

Irradiance of Different Curing Modes of Common Light Cure Devices: An *In Vitro* Study

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ABSTRACT **Aim:** The aim of this study was to test the irradiance values of different curing modes of commonly available light cure devices (LCDs). **Materials and Methods:** An *in vitro* investigation was carried out to compare the irradiance output of 10 brands of LCDs available in Saudi Arabia measured using a digital radiometer. Values were recorded for three time points when applicable (0, 10, and 20s). This technique was repeated five times for each LCD. Normal, high-intensity, and soft-start modes were evaluated for all brands with the features available. Irradiance values between brands were analyzed using one-way analysis of variance followed by Bonferroni method. Changes in irradiance between different time points were analyzed using one sample *t* test for normal and high-intensity modes and using paired *t* test for soft-start mode. All comparisons were carried out at 0.05 significance level. **Results:** The highest values were reported for Ortholux Luminous, Elipar DeepCure-S, Elipar DeepCure, and KaVo mini-LED with values above 1000 mW/cm². All LCDs showed values above 600 mW/cm². Three LCDs had high-intensity mode and only one device had soft-start mode. Changes over the different time points were not statistically significant except for soft-start mode. **Conclusion:** All tested LCDs had irradiance values sufficient for adequate polymerization of resin composite. Only four of these are capable of curing bulk-fill composites.

KEYWORDS: Curing modes, irradiance, light cure

INTRODUCTION

Resin composites are used widely in the dental field, due to their excellent aesthetic and physical properties.^[1-3] Resin composite formulations have advanced drastically to cope with clinical applications and patients' demands.^[4] The selection of a good light cure device (LCD) is an essential step for curing composite restoration.^[3,5,6] The polymerization of composite particles from monomer to polymer is initiated by photoinitiator activation; light cure quality will affect the degree of polymerization reaction. The number of photons generated by LCDs affect the light intensity and subsequent polymerization reaction.^[7]

The success and longevity of resin composite restorations can be affected by the quality of light

generated by LCDs. A common metric to depict this is the irradiance value (measured in mW/cm²), which is described as the amount of light reaching a particular surface area of composite.^[5] In general, irradiance values of <300 mW/cm² are not recommended to cure dental composites.^[8] Irradiance is affected by factors such as radiant power of the LCD and distance from composite surface.^[9] The longevity of the resin composite restorations can be affected by LCD performance owing to their irradiance values.^[10]

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This is especially true with the newly introduced bulk-fill composite materials that have different chemistry and photoinitiator formulations requiring greater irradiance values ($>1000 \text{ mW/cm}^2$) to achieve adequate polymerization.^[11]

Further, the polymerization reaction of resin composites can be affected by the different modes of light curing as these modes alter the light output of the device. In the traditional mode, a burst of light with high irradiance values will lead to fast polymerization and possibly high polymerization shrinkage stress. To minimize this problem, gradual polymerization mode is found that could potentially help in reducing the formation of marginal gap.^[4] High-intensity mode is sometimes used in orthodontic application where a relatively thin amount of resin is used to bond brackets. Still, irradiance values of different light-curing modes

are of a great importance to the practicing dentist. Therefore, the aim of this study was to measure the irradiance values of different brands of LCDs and their curing modes.

MATERIALS AND METHODS

STUDY DESIGN

This investigation was an *in vitro* cross-sectional study involving 10 LCDs available in the Saudi Arabian market. The irradiance values of different curing modes were recorded.

SAMPLING CRITERIA

Light irradiance of 10 light-emitting diode (LED) LCDs available in the Saudi market [Figure 1], Elipar DeepCure (3M, St. Paul, Minnesota), Elipar DeepCure-S (3M), Ortholux Luminous (3M), Bluephase N M (Ivoclar Vivadent, Schaan, Liechtenstein), VALO Cordless

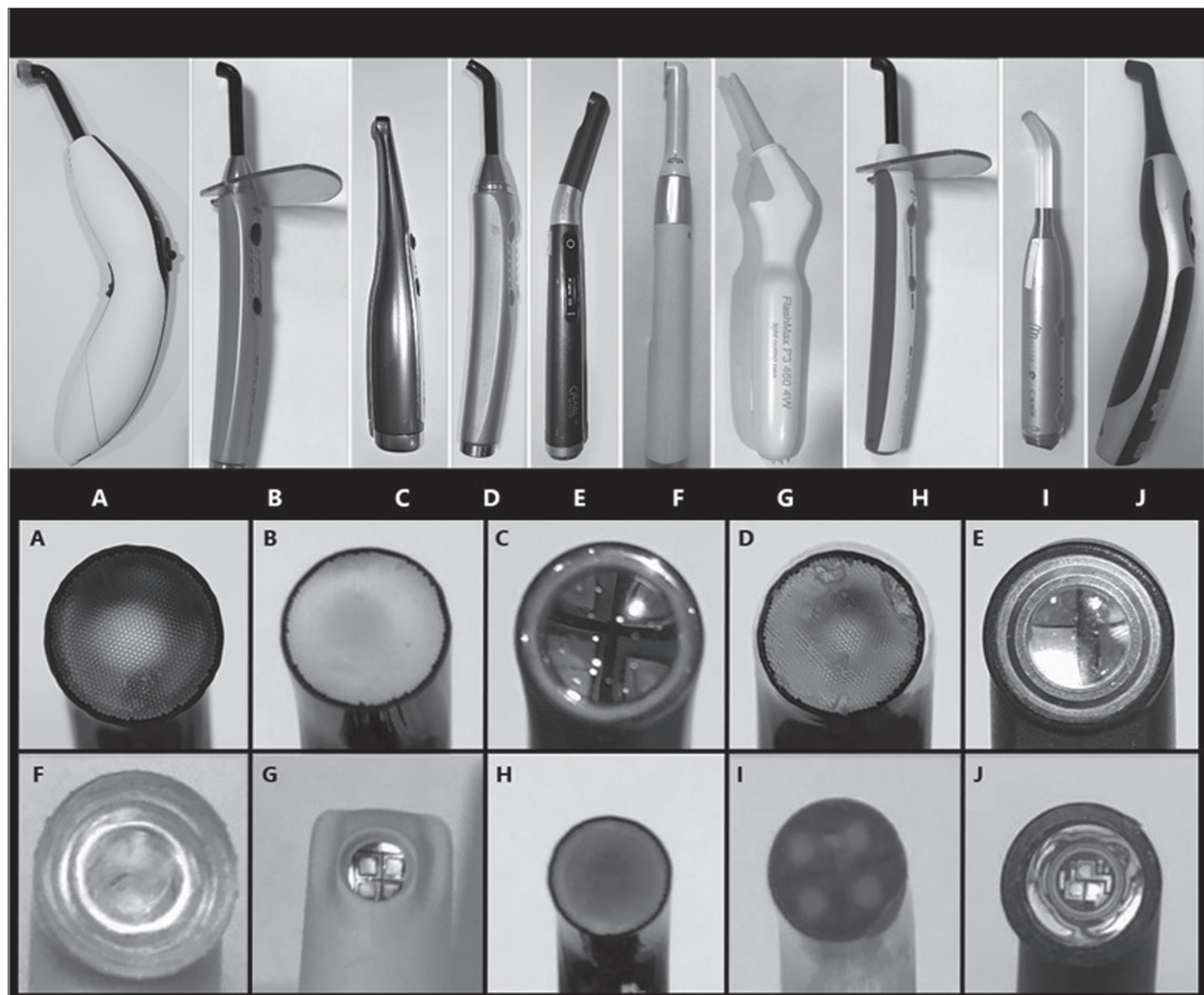


Figure 1: The different light cure devices included in the study. (A) Ivoclar Vivadent Bluephase N M. (B) 3M Elipar DeepCure-S. (C) Ultradent VALO Cordless. (D) 3M Ortholux Luminous. (E) Dr's Light Clever. (F) DTE-iLED. (G) FlashMax P3. (H) 3M Elipar DeepCure-L. (I) KaVo mini-LED. (J) Kerr Demi Ultra

(Ultradent Products, South Jordan, Utah), Demi Ultra (KaVo Kerr, Orange, California), Dr's Light Clever (Good Doctors, Incheon, Republic of Korea), KaVo mini-LED (KaVo Dental GmbH, Bismarckring, Germany), DTE-iLED (Woodpecker, Guilin, Guangxi, China), and FlashMax P3 (Ragnagade 7, Copenhagen, Denmark), was measured using a digital radiometer (Bluephase Meter II, Ivoclar Vivadent).

OBSERVATIONAL PARAMETERS

The tip of the LCD was measured using the radiometer's built in gauge and the value was plugged into the radiometer. The curing tip was laid flat on the radiometer sensor and the device was operated for 20s. Irradiance values were recorded for 0, 10, and 20s. Some devices did not support continuous curing for 20s; only values for 0 and 10s were recorded for those devices. This technique was repeated five times for each LCD and an average value was calculated. A similar approach was used for LCDs with soft-start mode. For high-intensity mode, irradiance value after 3s was reported.

STATISTICAL ANALYSIS

Data were collected, tabulated, and analyzed using Statistical Package for the Social Sciences software program, version 17.0 (IBM, Armonk, New York). Quantitative variables were described using the mean, standard deviation, and 95% confidence interval. For irradiance data among different brands, one-way analysis of variance (ANOVA) was used to test differences in mean values followed by Bonferroni

multiple comparison method to determine which devices are different from each other. Changes of irradiance values at different time points within the same brand were analyzed using one-sample *t* test for normal and high-intensity modes and using paired *t* test for soft-start mode. All comparisons were carried out at 0.05 significance level.

RESULTS

Overall, all LCDs tested registered irradiance values above the threshold of 600 mW/cm² [Figure 2]. However, only four of these were associated with irradiance values >1000 mW/cm² required to adequately polymerize bulk-fill formulation. Statistical testing of mean irradiance values for normal mode showed statistically significant differences among the tested brands [Tables 1 and 2; *P* < 0.001].

Irradiance values can be categorized into four groups: Group A with irradiance values between 600 and 800 mW/cm² that includes Dr's Light Clever, DTE-iLED, VALO Cordless, and Demi Ultra; Group B with values between 800 and 1000 mW/cm² that includes Bluephase N M; Group C with values between 1000 and 1200 mW/cm² that includes Elipar DeepCure-S, Elipar DeepCure, and KaVo mini-LED; Group D with values >1200 mW/cm² that includes Ortholux Luminous.

Only three LCDs had a high-intensity mode [Figure 3] with FlashMax P3 showing significantly higher irradiance values as compared to DTE-iLED and VALO Cordless [Tables 3 and 4; *P* < 0.001]. Regarding

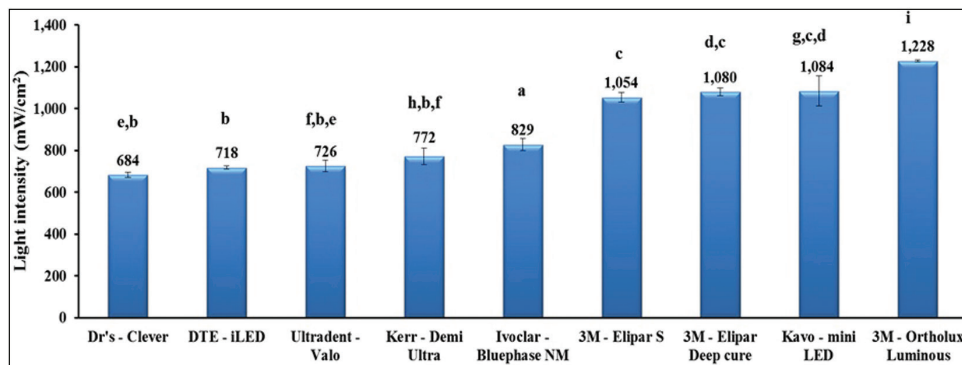


Figure 2: Mean values of light intensities with normal mode of various light cure unit brands. Error bars indicate standard deviation. Devices with the same letter are not statistically different (*P* > 0.05)

Table 1: One-way analysis of variance: tests between subjects effects for normal curing mode

Statistical test	Sum of squares	df	Mean square	F	P value
Between groups	2198061.3	8	274757.7	160.062428	0.000000
Within groups	113293.33	66	1716.566		
Total	2311354.7	74			

df = degrees of freedom

Dependent variable: light intensity mW/cm²

Table 2: Bonferroni test: tests whose devices are different for normal curing mode

Light cure device 1	Light cure device 2	Mean difference	SE	P value	Significance
Ivoclar Bluephase N M	DTE-iLED	110.67	21.40	0.000084	Yes
Ivoclar Bluephase N M	3M Elipar DeepCure-S	-225.33	21.40	0.000000	Yes
Ivoclar Bluephase N M	3M Elipar DeepCure	-251.33	21.40	0.000000	Yes
Ivoclar Bluephase N M	Dr's Light Clever	144.67	21.40	0.000000	Yes
Ivoclar Bluephase N M	Ultradent VALO Cordless	102.67	21.40	0.000342	Yes
Ivoclar Bluephase N M	KaVo mini-LED	-255.33	15.13	0.000000	Yes
Ivoclar Bluephase N M	Kerr Demi Ultra	56.67	15.13	0.013689	Yes
Ivoclar Bluephase N M	3M Ortholux Luminous	-399.33	21.40	0.000000	Yes
DTE-iLED	3M Elipar DeepCure-S	-336.00	26.20	0.000000	Yes
DTE-iLED	3M Elipar DeepCure	-362.00	26.20	0.000000	Yes
DTE-iLED	Dr's Light Clever	34.00	26.20	1.000000	No
DTE-iLED	Ultradent VALO Cordless	-8.00	26.20	1.000000	No
DTE-iLED	KaVo mini-LED	-366.00	21.40	0.000000	Yes
DTE-iLED	Kerr Demi Ultra	-54.00	21.40	0.504681	No
DTE-iLED	3M Ortholux Luminous	-510.00	26.20	0.000000	Yes
3M Elipar DeepCure-S	3M Elipar DeepCure	-26.00	26.20	1.000000	No
3M Elipar DeepCure-S	Dr's Light Clever	370.00	26.20	0.000000	Yes
3M Elipar DeepCure-S	Ultradent VALO Cordless	328.00	26.20	0.000000	Yes
3M Elipar DeepCure-S	KaVo mini-LED	-30.00	21.40	1.000000	No
3M Elipar DeepCure-S	Kerr Demi Ultra	282.00	21.40	0.000000	Yes
3M Elipar DeepCure-S	3M Ortholux Luminous	-174.00	26.20	0.000000	Yes
3M Elipar DeepCure	Dr's Light Clever	396.00	26.20	0.000000	Yes
3M Elipar DeepCure	Ultradent VALO Cordless	354.00	26.20	0.000000	Yes
3M Elipar DeepCure	KaVo mini-LED	-4.00	21.40	1.000000	No
3M Elipar DeepCure	Kerr Demi Ultra	308.00	21.40	0.000000	Yes
3M Elipar DeepCure	3M Ortholux Luminous	-148.00	26.20	0.000013	Yes
Dr's Light Clever	Ultradent VALO Cordless	-42.00	26.20	1.000000	No
Dr's Light Clever	KaVo mini-LED	-400.00	21.40	0.000000	Yes
Dr's Light Clever	Kerr Demi Ultra	-88.00	21.40	0.003976	Yes
Dr's Light Clever	3M Ortholux Luminous	-544.00	26.20	0.000000	Yes
Ultradent VALO Cordless	KaVo mini-LED	-358.00	21.40	0.000000	Yes
Ultradent VALO Cordless	Kerr Demi Ultra	-46.00	21.40	1.000000	No
Ultradent VALO Cordless	3M Ortholux Luminous	-502.00	26.20	0.000000	Yes
KaVo mini-LED	Kerr Demi Ultra	312.00	15.13	0.000000	Yes
KaVo mini-LED	3M Ortholux Luminous	-144.00	21.40	0.000000	Yes
Kerr Demi Ultra	3M Ortholux Luminous	-456.00	21.40	0.000000	Yes

SE = standard error

Dependent variable: light intensity mW/cm²

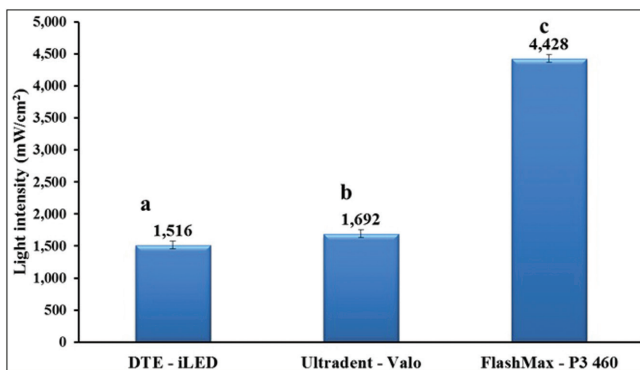


Figure 3: Mean values of light intensities with high-intensity mode of various light cure unit brands. Error bars indicate standard deviation. Devices with the same letter are not statistically different ($P > 0.05$)

changes in irradiance, no statistical significant changes were observed for 0, 10, and 20 s in all brands for normal and high-intensity modes (data not shown; $P > 0.05$).

For soft-start mode [Figure 4], only one device had this feature, which is KaVo mini-LED. Values for 0s were <300 mW/cm² and then increased significantly at 10 and 20 s ($P < 0.05$).

DISCUSSION

The use of composite resin restorations is increasing nowadays due to superior esthetics and good mechanical properties.^[2,12] The irradiance values of light-curing devices are an integral part in achieving predictable composite resin polymerization and subsequent

Table 3: One-way analysis of variance: tests between subjects effects for high-intensity curing mode

Statistical test	Sum of squares	df	Mean square	F	P value
Between groups	26660693	2	13330347	3501.84238	0.000000
Within groups	45680	12	3806.667		
Total	26706373	14			

df = degrees of freedom

Dependent variable: light intensity mW/cm²

Table 4: Bonferroni test: tests whose devices are different for high-intensity curing mode

Light cure device 1	Light cure device 2	Mean difference	SE	P value
DTE-iLED	Ultradent VALO Cordless	-176.00	39.02	0.002141
DTE-iLED	FlashMax P3 460	-2912.00	39.02	0.000000
Ultradent VALO Cordless	FlashMax P3 460	-2736.00	39.02	0.000000

SE = standard error

Dependent variable: light intensity mW/cm²

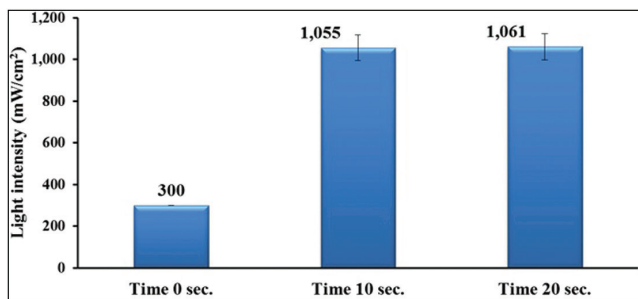


Figure 4: Mean light intensity for KaVo mini-light emitting device with soft-start mode. Error bars indicate standard deviation

restoration life span.^[13-15] Due to the introduction of new bulk-fill composite formulations, the need to ensure adequate light irradiance of curing units is even greater. The objective of the current investigation was to test the light irradiance of different light cure units in different modes.

The technology of light cure has been improved in the last decade due to foundation of high-intensity LED, quartz-tungsten-halogen (QTH) light, and plasma arc lights. These devices are manufactured to generate less heat and to cure the resin faster. Due to its advantages, LED recently is the most popular LCD as compared to halogen light.^[4] Among LEDs, 10 of the most used LCDs were chosen. Some of these have high-intensity mode, which is important in orthodontic brackets placement. We used a digital radiometer because it gives reliable results and takes into consideration the tip diameter.

In addition for testing light output for conventional composite curing, we wanted to investigate which LCDs in the market can do proper polymerization of bulk-fill composite materials. We found three devices (Ortholux Luminous, Elipar DeepCure, and Elipar DeepCure-S), which can do proper polymerization for bulk-fill composite due to their irradiance values being >1000 mW/cm². In a recent study, only 10% of the tested 166

LCDs produced values capable of polymerizing bulk-fill formulations.^[16] The bulk-fill formulation usually contains new photoinitiators that are more sensitive but still require higher irradiance values to produce adequate degree of conversion with 4mm or more increments.^[17,18] In general, bulk-fill composites require 10s of curing at >1000 mW/cm² according to most manufacturers.^[19]

Three LCUs have the high irradiance (DTE-iLED, VALO Cordless, and FlashMax P3 460), which can be used in placing orthodontic brackets. All tested LCDs can do proper polymerization of conventional composite with irradiance values of 600 mW/cm² and above. Of course, this setup must be accompanied by using incremental technique to reduce the inherent polymerization shrinkage of resins.^[20,21] Each layer has to be light cured for at least 20s to achieve proper degree of conversion^[10] and to avoid negative repercussions of inadequate polymerization that include discoloration, sensitivity, and pulpal irritation.^[3,5,6,22,23] In a clinical survey, Bansal *et al.*^[24] found that 54% of the 1000 tested devices gave output values <400 mW/cm². On the contrary of this and in accordance with our findings, Soares *et al.*^[10] reported that only 2 of 22 tested LCDs produced irradiance values of <400 mW/cm². Although all the tested devices of this study were new, frequent maintenance and check is required to ensure adequate output of LCDs.

As with other *in vitro* studies, this investigation has some limitations. The choice of LCDs was limited to devices available in the Saudi market. Also, effect of irradiance on actual composite was not tested. Still, dentists practicing in Saudi Arabia and neighboring countries would benefit from the current instigation's results as it has direct impact on the predictability and mechanical properties of composite restorations they place.^[3,22,23] Further, as depicted from previous investigations, mechanical characteristics of cured composite depend on

the irradiance values of LCDs and subsequent degree of conversion.^[14,15] On the basis of our results, the majority of investigated LCDs produced adequate irradiance values in their normal mode to achieve adequate polymerization of resin composite. Only three devices were able of producing values >1000 mW/cm² and are capable of curing bulk-fill composite formulations.

CONCLUSION

Using light-curing units with adequate irradiance and exposing each composite resin increment for the recommended curing time are important factors to achieve restorations with predictable properties and long service life.

ACKNOWLEDGMENTS

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Nil.

CONFLICTS OF INTEREST

There are no conflicts of interest.

AUTHOR CONTRIBUTIONS

Study conception (HN), data collection (AM, MA), data acquisition and analysis (AM, MA), data interpretation (HN, AM, MA), manuscript writing (HN, AM, MA).

ETHICAL POLICY AND INSTITUTIONAL REVIEW BOARD STATEMENT

This project is exempted from ethical approval due to lack of human and/or animal samples. All the procedures have been performed as per the ethical guidelines laid down by Declaration of Helsinki.

DATA AVAILABILITY STATEMENT

The data that support the study results are available from the author (Dr. Albaraa Makhdom, e-mail: fz1994@live.com) on request.

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