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Laboratory Research

Battery Charge Affects the Stability of Light Intensity from Light-emitting Diode Light-curing Units

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Clinical Relevance

Partial discharge of the battery may affect the stability of light intensity. Therefore, the light intensity of light-emitting diode (LED) light-curing units with an initially high intensity should be checked regularly.

SUMMARY

This study investigated the influence of battery charge levels on the stability of light-emitting diode (LED) curing-light intensity by measuring the intensity from fully charged through fully discharged batteries. The microhardness of resin composites polymerized by the light-curing units at various battery charge levels was measured. The light intensities of seven fully charged battery LED light-curing units—1) LY-A180, 2) Bluephase, 3) Woodpecker, 4) Demi Plus, 5) Saab II, 6) Elipar S10, and 7) MiniLED—were measured with a radiometer (Kerr) after every 10 uses (20 seconds per use) until the battery was discharged. Ten 2-mm-thick cylindrical specimens of A3 shade nanofilled resin composite (PREMISE, Kerr) were prepared per LED light-curing unit group. Each specimen was irradiated by the fully charged light-curing unit for 20 seconds. The LED light-curing units were then used until the battery charge fell to 50%. Specimens were prepared again as described above. This was repeated again when the light-curing units' battery charge fell to 25% and when the light intensity had decreased to 400 mW/cm^2. The top/bottom surface Knoop hardness ratios of the specimens were determined. The microhardness data were analyzed by one-way analysis of variance with Tukey test at a significance level of 0.05. The Pearson correlation coefficient was used to determine significant correlations between surface hardness and light intensity. We found that the light intensities of the Bluephase, Demi Plus, and Elipar S10 units were stable. The intensity of the MiniLED unit decreased slightly; however, it remained above 400 mW/cm^2. In contrast, the intensities of the LY-A180, Woodpecker, and Saab II units decreased below 400 mW/cm^2. There was also a significant decrease in the surface microhardnesses of the resin composite specimens treated with MiniLED, LY-A180, Woodpecker, and Saab II. In

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conclusion, the light intensity of several LED light-curing units decreased as the battery was discharged, with a coincident reduction in the units' ability to polymerize resin composite. Therefore, the intensity of an LED light-curing unit should be evaluated during the life of its battery charge to ensure that sufficient light intensity is being generated.

INTRODUCTION

Dental patients have become increasingly interested in highly esthetic treatment outcomes. Therefore, the use of light-cured resin composites has grown to meet this demand. A resin composite effects a cure as a result of the chemical reaction between its dimethacrylate resin monomer units, which produces a rigid cross-linked polymer network.[1] The degree of conversion of a resin composite is defined as the percentage of reacted C=C bonds of the monomer molecules. Resin composite requires an optimum degree of conversion to generate good physical and mechanical properties.[2]

Chemical bonding among layers of resin composite relies on copolymerization between new resin monomers and residual unreacted C=C bonds of the monomer molecules.[3] However, an insufficient degree of conversion can result in reductions in mechanical properties, wear resistance, and color stability as well as increased water sorption and secondary caries.[4-7] Ferracane and others[7] showed that a dental composite's resistance to abrasive wear could be improved by increasing its degree of conversion. The factors influencing the degree of conversion include resin composite composition,[8] fillers,[9] type of photoinitiator,[10] temperature,[11] type of light-curing unit, curing time, light guide tip positioning, light wavelength, and light intensity.[12]

By 2007, the use of light-emitting diode (LED) light-curing units had increased because of their many advantages, such as their high light intensity, ease of use, reasonable price, and long life span. Following technological improvements, there are currently many brands of LED light-curing units available. Although each LED light-curing unit brand has different specifications, such as size, weight, and price, the most important factors are the properties of its emitted light. A light-curing unit should produce a light intensity of more than 400 mW/cm^2.[13] Several surveys[14-16] found that not all light-curing units in dental practices produced a sufficient intensity. Indeed, approximately 27% of the light units examined had a light output of only 200 mW/cm^2 or less. It is important that the light intensity remains high and stable to ensure adequate resin composite polymerization. In addition, numerous factors can interfere with efficient functioning of the light-curing unit, such as contamination of the light guide, damage to the fiber optic bundle,[17] reduced light output after repeated sterilizations,[18] and dwindling battery power. However, there are no studies concerning the effect of battery power on the stability of the light intensity of an LED light-curing unit throughout the life of the battery charge.

Table 1: *LED Light-curing Units*

Unit	Manufacturer
LY-A180	Anyang Zongyan Dental Material Co, Ltd, Anyang City, China
Bluephase	Ivoclar Vivadent, Schaan, Liechtenstein
Woodpecker	Guilin Woodpecker Medical Instrument, Guilin, Guangxi, China
Demi plus	Kerr, Orange, CA, USA
Saab II	Foshan Keyuan Medical Equipment Co, Ltd, Foshan, China
Elipar S10	3M ESPE, St Paul, MN, USA
MiniLED	Acteon, Mettmann, Germany

The aim of the present study was to evaluate the stability of the light intensity from different brands of LED light-curing units by measuring the intensity from the point at which the battery was fully charged until the point at which the battery was fully discharged. Furthermore, resin microhardness was used to evaluate the performance of the light intensity during the life of the battery charge.

METHODS AND MATERIALS

Light Intensity Measurement

Seven new different, fully charged LED light-curing units were used in the present study (Table 1). The light intensity was measured 0 mm from the tip of the light guide by means of an LED radiometer (Kerr, Orange, CA, USA). The light guide was positioned over the radiometer sensor, and the light intensity was recorded in mW/cm^2. To represent the clinical situation, the LED light-curing units were used repeatedly for 20 seconds until the battery was fully discharged. The light intensity measurements were obtained after every 10 uses. When the light-curing unit batteries were fully discharged they were fully recharged, and this procedure was repeated for five charging cycles.

Resin Microhardness Measurement

An A3 shade nanofilled resin composite (PREMISE, Kerr) was used in the present study (Table 2). The

Table 2: *Resin-based Composite Material Used in the Study*

Composite	Matrix	Photo Initiator	Particle Size, μm (Mean)	Filler Type
Premise (Kerr, Orange, CA, USA)	Bis-EMA/TEGDMA	CQ/amine	PPF, 30-50	Prepolymerized filler, barium glass, silica filler
			Silica, 0.02	
			Barium, 0.4	

Abbreviations: Bis-EMA, Ethoxylated bisphenol A dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; CQ, camphorquinone; PPF, Prepolymerized filler.

resin composite was placed in a cylindrical stainless-steel mold (4 mm in diameter and 2 mm deep). The resin was covered with a transparent celluloid strip and a glass microscope slide to remove the excess material. Each specimen was irradiated by means of a fully charged light-curing unit for 20 seconds and then stored in the dark for 15 minutes. Ten specimens were prepared for each light-curing unit. The LED light-curing units were then used until the battery charge fell to 50%. Specimens were prepared again as described above. This was repeated again when the light-curing units' battery charge fell to 25% and when the light intensity had decreased to 400 mW/cm^2.

The microhardness measurements were made by means of a universal testing machine (FM-700e TYPE D, FUTURE-TECH, Kawasaki-City, Japan) on the top and bottom surfaces of the resin samples. Three measurements were made per surface, 1 mm from each other for each specimen under a 100 *g* load for 10 seconds.

Knoop hardness $= F/A = F/Cd^2$ where $F =$ applied load (kgf); $A =$ the unrecovered projected area of indentation (mm^2); $d =$ measured length of long diagonal (mm); and $C = 0.07028$.

The mean Knoop hardness and hardness ratio (hardness ratio = Knoop hardness of the bottom surface/Knoop hardness of the top surface) of the specimens were calculated. The hardness data were analyzed by one-way analysis of variance/Tukey post hoc test at a significance level of 0.05. The Pearson correlation coefficient was used to determine significant correlations between surface hardness and light intensity.

RESULTS

We analyzed the light intensities of the various LED units throughout the life of their respective battery charge (Figure 1; Table 3). The light intensity of the Saab II unit gradually decreased from the start of the charge to approximately 0 mW/cm^2 at the end of the charge. The Woodpecker and LY-A180 units demonstrated light intensities that were stable throughout most of the charge; however, at the end of the charge, their intensities decreased rapidly to nearly 0 mW/cm^2. In contrast, the light intensity of the MiniLED unit at the end of the charge cycle was only slightly lower than at the start. The Bluephase, Demi Plus, and Elipar S10 units produced a stable light intensity throughout the life of their respective batteries.

To identify the effects of changes in light intensity on resin polymerization, we determined the Knoop hardness and hardness ratios of the irradiated samples (Table 4). We observed that the hardness values were coincident with the light intensity produced by the units. In the groups in which the light intensity decreased, the samples' hardness also decreased. When the battery charge decreased to 50%, the top and bottom surface hardnesses of the Saab II group samples were significantly lower than those polymerized with a fully charged battery

Table 3: *Light Intensity of the LED Light-curing Units and the Number of Irradiations*

	Light Intensity (Fully Charged), mW/cm^2	Light Intensity (Discharged Battery), mW/cm^2	No. of Irradiations per Charge (20 seconds/use)
LY-A180	850	200-250	145-165
Bluephase	900	900	80-90
Woodpecker	950	50	595-608
Demi Plus	1000-1200	1000-1200	380-406
Saab II	1200	0	360-390
Elipar S10	1250	1250	240-254
MiniLED	2000	1900-2000	90-104

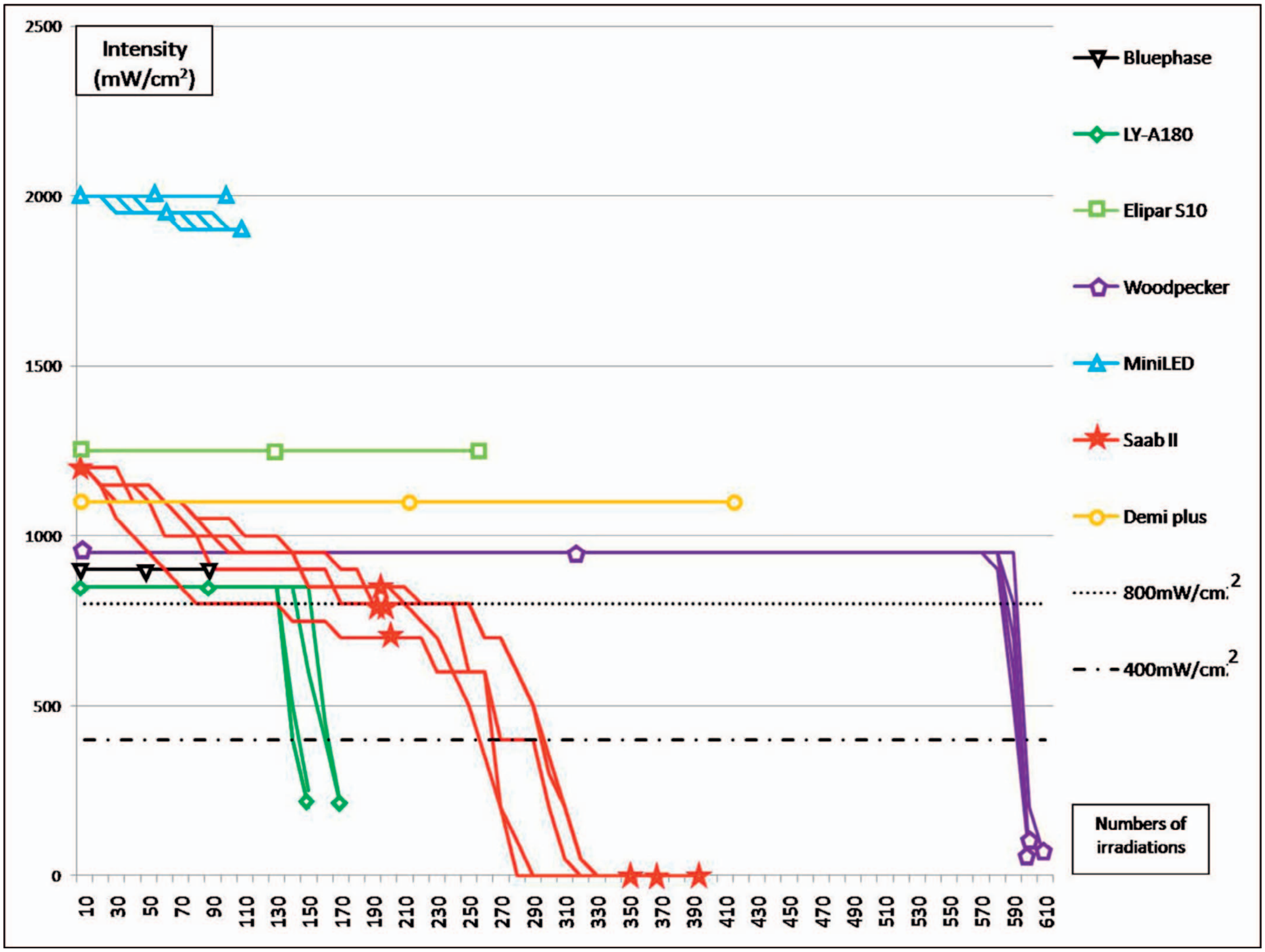

Figure 1. *Light intensity of the LED light-curing units during use.*

($p<0.05$). When 25% of the battery charge remained, the hardnesses of the Woodpecker and the top surface hardnesses of MiniLED group samples were significantly lower than when the batteries were fully charged ($p<0.05$). When the light intensity in the LY-A180, Woodpecker, and Saab II groups became lower than 400 mW/cm^2, the hardnesses of their samples were significantly lower compared with those at 100% charge ($p<0.05$).

The light-curing unit groups all demonstrated hardness ratios greater than 80% when their batteries were fully charged and when they were 50% discharged. However, when only 25% of the battery charge remained, the hardness ratios of the Saab II samples were lower than 80%. Furthermore, when the light intensities of the LY-A180, Woodpecker, and Saab II units decreased to 400 mW/cm^2, the hardness ratios of their samples were lower than 80%.

Results of the Pearson correlation between surface hardness and light intensity revealed that there was a significant direct correlation between top surface hardness and light intensity (r=0.607, p[two-tailed]$\leq$0.01), and there was a significant direct correlation between bottom surface hardness and light intensity (r=0.727, p[two-tailed]$\leq$0.01) (Figure 2).

DISCUSSION

The present study examined the light intensity from seven brands of LED light-curing units over the life of the respective battery charge in each unit. According to the manufacturers, the light intensity of these units ranged from 850 to 2000 mW/cm^2. However, we found that during the battery life of some brands the light intensity decreased. This indicates that the battery power level affected the

Table 4: *The Knoop Hardnesses and Hardness Ratios of the Resin Composites during Usage Simulation*

	Battery	100%		50%		25%		400 mW/cm^2	
		Hardness	Ratio	Hardness	Ratio	Hardness	Ratio	Hardness	Ratio
LY-A180	Top	45.91^{a}	90.59%	46.20^{a}	90.97%	45.53^{a}	91.15%	40.51^{b}	59.76%*
	Bottom	41.59^{a}		42.03^{a}		41.51^{a}		24.21^{b}	
Bluephase^{R}	Top	44.23^{a}	88.04%	43.71^{a}	87.08%	43.56^{a}	87.75%	-	-
	Bottom	38.94^{a}		38.06^{a}		38.22^{a}		-	
Woodpecker^{R}	Top	44.27^{a}	92.86%	45.80^{a}	89.18%	44.1^{b}	87.85%	39.87^{c}	71.51%*
	Bottom	41.11^{a}		40.84^{a}		38.74^{b}		28.52^{c}	
Demi™ plus	Top	45.81^{a}	92.68%	46^{a}	91.68%	45.67^{a}	91.39%	-	-
	Bottom	42.46^{a}		42.18^{a}		41.74^{a}		-	
Saab II	Top	42.61^{a}	93.65%	40.06^{b}	93.07%	39.36^{b}	77.41%*	39.36^{b}	77.41%*
	Bottom	39.90^{a}		37.29^{b}		30.47^{c}		30.47^{c}	
Elipar™ S10	Top	45.06^{a}	91.78%	45.43^{a}	90.88%	44.28^{a}	92.15%	-	-
	Bottom	41.35^{a}		41.29^{a}		40.80^{a}		-	
MiniLED^{R}	Top	46.26^{a}	93.92%	46.40^{a}	92.91%	45.28^{b}	94.63%	-	-
	Bottom	43.45^{a}		43.17^{a}		42.85^{a}		-	

(*) indicates a hardness ratio lower than 80%.
Different letters in a row indicate statistically significant differences in hardness (p<0.05).

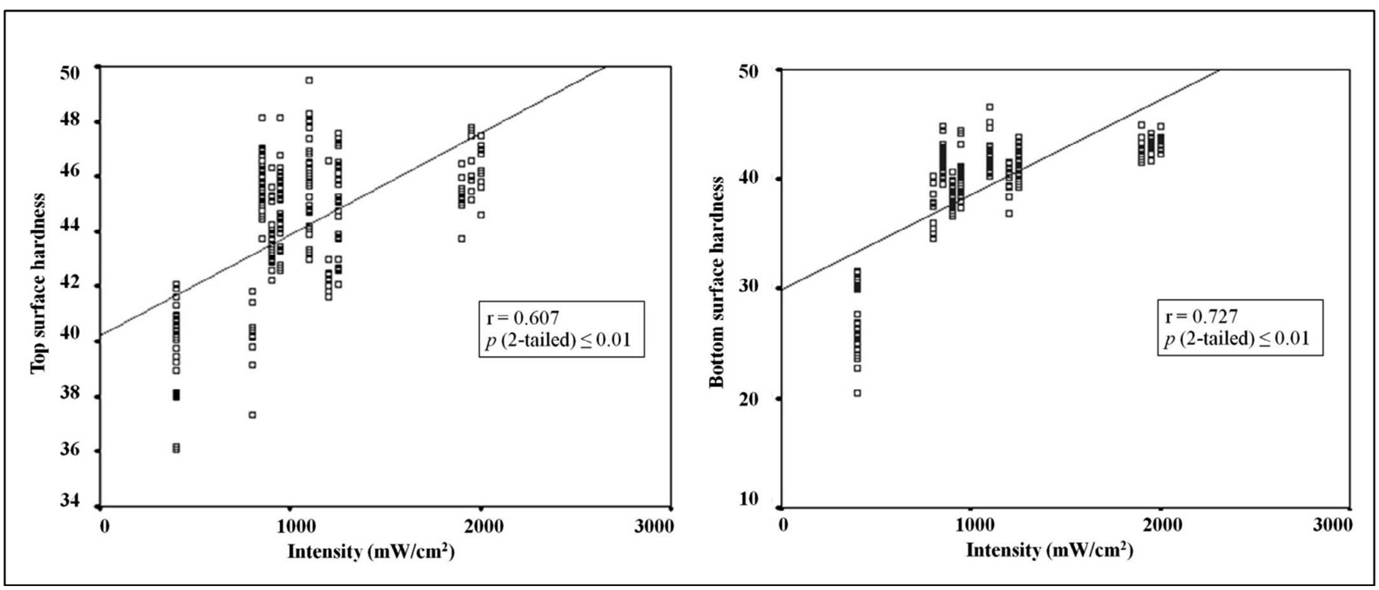

Figure 2. *Pearson correlation between surface hardness and light intensity.*

light intensity of several of the LED light-curing units we evaluated.

It has been reported[13] that the minimum light intensity required for adequate cure of 2 mm of resin composite is approximately 400 mW/cm^2, with an exposure time of 40 seconds. In addition, this study recommended that a light-curing unit with a light intensity lower than 233 mW/cm^2 not be used because this intensity cannot optimally polymerize any depth of resin composite. There are many possible combinations of light energy density (intensity×time) that can be used to achieve an effective resin cure. Most new LED light-curing units produce a light intensity that is greater than 800 mW/cm^2; thus, the irradiation time may be reduced to 20 seconds for a 2-mm-deep resin composite restoration.[19-21] The light intensities of the Saab II, LY-A180, and Woodpecker units all decreased below both 800 and 400 mW/cm^2 as their batteries became discharged. The number of times (20 seconds each) the Saab II unit could be used from the point at which the battery was fully charged until it was fully discharged was approximately 360-390 times/charge. The light intensity was initially 1200 mW/cm^2 and gradually decreased. When the Saab II unit was used 260 times (approximately 70% of the number of irradiations/charge), the light intensity was below 800 mW/cm^2. The Saab II unit was able to be used 110 more times (30% of the number of irradiations/charge) with a decreasingly low intensity that neared 0 mW/cm^2 when the battery was fully discharged, which can affect the degree of polymerization of resin composite.[22] The LY-A180 and Woodpecker units exhibited a stable light intensity of 850 mW/cm^2 and 900 mW/cm^2, respectively, throughout most of their charge. However, at the end of the charge, the light intensity dropped rapidly below 800 mW/cm^2. These units could be used 25 and 20 more times (15% and 3% of the charge, respectively) before their batteries were fully discharged. The MiniLED unit initially produced a very high light intensity of 2000 mW/cm^2 that gradually decreased until the battery was discharged. However, at that point the intensity was at 1900 mW/cm^2, which is higher than the 800 mW/cm^2 considered optimal. We observed that battery power influenced the light intensity output for all of the light-curing units evaluated. We speculate that in some light-curing units on the market, the battery may produce a varied line voltage, which affects the stability of the light intensity output.[23] However, the present study simulated light-curing unit use for only five charging cycles, which is a short portion of the LED lifetime. Further research is required to investigate the light intensity from an LED light-curing unit throughout its lifetime.

Hardness testing is a reliable and commonly used method to evaluate how well a resin has been cured. The Knoop microhardness test is one of the best methods for determining the hardness of resin composites, and a good correlation has been reported[24,25] between the degree of conversion of a resin composite and its Knoop microhardness value. In our study, we found that the hardness values were coincident with the light intensity. The top and bottom surface hardnesses of the Saab II samples at 50% and 25% of the battery charge and at 400 mW/cm^2 were significantly lower than those at 100% charge, and the lowest hardness was found when the light intensity was 400 mW/cm^2. This can be explained by the fact that the light intensity of the Saab II unit gradually decreased throughout its battery charge. In contrast, only the top surface hardnesses of the MiniLED samples decreased at 25% of its battery charge, reflecting its light intensity pattern, which decreased from 2000 mW/cm^2 to 1900 mW/cm^2. Furthermore, the lowest top and bottom surface hardnesses of the LY-A180 and Woodpecker unit samples were observed when their light intensity was 400 mW/cm^2. This is likely because the light intensities of these units were stable at 100%, 50%, and 25% of the battery charge, until at the end of the cycle the light intensities dramatically decreased below 400 mW/cm^2. Based on our results, when the light intensity was higher than 400 mW/cm^2, the Knoop hardness values were still high. In clinical practice, we suggest that the light intensities of LED light-curing units should be more than 400 mW/cm^2 to optimize the degree of conversion and increase the mechanical properties of resin composites.

The degree of polymerization of a resin composite should be the same throughout its depth, and its hardness ratio should be 1 or approximately 1. As the curing light passes through the bulk of the resin composite, its intensity is greatly reduced as a result of light-scattering, thus decreasing curing effectiveness.[26] Light-scattering likely accounted for the differences in hardness between the top and bottom surfaces of our samples. The hardness ratio should be equal to or greater than 80% for visible-light-cured composites.[27] When the light intensities of the LY-A180, Woodpecker, and Saab II units (25% of the battery charge and 400 mW/cm^2 were coincident only for the Saab II unit) were at 400 mW/cm^2, the hardness ratios of their samples were less than 80%. This indicates that an effective cure depth of 2 mm of the resin composite could not be achieved with 20 seconds of a 400 mW/cm^2 light intensity.

In the present study, the distance from the light guide tip to the resin composite surface was 0 mm, and the direction of the light guide was perpendicular to the surface. However, in clinical practice, there can be hard-to-reach restoration areas requiring polymerization, and it is difficult to position the light guide close to and perpendicular to these surfaces. Thus, the amount of light energy delivered to a restoration under ideal laboratory conditions may be greater than that which can be achieved clinically.[28]

Clinically, it is important to select stable light intensity light-curing units and to monitor light intensity by means of radiometry or manufacturers' light intensity indicators during the LED lifetime. In this study, some LED light-curing units underperformed when the battery charge decreased to 25%. This can be avoided if the dental staff replaces the light-curing units on the charging stand regularly or keeps the battery fully charged.

CONCLUSIONS

The present study demonstrated that the light intensities of some LED light-curing units currently on the market are stable throughout their battery charge, regardless of the remaining battery power. However, there are some LED light-curing units whose light intensity stability is dependent on battery power, which can affect the degree of conversion of a resin composite. Evaluating the light intensity of a LED light-curing unit regularly during its use is recommended, especially as the unit ages.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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