a more heterogeneous beam results in more areas with varying degrees of cure within the same restoration. These variables help explain why a drop in irradiance associated with usage cycles can have more pronounced clinical consequences when applied to the actual operating scenario, where these other factors are taken into account (4,10-13).

The focus of this work on the decline in curing efficiency during usage cycles is because it is a crucial element of clinical performance that is often overlooked. As the curing light discharges or ages, not only can the irradiance decrease, but also the effective power and the dose delivered to

the restorative material. Consequently, the degree of conversion achieved by the resin can progressively decline, even when the operator follows the same clinical exposure protocol (1,5).

The evidence consulted also shows that the drop in performance is not identical across devices. Some, especially the lower-cost ones, exhibit marked reductions from the first to the last discharge cycles, while the reference and higher-cost devices maintain a more stable output (1,2). This behavior is clinically relevant because the actual performance of a unit should not be judged by the nominal value reported by the manufacturer, but by the energy it is able to deliver consistently throughout usage cycles.

Likewise, the performance of light-curing units may be affected both by battery discharge during clinical use and by device aging. In parti-

cular, the decrease in output intensity associated with battery discharge has been widely documented (1,2,11), whereas the clinical age of the device has also been associated with progressive reductions in emitted irradiance (14). The reduction in intensity directly affects material polymerization, because it depends on emitted wavelength, output intensity, and exposure time (3,7). In addition, several units showed fluctuations in cycle duration, between 6 and 10 seconds, which reduced the actual exposure time and limited the total energy delivered to the restorative material (1).

In line with this, some units, such as certain low-cost models, showed marked decreases in power, irradiance, and dose from the first to the last cycle, whereas others, such as reference devices, maintained more stable and even consistent values until the end of discharge (Table 1).

Table 1. Power, irradiance, and dose values in light-curing units during usage cycles.

Unit model	Manufacturer city	No. of cycles	Initial power (mW)	Final power (mW)	First-cycle irradiance (mW/cm ²)	Last-cycle irradiance (mW/cm ²)	Initial dose (J/cm ²)	Final dose (J/cm ²)
LY-A180 (#1)	Guangdong, China	493	341.0	176.0	885.0	457.0	9.7	4.8
LY-A180 (#2)	Guangdong, China	326	307.7	58.0	779.3	150.3	8.0	1.5
LED-CL (#1)	Putian City, China	751	205.3	60.7	533.7	157.3	5.3	1.6
LED-CL (#2)	Putian City, China	764	444.0	337.5	1154.0	876.5	11.5	8.8
Elipar DeepCure-S	St. Paul, Minnesota, USA	959	906.3	951.1	1427.9	1498.3	14.3	15.0

Note: Data compiled by the authors from previously published experimental studies that measured the output of these devices throughout successive battery-discharge cycles: results for the LY-A180 and LED-CL low-cost units and for the Elipar DeepCure-S reference unit were obtained from Al-Zain et al. (1) and Peres et al. (2), who used calibrated laboratory-grade integrating-sphere systems to record radiant power, tip irradiance, and radiant exposure from the first to the last cycle of a fully charged battery. Power and irradiance values are reproduced as reported in each source study; because those studies may have used different active-area conventions when normalizing tip irradiance, the ratio P/I does not necessarily correspond to the nominal geometric area of the light tip.

The table shows an overall decrease in photocuring efficiency with accumulated use, although variability exists according to the device. In LY-A180 and LED-CL (#1), there is a marked decline in power, irradiance, and final dose, with reductions greater than 50-80% after hundreds of cycles, suggesting substantial degradation in optical performance. In contrast, LED-CL (#2) shows a more moderate decrease, maintaining relatively high irradiance and dose values, whereas Elipar DeepCure-S even shows stability or a slight improvement in some parameters, which could be attributed to technological differences or thermal management.

Furthermore, the results indicate that devices with greater performance loss show clinically relevant reductions after approximately 300-750 cycles, which is equivalent to 15-125 minutes of effective use depending on the duration of each cycle, in agreement with the concept of radiant exposure as the product of irradiance and exposure time (6,7).

CLINICAL MONITORING AND RECOMMENDATIONS

In this context, for devices with more unstable behavior (such as LY-A180 and LED-CL #1), it is advisable to verify irradiance or battery status every 50-60 minutes of effective use (approximately equivalent to 300-400 cycles of 10 s or 600-1200 cycles of 3-5 s). These intervals are derived from experimentally observed patterns and are consistent with the fact that performance decreases during battery discharge (1,2,11).

The most stable devices (LED-CL #2 and Elipar DeepCure-S) can achieve cumulative usage cycles of approximately 90-120 minutes without requiring periodic checks. These periodic checks are necessary to ensure that the intensity remains constant for proper polymerization (3,7).

Finally, it is recommended that clinical protocols include: i) periodic monitoring with a calibrated radiometer, ii) recording of usage time, and iii) preventive maintenance, which includes cleaning the tip and checking the battery. Factors such as tip contamination, degradation of optical components, and device aging can significantly reduce curing efficiency (3,4,12).

CONCLUSION

The performance of curing lights cannot be evaluated solely by the nominal irradiance declared by the manufacturer, since as usage cycles accumulate and the battery discharges, radiant power, irradiance, and radiation exposure decrease; this is particularly noticeable in low-cost, cordless lights. Because the degree of conversion of resin-based composites depends on the dose delivered to the material, the clinically relevant factor is the stability of the irradiance over the cycles, not just its initial value, as is often assumed. Therefore, periodic monitoring with a calibrated radiometer, recording of accumulated usage time, and preventive maintenance of the tip and battery should be incorporated into routine clinical protocols. Adopting these measures will help preserve the mechanobiological quality of restorations and reduce the risk of premature failure resulting from undercured resin composites.

CONFLICT OF INTEREST: None to declare.

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