

Temperature rise and Knoop hardness promoted by different light-curing units

Aumento de temperatura e dureza Knoop promovida por diferentes unidades de fotoativação

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ABSTRACT

This study characterized the light emitted by a quartz-tungsten-halogen (QTH) and three light-emitting diode (LED) light curing units (LCUs) and investigated the temperature rise and composite hardness promoted by these sources. XL2500 QTH (3M ESPE), Freelight LED (3M ESPE), Ultrablue Is LED (DMC) and Cool Blue Wand LED (Milestone Scientific) were investigated. The irradiance was measured with a power meter, and the light spectral distribution obtained with a spectrometer. Temperature rise was recorded using a thermocouple connected to a digital thermometer during light-activation of Filtek Z250 (3M ESPE) resin composite. Data were submitted to ANOVA and Tukey's test ($\alpha=0.05$). Knoop hardness was assessed at different composite depths (20, 1000 and 1980 μm), and data submitted to split-plot design two-way ANOVA and Tukey's test ($\alpha=0.05$). Correlation between irradiance and temperature rise was investigated by Pearson's test. All units presented 95% of irradiance between 400-515nm. Temperature rise means ($^{\circ}\text{C}$) varied between 1.05 ± 0.16 and 2.74 ± 0.27 . The Cool Blue LED presented significantly higher temperature increase than the other LCUs, and the QTH promoted significantly higher temperature rise than Ultrablue Is and Freelight LEDs. Significant relationship between irradiance and temperature increase was detected ($r=0.867$; $p<0.001$). Hardness means (kg/mm^2) varied between 40.1 ± 3.6 and 92.7 ± 6.6 . Samples activated by the Freelight LED presented significantly lower hardness than samples activated by the others units.

UNITERMS

Light-activation; hardness; resin composites; temperature.

INTRODUCTION

Photo-activation of resin composites has been an issue of major interest in dental research during the last years. Although quartz-tungsten-halogen (QTH) light-curing units (LCUs) are the most traditional ones, blue light-emitting diodes (LEDs) are increasingly popular among clinicians. These LCUs emit a narrow spectrum that is better correlated with the spectral absorbance peak of camphorquinone (CQ), the most commonly used photo-initiator in dental composites.¹⁵

Therefore, it has been advocated that LED can prevent overheating as compared to QTH units,^{21,24,25} which produce a broader band of wavelengths and require filters to remove those that are not useful.¹⁵

The first-generation of LED sources, however, presented lower power outputs compared to QTH units.⁵ In order to increase the emitted irradiance and thus enhance the polymerization potential of LED lights, manufacturers are currently using large surface-emitting chips.

Nonetheless, increasing the light irradiance might also result in higher temperature rise due to radiation energy. Previous studies have pointed out for the risk of heat-generation during light-activation procedures,^{2,4,9,12,17-21,24,25} and clinicians should be aware of the potential thermal hazard to pulp tissues during photo-activation of resin materials,¹² mainly in deep cavities.

In spite of the temperature rise, a low resulting temperature could also be related to poor mechanical properties of the cured composite.^{17,18} An effective polymerization is important to avoid clinical problems due to cytotoxicity effects, increased wear and marginal breakdown, and lower hardness.^{6,7,18} Therefore, the aim of this study was to analyze the irradiance of one QTH and three LED LCUs at different regions of the light spectrum (between 190-400nm, between 400-515nm, and above 515nm), in order to characterize each LCU, and also to investigate the temperature rise and the composite hardness promoted by these different units. This investigation tested the hypothesis that LED LCUs always produce similar cure as the QTH one, however, with less heat development.

MATERIAL AND METHOD

The resin composite Filtek Z250 (3M ESPE, St. Paul, MN, USA), shade A2, was selected, and four LCUs investigated: QTH XL2500 (3M ESPE, St. Paul,

MN, USA), Freelight LED (3M ESPE), Ultrablue Is LED (DMC Ltda., São Carlos, SP, Brazil), and Cool Blue Wand LED (Milestone Scientific, Livingston, NJ, USA).

Light characterization

The output power (mW) emitted by each LCU was measured with a digital power meter (Ophir Optronics Inc., Danvers, MA, USA), and the diameter of the light guide tip (cm) with a digital caliper (Mitutoyo Tokyo, Japan). The irradiance (mW/cm²) of each LCU was computed as the ratio of the output power by the area of the light guide. The light spectral distribution emitted by each LCU was obtained using a computer-controlled spectrometer (USB 2000, Ocean Optics, Dunedin, FL, USA). Data from irradiance and spectral analyzes were tabulated in an appropriate software (Origin 6.1, OriginLab Corp., Northampton, MA, USA) to obtain, by numerical integration, the specific irradiance of the light spectrum in the regions between 190-400nm, 400-515nm, and above 515nm.

Temperature rise analysis

The temperature increase (°C) was recorded using a type-K thermocouple connected to a digital thermometer (Iopetherm 46, IOPE, São Paulo, SP, Brazil). The

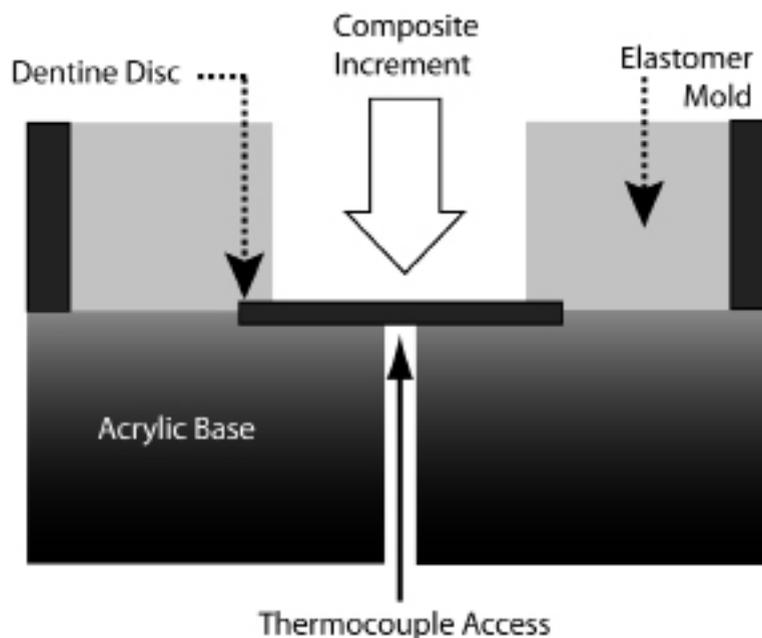


Figure 1 – Apparatus for measurement of the temperature rise

composite was placed into a cylindrical elastomeric mold (3mm in inner diameter vs. 2mm in height) with the thermocouple positioned in the center of the mold. A 0.5mm-thick bovine dentin disc was positioned between the thermocouple and the composite to simulate the leftover dentin, as shown in Figure 1. The composite was covered with a Mylar strip and hand pressure was applied. The material was photo-activated for 20s, as recommended by the manufacturer, with the light guide tip placed leaned to the composite/mold. Ten specimens were prepared for each LCU.

All measurements were made in a room with controlled temperature ($20 \pm 1^\circ\text{C}$). The initial temperature was recorded following stabilization. The composite was then light-activated and the temperature rise peak registered, even when the light was turned off. Temperature variation was recorded as the difference between final and initial values. Data were submitted to one-way ANOVA and Tukey's test ($\alpha=0.05$). In addition, correlation between light irradiance and temperature rise was investigated by Pearson's correlation test.

Hardness assessment

After the photo-activation procedures, specimens were placed in light-proof containers and stored at 37°C , for 24h. Thereafter, samples were embedded in epoxy resin and transversally flattened through 320-, 400-, 600- and 1200-grit silicon carbide papers in a water-cooled automatic polisher (APL-4, Arotec, Cotia, SP, Brazil). Knoop hardness measu-

rements were conducted with an indenter (HMV-2, Shimadzu, Tokyo, Japan) under a load of 50g for 15s. Three indentations were performed at three different composite depths: $20\mu\text{m}$ (top), $1000\mu\text{m}$ (middle) and $1980\mu\text{m}$ (bottom), as shown in Figure 2. The average value among the three readings was recorded as the Knoop hardness number (KHN, kg/mm^2) for each layer. Data were submitted to a split-plot design two-way ANOVA followed by Tukey's test for multiple comparisons ($\alpha=0.05$).

RESULTS

Figure 3 depicts the spectral distribution of the LCUs. Narrower wavelength spectra were observed for LED units as compared to the QTH one. Table 1 summarizes the characteristics of the emitted light. All units presented approximately 95% of the light irradiance concentrated at the 400-515nm wavelength range.

Table 2 shows the temperature change data. The Cool Blue LED presented significantly higher temperature rise than all other units ($p<0.05$), and the QTH unit promoted significantly higher temperature increase when compared to Ultrablue Is and Freelight LEDs ($p<0.05$). In addition, Pearson's correlation test detected a significant positive relationship between irradiance and temperature rise ($r=0.867$; $p<0.001$).

Table 3 presents the mean KHN for the different composite depths. Samples light-activated by QTH, Ultrablue Is and Freelight LCUs presented significantly higher hardness values than Freelight LED specimens.

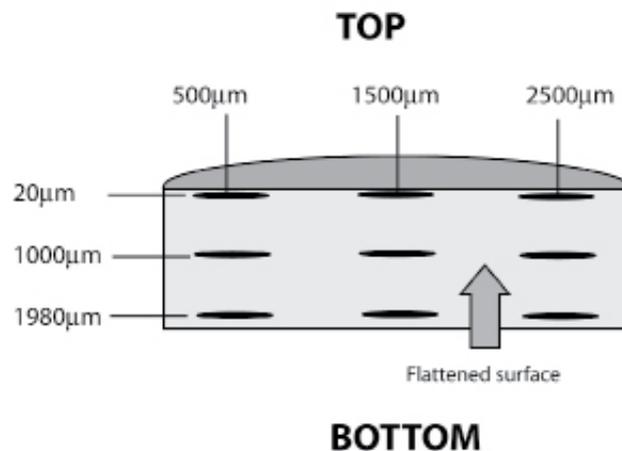


Figure 2 – Diagram of Knoop hardness readings localizations

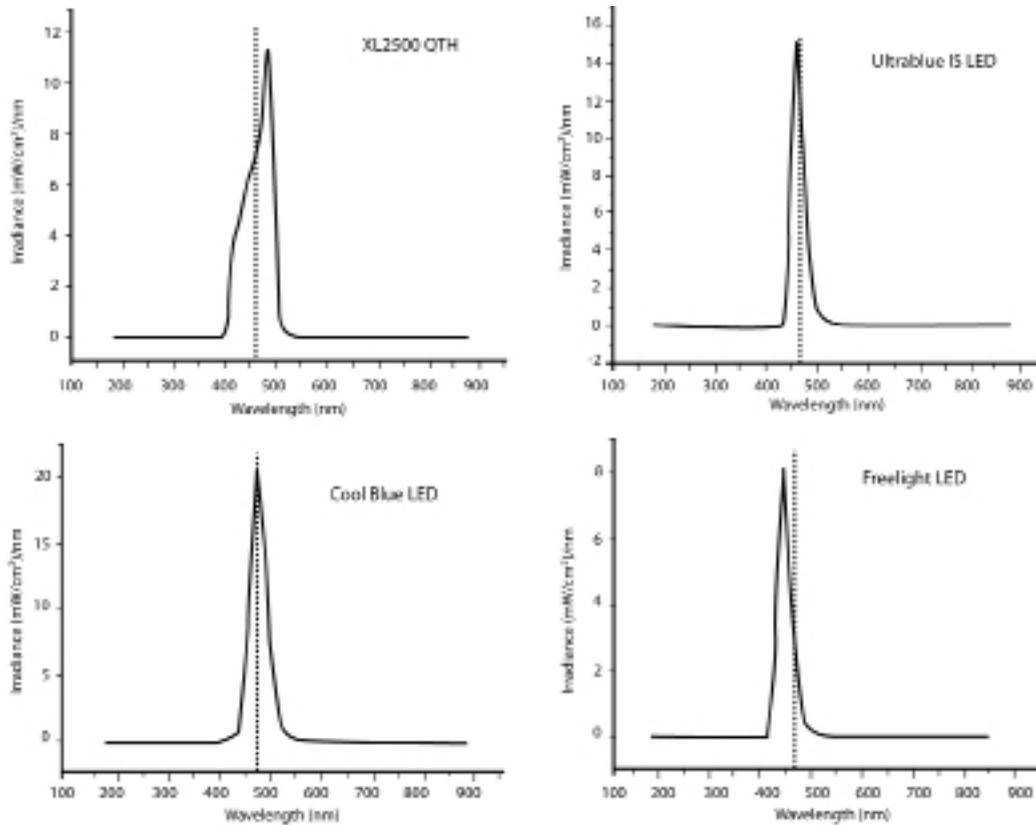


Figure 3 - Light spectrum profiles emitted by the curing units. The dotted line indicates the absorbance peak of camphorquinone (468nm)

With respect to hardness at different depths, no significant differences were observed between the Freelight and Cool Blue LEDs. However, for Ultrablue Is, the middle layer was found to be significantly harder than the bottom and top ones. For the QTH unit, hardness at the middle layer was significantly higher than bottom hardness.

DISCUSSION

LED LCUs have a great potential for achieving a clinical quality of composite cure with the advantage of converting electricity into light more efficiently than QTH LCUs.³ Owing to a narrow wavelength range of light emission, it has been generally attributed to LED units advantageous characteristics such as consuming less power and generating less heat than halogen lamps.²² In fact, other authors^{19,20} have cited the heat development as the major disadvantage of QTH LCUs. Nonetheless, the present study shows different outcomes.

A positive and significant relationship between irradiance intensity and temperature rise was detected. As recommended by the composite's manufacturer, a 20s time of light exposure was used for all LCUs. Thereby, the differences in temperature change might be in part related to differences in the radiant exposure (irradiance intensity x exposure time, in J/cm^2) emitted by each LCU, what is in agreement with previous findings.¹⁸ In fact, the Cool Blue LED LCU, which emitted the highest radiant exposure dose ($783mW/cm^2 \times 20s = 15.6 J/cm^2$), also produced the highest temperature increase. However, care should be taken when concluding that the temperature change is directly related to radiant exposure and light irradiance. A recent study¹⁷ showed that the effect of radiant exposure on the temperature increase might be dependent upon both the mode of radiant exposure distribution and its dissipation along the time. For example, the effect of a light energy of $12 J/cm^2$ along 30s is probably different from the application along 3s. However, as in the present study the same exposure time was used for all LCUs, a direct relationship was shown. Regarding

Table 1 – Light characteristics of the different curing units

Unit	Irradiance (mW/cm ²)	Peak of emission (nm)	Irradiance (mW/cm ²) at different regions of the light spectrum		
			190-400nm	400-515nm	above 515nm
XL2500 QTH	669	483	3.94	658	6.64
Cool Blue LED	783	472	6.93	758	4.3
Ultrablue Is LED	53	457	5.18	437	9.5
Freelight LED	270	452	3.74	259	5.88

Table 3 – Means (standard deviation) for hardness at different depths

Layer	XL2500 QTH	Ultrablue Is LED	Freelight LED	Cool Blue LED
Top	81.7 (17.3) ^{A,ab}	76.6 (11.5) ^{A,b}	40.1 (3.6) ^{B,a}	88.2 (7.6) ^{A,a}
Middle	88.2 (14.4) ^{A,a}	92.7 (6.6) ^{A,a}	44.2 (8.2) ^{B,a}	84.4 (5.7) ^{A,a}
Bottom	74.2 (15.7) ^{A,b}	78.5 (7.9) ^{A,b}	43.9 (5.6) ^{B,a}	79.3 (5.9) ^{A,a}

Means followed by different capital letters in the same line, and small letters in the same column, were significantly different (p<0.05).

the different light systems, the present findings agree with those from Asmussen e Peutzfeldt² (2005), which showed that the temperature rise induced by QTH LCUs is not always higher compared to LED units.

Another factor associated with temperature change during light-activation procedures is the emission spectrum of the LCUs.^{9,10,13} The light output outside the effective curing range (between 400-500nm)¹⁵ could significantly contribute to heat production. Asmussen e Peutzfeldt² (2005) also suggest that the temperature change can be associated with the effectiveness of QTH heat filters. Figure 3 shows the spectral emission of the LCUs. It can be seen that the QTH LCU has a broader spectrum than the LED LCUs. However, the efficiency of the QTH LCU filters, in numerical terms, is shown in the Table 1, where it can be observed that this LCU emitted very low values of irradiance above 515nm. Therefore, care should be taken with general statements. Furthermore, it is well known that not only the irradiance but also the spectral distribution can vary among LCUs systems, brands and even among lights of the same model.¹³

Spectral output, irradiance intensity and curing mode are the major features associated with effectiveness of cure promoted by a LCU.¹⁵ If a photo-activated

Table 2 – Temperature rise means (standard deviation) for each light-curing unit

Light-curing unit	Temperature rise (°C)
Cool Blue LED	2.74 (0.27) ^a
XL2500 QTH	1.58 (0.12) ^b
Ultrablue Is LED	1.13 (0.05) ^c
Freelight LED	1.05 (0.16) ^c

Means followed by different letters were significantly different (p<0.05).

composite does not receive a sufficient number of photons at a proper wavelength, the polymerization process may be compromised.^{11,16} The present study used the hardness test as an indirect method to assess degree of conversion, and 2mm-thick composite specimens were used to ensure uniform and maximum polymerization. According to the present outcomes, the Freelight LED produced significantly lower hardness values than the other LCUs, regardless of the appraised depth, and this can be explained by the very low irradiance emitted by this unit, interfering with monomers conversion. On the other hand, no signifi-

cant differences were observed for samples activated by the QTH and the other two LED LCUs, despite discrepancies in the radiant exposure level. This outcome might be in part related to the high irradiance emitted by the QTH and the Cool Blue LED LCUs, which were probably high enough to excite the photoinitiator and to achieve maximum polymerization. On the other hand, although the Ultrablue Is LED emitted lower irradiance than both the QTH and the Cool Blue LED, a similar polymerization potential was obtained probably due to its light emission spectrum, which, as shown in Table 1 and Figure 3, is closer to the CQ absorption peak (468nm) as compared to the QTH unit.

Using the QTH and the Ultrablue IS LCUs, hardness at the subsurface (1mm) was significantly higher than top hardness, and the same trend was observed for samples activated by the Freelight LED LCU. There are some theories that try to explain this phenomenon. For example, this could be related to fact that in the bulk of the material a free radical is three-dimensionally surrounded by possible reaction partners, while a radical located at the interface can find possible partners to react only on one side of a hypothetical sphere centered on the free radical.¹⁴ An additional explanation is that, during photo-activation procedures, the temperature rise in the deeper of the composite is greater than in the surface due to reduced heat conduction,¹ and it has been demonstrated that even small increases in temperature may give rise to significant increases in hardness.²³

The present study highlights that care should be taken when analyzing the results of *in vitro* studies concerning temperature changes promoted by different LCUs. According to Hofmann et al.⁸ (2002), these studies tend to overestimate the thermal changes during

photo-activation, as in clinical situation there is more surface area of the restoration in contact with the cavity walls, hence facilitating the heat dissipation. Moreover, the temperature rise could be reduced by blood circulation in the pulp chamber as well by fluid motion in the dentinal tubules. However, further studies are required to confirm these hypotheses. On the other hand, a previous study⁴ suggests that thermocouples may underestimate the temperature applied to the tooth and also that LED LCUs may not be as innocuous as it has been assumed in some investigations. Nevertheless, the aim of the present study was not focused on revealing the exact temperature increase inside the pulp chamber, but on verifying whether LED LCUs can really promote lower temperature generation than QTH ones. The current findings show that depending on the LED LCU used it is possible to obtain similar hardness values with lower (in the case of Ultrablue IS LED) or even with higher (in the case of Cool Blue LED) temperature increase than QTH lights. However, in some cases, lower temperature generation can be associated with poor hardness values, and this could be of clinical significance. In conclusion, the hypothesis tested here must be rejected, as it was not a general outcome that LED LCUs always produce similar cure as QTH ones with less heat development.

CONCLUSION

Among the LED LCUs tested, only the Ultrablue Is LED was capable to produce similar hardness with lower heat development than the QTH unit. The high-irradiance Cool Blue LED promoted higher temperature increase than the QTH unit, and the Freelight LED did not produce an effective cure of the tested material when compared to the other LCUs.

RESUMO

Este estudo caracterizou a luz emitida por uma unidade de fotoativação (UF) de lâmpada halógena de quartzo de tungstênio (HQT) e três diodos emissores de luz (LED) e investigou o aumento de temperatura e a dureza do compósito promovida por estas fontes. HQT XL2500 (3M ESPE), LED Freelight (3M ESPE), LED Ultrablue Is (DMC) e LED Cool Blue Wand (Milestone Scientific) foram as UF investigadas. A irradiância (mW/cm^2) foi aferida com um medidor de potência e o espectro de luz obtido com um espectrômetro. O aumento de temperatura ($^{\circ}\text{C}$) foi registrado utilizando um termopar conectado a um termômetro digital, durante a fotoativação do compósito Filtek Z250 (3M ESPE). Os dados foram submetidos à ANOVA e teste de Tukey ($\alpha=0,05$). A dureza Knoop foi avaliada em diferentes profundidades do compósito (20, 1000 e 1980 μm) e os dados submetidos à ANOVA de dois critérios, com parcelas subdivididas, e teste de Tukey ($\alpha=0,05$). A correlação entre irradiância e aumento de temperatura foi investigada pelo teste de Pearson. Todas as UF apresentaram 95% da irradiância concentrada entre 400-515nm. Médias para aumento de temperatura variaram entre $1,05\pm 0,16$ e $2,74\pm 0,27$. O LED Cool Blue apresentou aumento significativamente maior de temperatura que as

demais UFs, e a HQT promoveu aumento significativamente maior de temperatura comparada aos LEDs Ultrablue Is e Freelight. Correlação significativa entre irradiância e elevação de temperatura foi detectada ($r=0,867$; $p<0,001$). Médias de dureza (kg/mm^2) variaram entre $40,1\pm 3,6$ e $92,7\pm 6,6$. Amostras ativadas pelo LED Freelight apresentaram dureza significativamente menor que amostras ativadas pelas demais unidades.

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Fotoativação; dureza; resinas compostas; temperatura.

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