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INVESTIGATION OF LIGHT INTENSITY OF WIRELESS LED LIGHT CURING UNITS

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ABSTRACT

In recent years, LED light curing units (LCUs) have become the main source of light for the polymerization of resin based composites (RBCs). Various factors can affect the normal functioning of LCUs, one of which is the battery charge of the wireless models. The aim of this study is to evaluate the stability of the light intensity of different brands of wireless LED LCUs by measuring it from a fully charged to a fully discharged battery. For this purpose 10 new different fully-charged wireless LED LCUs are used. Light intensity is measured with a digital radiometer. For each unit, the number of curing cycles of 20 s until full battery drop is determined as well as the change in light intensity with increasing the number of cycles (N) and decreasing the battery life (%). It has been found that for some devices (LY-C240, SK-L029A, CV-215, OSA-F686C, Xlite4, D-Light Duo) the light intensity is lower than specified by the manufacturer, which may cause incorrect determining of the optimal polymerization time. In six of the examined models - Bluephase N, D-Light Duo, LY-C240, Demi Plus, I-LED 2500 and Elipar Deep Cure S, the light intensity is stable and independent of the battery life. In the other devices (SK-L029A, CV-215, Xlite4, OSA-F686C), the battery discharge causes a decrease in light intensity. It can be concluded that dentists have to periodically measure the light intensity of their LCUs and regularly recharge them, especially in battery-dependent models.

INTRODUCTION

In many countries the use of dental amalgam is being phased out and replaced by the contemporary composite materials in restorative treatment of dental caries [1-4]. This is due to the disadvantages of the amalgam such as poor aesthetics, occurrence of galvanic current and corrosion, discoloration of enamel, dentin and soft tissues, release of mercury vapors, etc., as well as the increased aesthetic requirements of the patients.

The polymerization of RBCs depends on the composition and the amount of their organic component. Most of the composites, available on the market today, contain photo-initiating systems that absorb the blue visible light with a wavelength spectrum from $450\,nm$ to $500\,nm$ [5,6]. The beginning of the polymerization process starts with the activation of the initiator (champhoroquinone; 2,4,6 trimethylbenzoyldiphenylphosphine oxide (TPO); 1-phenyl-1,2-propanedione (PPD); Ivocerin), as a result of which the carbon double bonds (C=C) of the monomers are broken and hundreds of monomers are joined together to form a polymer network [5,7]. The percentage of the transformed double to single carbon bonds is called degree of monomer-polymer conversion or polymerization degree.

Although the composite surface, close to the light source, solidifies easily and it seems that the material is completely polymerized, that does not always happen in the deeper layers of the restoration. According to different authors the degree of conversion of RBCs varies between 35% and 77% [8-10]. The unfavorable consequences of the incomplete polymerization of the material are a risk of fractures, lower wear resistance, elution of residual monomers, lower adhesive bond strength and faster change of the color [11,12]. The monomer – polymer conversion depends on many factors. The most important ones are: light intensity, curing time, thickness of the layers, distance and angulation of the tip of light curing units (LCUs), composite color etc. [5,7,13].

Many *in-vitro* studies have been conducted over the years to show how different irradiation times affect the mechanical properties of the restoration. For proper polymerization of a $2\ mm$ composite layer, the light energy received must be in the range of $16-24\ J/cm^2$ [6,14]. It is calculated according to the "total energy concept" [14,15] by the formula (1):

$$E_L = I_L.\tau\ , \qquad (1)$$

where: E_L is the energy, necessary for complete polymerization of one dose composite with $2\,mm$ thickness [J/cm^2]; τ is curing duration [s]; I_L is the light intensity [W/cm^2], given by the manufacturer or calculated by formula (2):

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$$I_L = \frac{P}{S}, \qquad (2)$$

where: P is power [W] and S is the surface area [cm^2].

Therefore, the higher the intensity of the LCU is, the shorter the irradiation time can be.

Another factor that affects the quality of composite restorations is the distance between the LCU's tip and the irradiated surface. A number of studies have reported a reduction in the degree of conversion of RBCs as the distance between the LCU's tip and the irradiated surface increases, because this leads to a decrease in the total amount of light energy reaching the restoration [17,18]. Improper angulation (keeping the light guide tip at an angle different than $90°$) also causes a decrease in light intensity [19,20]. In some clinical situations, especially in the distal area, the access of the tip is severely limited and it is almost impossible to point it at an angle of $90°$ and be as close as possible to the restoration surface. In these cases, the same amount of light energy cannot be delivered to the composite surface as under *in-vitro* conditions, so it must be compensated by extending the curing time or increasing the light intensity.

As technology advances, from the beginning of the new century LED (light emitting diodes) LCUs have become the main source of light for the photo-curing of RBCs. Third generation LED LCUs have a number of advantages over the rest of the curing devices: 1) the intensity of the emitted light is very high - from $500\ mW/cm^2$ to $3000\,mW/cm^2$ [21]; 2) light and compact wireless models with long-lasting batteries; 3) affordable price; 4) low heat generation; 5) no need of a cooling fan [22]. Today, there are hundreds of models of LED LCUs from different manufacturers. Although they have different specifications such as shape, size, weight, price, working modes, etc., the most important one is the intensity of the light they emit. According to some authors, for the proper polymerization of a $2\,mm$ composite layer for $60\,s$, the emitted light must be with intensity of at least $400\,mW/cm^2$, with the same authors claiming that with an intensity of less than $233\,mW/cm^2$ no effective polymerization of the material can occur, regardless of the irradiation time [14]. Most manufacturers of RBCs recommend that the polymerization of a $2\,mm$ composite layer for $20\,s$ should be performed with light intensity between $400-800\,mW/cm^2$ and above [23-27].

Various factors can influence on the optimal functioning of LCUs such as contamination or partial fracture of the light guide tip, diode aging [28], repeated sterilization [29,30]. Another factor that affects wireless models is the battery charge. A study shows that in some devices with a decrease in the battery life the LCUs light intensity decreases [7]. Because light intensity is a very important factor for the polymerization of RBCs and the information in the literature on the relationship between light intensity and battery power is relatively scarce, this study further deals with this slightly researched topic.

The aim of the present paper is to evaluate the stability of the light intensity of ten different brands of wireless LED LCUs by measuring it from a fully charged to a fully discharged battery. A comparative analysis of the actual light intensity of the LCUs with that, specified by the manufacturers, is made.

MATERIALS AND METHODS

In this study, 10 new different fully-charged wireless LED LCUs are used (Table 1). Light intensity is measured with a digital radiometer (*Woodpecker, China*). The light guide tip is placed in contact with the radiometer sensor at an angle of $90°$. Orange glasses ("*blue blockers*") are used to protect the operator from eye damage, caused by the blue visible light. To reproduce the clinical situation measurements are made every 10 curing cycles of $20\,s$ each in continuous mode of operation until the LCU's battery is completely discharged.

Table 1 *Data about the LED LCUs, given by the manufacturer*

№	**LED LCU type**	**Manufacturer**	**Light intensity, mW/cm²**	**Wave length, nm**
1	*Xlite4*	ThreeH, China	800	385-515
2	*Bluephase N*	Ivoclar Vivadent, Lichtenstein	1200	385-515
3	*D-Light Duo*	GC, Japan	1200	400-480
4	*LY-C240*	BDMED, China	1200	420-480
5	*OSA-F686C*	Osaka Dental, China	1200	440-480
6	*Demi Plus*	Kerr, USA	1200	450-470
7	*I-LED 2500*	Woodpecker, China	1300	420-480
8	*Elipar Deep Cure S*	3M ESPE, USA	1470	430-480
9	*CV-215*	Cicada Dental, China	1500	430-480
10	*SK-L029A*	Spark Dental, China	2200	385-430

In Table 1, the light intensity values by specification refer to continuous mode of operation of the LCUs, not taking into account the turbo-modes ($3\,s$) with higher intensity in some models. *D-Light Duo* have only one polymerization mode of $10\,s$, so two cycles of $10\,s$ are counted as one cycle of $20\,s$.

For each LCU, the number of curing cycles of $20\,s$ until the battery is completely discharged is determined. With the use of *Microsoft Excel* software, the change of the light intensity is expressed by increasing the number of polymerization cycles (N) and by decreasing the battery life (%).

RESULTS OBTAINED

In the present study, LCUs are divided into two groups depending on the light intensity. The first group includes 6 models with intensity lower than $1200\,mW/cm^2$, and the second group consists of 4 models with intensity higher than $1200\,mW/cm^2$.

In Fig. 1 the battery life of the tested LCUs is shown, expressed by the number of polymerization cycles. It can be clearly seen that there is a big difference in the battery life of the devices in the two groups, but no definite dependence is found either on the light intensity or on the wavelength range.

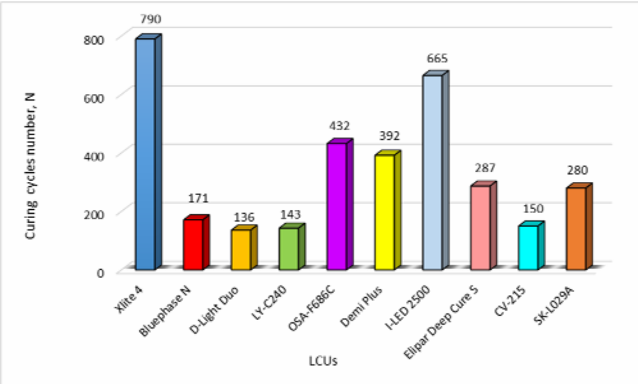
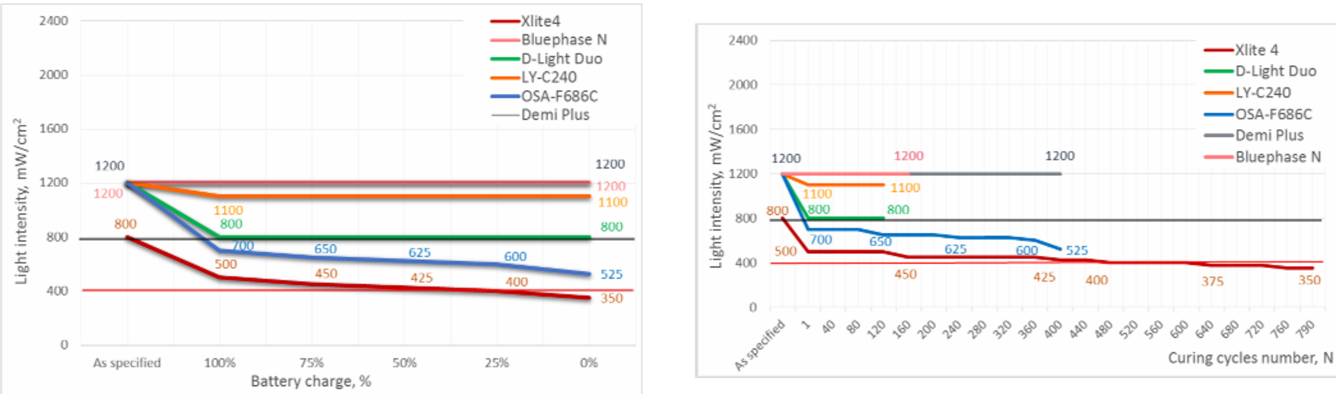


Fig. 1. LED LCUs battery life, expressed by the number of curing cycles

When irradiating for $20\,s$ in continuous mode, in the lower light intensity group, the largest number of curing cycles before the complete battery discharge is observed on *X-lite 4* (790), followed by *OSA-F686C* (432) and *Demi Plus* (392), with the lowest being observed on *D-Light Duo* (136), *LY-C240* (143) and *Bluephase N* (171) (Fig. 1). It should be noted that the LCU with the highest number of cycles - *X-lite 4* is characterized by the lowest intensity ($800\,mW/cm^2$) and the broadest wavelength range ($385-515\,nm$) (Table 1). The other 5 LCUs have the same light intensity ($1200\,mW/cm^2$) and close narrow wavelength ranges (from $400-480\,nm$ for *D-Light Duo* to $450-470\,nm$ for *Demi Plus*). The model with the broadest wavelength range - *Bluephase N* has one of the lowest battery life.

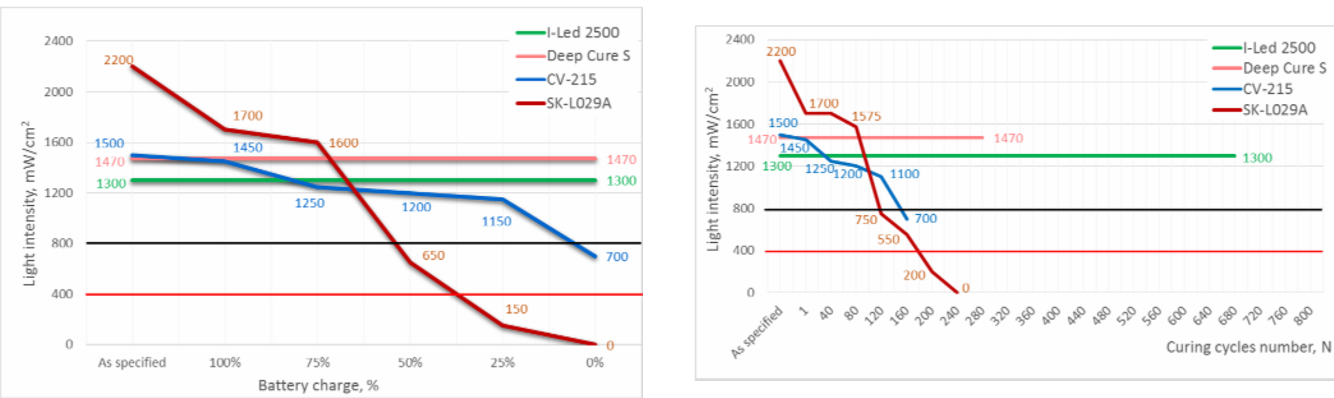
In the second group of LCUs, characterized by a higher light intensity, there is also a big difference in the life of the batteries. The highest battery life is observed on *I-LED 2500* (665 cycles), followed by *Elipar Deep Cure S* (287 cycles), *SK-L029A* (280 cycles) and the shortest - *CV-215* (150 cycles).

Fig. 2 shows the alteration in the light intensity of the first group LCUs with the discharge of the battery (Fig. 2a) and with the increase in the number of the curing cycles (Fig. 2b). It is noteworthy that only in two cases (*Demi Plus and Bluephase N*) the light intensity measured at 100% battery charge matches the intensity, specified by the manufacturer (Fig. 2a). The largest reduction is measured in *OSA-F686C* - 42%, followed by *X-lite 4* - 37.5% and *D-Light Duo* - 33.3%



a) b)

Fig. 2. Change of the light intensity of LED LCUs ($I_L < 1200\,mW/cm^2$) with alteration of the battery charge – a) and increase of the curing cycles – b)



a) b)

Fig. 3. Change of the light intensity of LED LCUs ($1200 < I_L < 2200\,mW/cm^2$) with alteration of the battery charge – a) and increase of the curing cycles – b)

The light intensity of the LCUs is measured every 10 polymerization cycles of $20\,s$ each during the different phases of the battery life (the amount of time a device works before it needs recharging). In the first group, for four of the units, the intensity is constant as the number of curing cycles increases (Fig. 2b) throughout the whole battery life (Fig. 2a), even when battery is completely discharged (*Bluephase N, Demi Plus, LY-C240 and D-Light Duo*), although the measured intensity of the last two devices is lower than the one specified by the manufacturer. For the *OSA-F686C* and *Xlite 4*, the light intensity values decrease with battery charge decrease and curing cycles increase. For *Xlite 4* at 50% battery power and 480 cycles, the light intensity is less than the minimum required $400\,mW/cm^2$.

In the second LED LCUs group (Fig. 3), the light intensity by specification and when measured at 100% charged battery coincides for *Elipar Deep Cure S* and *I-led 2500* (Fig. 3a) and also remains unchanged with the increasing number of curing cycles (Fig. 3b) until the battery is completely discharged. The measured light intensity of *CV-215* and *SK-L029A* is less than the one in specification by 3% and 23% respectively, and gradually decreases with the battery charge decrease and the increase of the curing cycles. The reduction in the light intensity is especially intensive for *SK-L029A*, where at 180 cycles or 37% remaining battery power, the intensity is already less than the minimum required $400\,mW/cm^2$.

DISCUSSION

This study examines the light intensity of 10 LED LCUs from different brands throughout the life of their battery - from full charge to full discharge. It is established that in four of the devices the intensity decreases with the battery charge decrease, respectively with increasing the number of polymerization cycles. This proves that in some LED LCUs, the charge of the battery affects the intensity of the light they emit.

According to the "total energy concept", in order to achieve an adequate polymerization of a $2\,mm$ layer of composite, the light energy received from it should be in the range $16-24\,J/cm^2$ [14,15]. It is shown in formula (1) that this can be achieved by many different combinations between light intensity and curing time. According to some authors, the light emission should be with intensity of at least $400\,mW/cm^2$ when the duration is $60\,s$ [12] and according to different RBCs manufacturers – at least between $400-800\,mW/cm^2$ for $20\,s$ curing time [23-27]. Based on these data, we assume that the minimum required light intensity should be $400\,mW/cm^2$ and the recommended one should be not less than $800\,mW/cm^2$, since according to our study, 63% of the dentists polymerize each composite layer for $20\,s$ [31].

When measuring at full charge of the battery, all LCUs meet the minimum light intensity requirement ($400\,mW/cm^2$) and 8 out of 10 devices – the recommended light intensity of $800\,mW/cm^2$ (Fig. 2 and Fig. 3). For *Xlite 4* and *OSA-F686C* only, the intensities are $500\,mW/cm^2$ and $700\,mW/cm^2$, respectively (Fig.2). However, for 6 of the devices (*LY-C240, SK-L029A, CV-215, Xlite4, OSA-F686C, D-Light Duo*), the measured intensity is lower than the specified by the manufacturer (Fig. 2 and Fig. 3). This can be misleading for dentists and can lead to incomplete polymerization of the material if the irradiation time is decreased.

By measuring the light intensity after every 10 curing cycles of $20\,s$ each, it is found that in 60% of the tested LCUs the intensity remains unchanged from a state of full charge to full discharge of the battery (*LY-C240, SK-L029A, D-Light Duo, Elipar Deep Cure S, Bluephase, DemiPlus*) (Fig. 2 and Fig. 3). In the other 4 models, however, the light intensity of the LCUs decreases with the battery charge decrease. In *Xlite4* (Fig. 2), the light intensity shows a decrease from the initial $500\,mW/cm^2$ to the minimum $400\,mW/cm^2$ with remaining 25% of the battery charge, while in the last 12% or 180 cycles the values fall below the minimum - up to $350\,mW/cm^2$. For *OSA-F686C*, the light intensity in full-charge battery is $700\,mW/cm^2$ and decreases to $525\,mW/cm^2$ at the end of the battery life. The most dramatic drop is observed for *SK-L029A* where the intensity decreases from an initial $1700\,mW/cm^2$ below $400\,mW/cm^2$ at 38% remaining battery power, and when the battery is completely discharged, the radiometer measures $0\,mW/cm^2$ (Fig. 3). This means that in the remaining 38% of the battery or about 100 curing cycles, the LCU cannot ensure a complete polymerization of the composite, which in turn leads to poor restoration properties [9,10]. For *CV-215*, initially the light intensity is $1450\,mW/cm^2$ and when the battery is completely discharged, it decreases to $700\,mW/cm^2$. The drop is more than 50%, but the unit still meets the minimum and almost reaches the optimum intensity requirement.

Table 2 summarizes the results of this study that can be used by dentists in their practice. In six of the LCUs examined - *Bluephase N, D-Light Duo, LY-C240, Demi Plus, I-LED 2500* and *Elipar Deep Cure S*, the light intensity never drops below the recommended $800\,mW/cm^2$. Therefore, they will provide adequate polymerization of the RBCs regardless of the remaining battery charge. For *Xlite4* during the first 620 curing cycles of $20\,s$ or 78% of the battery life, the intensity is between $500\,mW/cm^2$ and $400\,mW/cm^2$, which necessitates an increase in the irradiation time. In the remaining 22% of the battery charge, the light intensity falls below the minimum $400\,mW/cm^2$, which requires the stop of use of the device until recharging its battery. For *OSA-F686C*, the light intensity varies between $700\,mW/cm^2$ and $525\,mW/cm^2$, allowing the LCU to operate until its battery is completely discharged, but with increased curing time to achieve adequate composite polymerization. For *CV-215*, the intensity is $1450\,mW/cm^2$ at full charge and falls below the recommended $800\,mW/cm^2$ only after 140 polymerization cycles, equivalent to 93% of battery life. This means that only during the last 7% of the remaining battery charge the irradiation time must be increased in order not to impair the quality of the restoration. The highest correlation between light intensity and battery charge is observed for *SK-L029A*. In this model, during the first 57% of battery life or 120 curing cycles of $20\,s$, the intensity of the light is above the recommended $800\,mW/cm^2$. However, in the next 18%, due to the decrease in the intensity, it is necessary to increase the irradiation time and in the last 39% of the battery charge the device should not be used at all, since the values fall below the required minimum of $400\,mW/cm^2$.

The present study shows that dentists must be well aware of the characteristics of their LCUs and periodically check the light intensity values using a radiometer, because in 60% of the tested devices the actual light intensity does not correspond to the one specified by the manufacturer. This misleading information may cause clinicians to spend less time than necessary for the polymerization of RBCs, which would adversely affect the properties of the restoration. Also, at 40% of the LCUs, the light intensity decreases when battery gets discharged, with some devices falling below the required minimum of $400\,mW/cm^2$. In the models, dependent on the battery charge, this can be avoided if dentists and their staff regularly recharge the LCUs and do not allow the battery to be discharged to an extent that would affect their normal functioning.

Table 2 *Recommendations for effective use of LCUs for high quality composite fillings*

№	**LED LCUs type**	**Number of curing cycles (20s) before light intensity drops below**		**Remaining battery life (%) at which light intensity drops below**	
		800 mW/cm²	**400 mW/cm²**	**800 mW/cm²**	**400 mW/cm²**
1	*Xlite4*	0	620	100%	22%
2	*Bluephase N*	No drop	No drop	No drop	No drop
3	*D-Light Duo*	No drop	No drop	No drop	No drop
4	*LY-C240*	No drop	No drop	No drop	No drop
5	*OSA-F686C*	0	No drop	100%	No drop
6	*Demi Plus*	No drop	No drop	No drop	No drop
7	*I-LED 2500*	No drop	No drop	No drop	No drop
8	*Elipar Deep Cure S*	No drop	No drop	No drop	No drop
9	*CV-215*	140	No drop	7%	No drop
10	*SK-L029A*	120	170	57%	39%

CONCLUSIONS

This article deals with investigation of the change in the light intensity of ten LCUs measured from the point of full battery charge to full battery discharge. It is found out that:

● For some devices (*LY-C240, SK-L029A, CV-215, OSA-F686C, Xlite4, D-Light Duo*), the light intensity is lower than that specified by the manufacturer, which may cause incorrect determination of the optimum polymerization time.

● For six of the LCUs tested - *Bluephase N, D-Light Duo, LY-C240, Demi Plus, I-LED 2500* and *Elipar Deep Cure S,* the light intensity is stable and independent of the battery life.

● For the rest of models (*SK-L029A, CV-215, Xlite4, OSA-F686C*), the battery discharge causes a decrease in the light intensity. Recommendations are given for the effective use of these LCUs to obtain high quality restorations.

● Dentists need to periodically measure light intensity of LCUs and regularly recharge them, especially for the battery-dependent models.

In order for this research to be completed, further longer and more complex studies are needed to provide information on the stability of the light intensity of LCUs as they age.

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