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Evaluation of Eye Protection Filters Used with Broad-Spectrum and Conventional LED Curing Lights

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The high irradiance and the different emission spectra from contemporary light curing units (LCU) may cause ocular damage. This study evaluated the ability of 15 eye protection filters: 2 glasses, 1 paddle design, and 12 dedicated filters to block out harmful light from a monowave (HP-3M ESPE) and a broad-spectrum (Valo, Ultradent) LED LCU. Using the anterior sensor in the MARC-Patient Simulator (BlueLight Analytics) the irradiance that was delivered through different eye protection filters was measured three times. The LCUs delivered a similar irradiance to the top of the filter. The mean values of the light that passed through the filters as percent of the original irradiance were analyzed using two-way ANOVA followed by Tukey test ($\alpha = 0.05$). The emission spectra from the LCUs and through the filters were also obtained. Two-way ANOVA showed that the interaction between protective filters and LCUs significantly influenced the amount of light transmitted ($p < 0.001$). Tukey test showed that the amount of light transmitted through the protective filters when using the HP-3M-ESPE was significantly greater compared to when using the Valo, irrespective of the protective filter tested. When using the HP-3M-ESPE, the Glasses filter allowed significantly more light through, followed by XL 3000, ORTUS, Google Professional, Gnatus filters. The Valo filter was the most effective at blocking out the harmful light. Some protective filters were less effective at blocking the lower wavelengths of light (<420 nm). However, even in the worst scenario, the filters were able to block at least 97% of the irradiance.

Key Words: protection filters, light curing unit, irradiance, retinal damage.

Introduction

Many thousands of light-curing procedures that involve direct composite resins, sealants, cementation of indirect restorations and orthodontic brackets are being performed every day in dental offices. Conventional light-emitting diode (LED) light curing units (LCUs) deliver a relatively narrow band of visible blue light in the wavelengths between 420 and 500 nm. However, some broad-spectrum LED units contain additional LED(s) and deliver additional violet light in the 380 to 420 nm region of the spectrum (1). The frequent use of LCUs that deliver very bright light in the wavelengths between 380 and 500 nm means that many dental professionals may be exposed to harmful amounts of violet and blue and light on a daily basis (2).

The retina is the only part of the central nervous system that is directly exposed to light (3). The dental LCU emits blue light at a much greater intensity than from cell phones, computers and other devices that are in daily use. Exposure to the short wavelength blue light may cause a negative effect on the mitochondria that are essential for neuronal cell function (3) and may damage the mitochondria (4), reduce visual acuity and contrast sensitivity (2,5). Ultra violet (UV) light also accelerates the formation of cataracts and also has a negative effect on cell health (6). All LCU manufacturers supply and recommend the use of protective blue blocking orange filters to protect the eyes from the bright blue light (2). These orange plastic shields are attached to the light tip and can be adjusted to provide the best eye protection to the operator. Other types of protective filters are also available and they come in various sizes, thickness and design.

The majority of the protective orange filters used in dentistry are designed to reduce the risks of exposure to blue light with a wavelengths between 420 and 500 nm because this range of wavelengths will activate the commonly used camphorquinone photoinitiator that is used in most resins. However new restorative materials have been introduced that use alternative photoinitiators such as: trimethylbenzoyl-diphenylphosphine oxide (TPO) and 1-phenyl-1,2-propanedione (PPD), and derivatives of dibenzoyl germanium (Ivocerin®) that are most effectively activated by wavelengths below 420 nm (7). Conventional LCUs often deliver a radiant exitance of approximately 1200 mW/cm² and at wavelengths between 420-490nm, that are capable to activate the camphorquinone photoinitiator used in most dental resins (8,9). Consequently, some manufacturers have developed broad-spectrum LCUs that usually deliver the same radiant exitance, but include additional light below 420 nm. This broader range can improve the degree of conversion of the new resin based composites that include the aforementioned alternative photoinitiators (9,10,11). The ability of protective filters to block the damaging light from contemporary light curing units (LCU) continues to be unclear (12).

The aim of this study was to evaluate the ability of different designs of the eye protective filters to block the light from a conventional and a broad-spectrum LED LCU. The null hypothesis was that all the protective filters would be equally effective in blocking the wavelengths of light from these two types of dental LCUs.

Table 1. Characteristics of the dental curing lights tested

LCU	Valo Cordless	High Power 3M-ESPE
Peak broad-spectrum	Multiple peak broad-spectrum	Conventional
Irradiance (mW/cm^2)	1625	1680
Wavelength (nm)	389-500	410-510
Tip diameter (mm)	9.9	6.1
Tip area (mm^2)	77.0	29.2
Manufacture	Ultradent, South Jordan, UT, USA	3M-ESPE, St. Paul, MN, USA

Material and Methods

Two LED LCUs, a conventional blue light-emitting diode - High Power LED (3M ESPE, St. Louis, MN, USA) and a broad-spectrum LED unit - Valo Cordless (Ultradent Products Inc., South Jordan, UT, USA) were used in this study (Table 1). Fifteen protective filters were tested: 2 were glasses, 1 was a paddle design, and 12 were dedicated filters. The protective filters are shown in Table 2 and Figure 1.

The irradiance (mW/cm^2) delivered through the various eye protective filters was measured using MARC patient simulator (MARC- PS, BlueLight Analytics, Halifax, NS, Canada). The MARC-PS measures the irradiance, spectral emission, and radiant exposure delivered from light-curing devices to simulated dental restoration sites in a mannequin head (13). The detectors are connected to a fiberoptic spectrometer (USB4000, Ocean Optics, Dunedin, FL, USA) that is inside the head. One detector is located at the facial surface of the maxillary central incisors, simulating the surface of a class III restoration (Fig. 2). By adjusting the distance to the light detector and the power setting, the HP-3M-ESPE delivered 1680 mW/cm^2 and the Valo Cordless delivered 1625 mW/cm^2 to the top surface of the filters. The LCU batteries were fully charged before testing each filter.

Using a support device (ODEME, Brazil) the LCUs were

Table 2. Characteristics of the protective filters tested

Eye Protective Filter	Design		Color	Thickness (mm)	Manufacturer
Premier Cure-Shield		Paddle	Orange	2.8	Premier Dental Plymouth Meeting, PA, USA
Google Professional		Replacement Glasses	Orange	0.3	Kerr, Orange, CA, USA
Glasses		Glasses	Red	2.7	Seven Tao, China
Laser Safety Glasses SS5-0		Glasses	Orange	1.6	Super Safety, Pinhais, PR, Brazil
UVEX Safety Eyewear		Glasses	Orange	2.1	Honeywell, Morris Plains, NJ, USA
High Power 3M-ESPE protective filter	Stationary	Oval	Orange	2.6	3M-ESPE, St Paul, MN, USA
BioLux protective filter	Stationary	Circular	Orange	2.9	BioArt, CIDADE, SP, Brazil
Demetron LC protective filter	Stationary	Oval	Orange	3.1	Kerr, Orange, CA, USA
DB685 Eye protection	Stationary	Oval	Orange	2.4	Dabi Atlante, Ribeirão Preto, SP, Brazil
Led Lux II protective filter	Stationary	Oval	Orange	3.0	Ortus, Campo Mourão, PR, Brazil
Optilight Max protective filter	Stationary	Oval	Orange	2.6	Gnatus, Ribeirão Preto, SP, Brazil
Radii-Cal protective filter	Stationary	Circular	Orange	2.2	SDI, Basywater, Victoria, Australia
Schuster protective filter	Stationary	Oval	Orange	2.6	Schuster, Santa Maria, RS, Brazil
Valo protective filter	Stationary	Oval	Orange	2.8	Ultradent, South Jordan, UT, USA
XL 3000 protective filter	Stationary	Oval	Yellow	3.3	3M-ESPE, St Paul, MN, USA

rigidly fixed approximately 5 mm away from the anterior detector in the MARC-PS head. This distance allowed the various filters to be easily interposed between the LCU tip and the light detector (Figure 2). A light exposure time of 10 seconds was used for both LCUs. The filters were positioned always with the external surface facing the light source. In

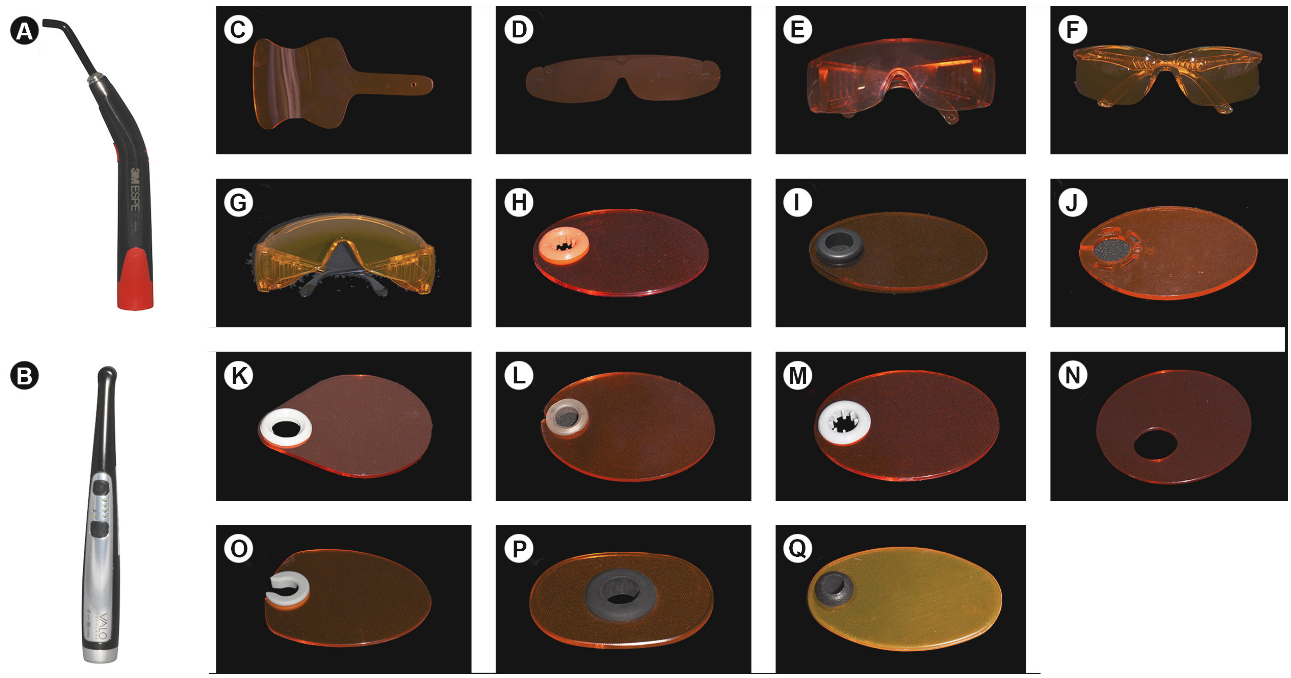

Figure 1. Light curing units used in this study. A: High Power 3M-ESPE; B: Valo Cordeless. Protection filters used in this study: C: Premier Cure-Shield; D: Google Professional; E: Glasses; F: Laser Safety Glasses SS5-0; G: UVEX Safety Eyewear; H: High Power 3M-ESPE protective filter; I: BioLux protective filter; J: Demetron LC protective filter; K: DB685 Eye protection; L: Led Lux II protective filter; M: Optilight Max protective filter; N: Radii-Cal protective filter; O: Schuster protective filter; P: Valo protective filter; Q: XL 3000 protective filter.

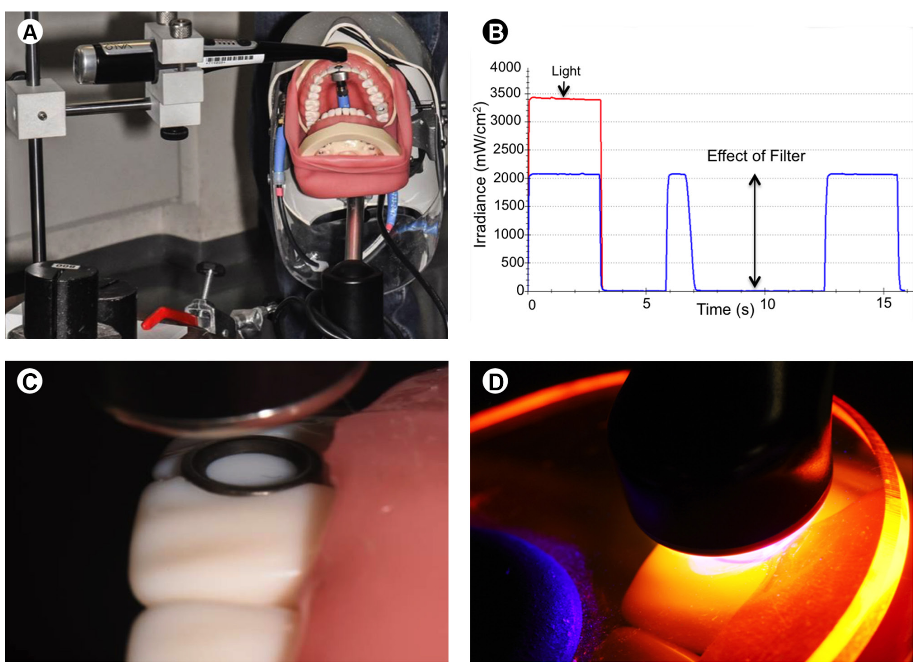

Figure 2. A: MARC-PS with LCU stabilized positioned approximately 5 mm away from the light detector; B: Irradiance received by the anterior detector in the MARC-PS showing the light delivered by the Valo when in contact with detector (red line); when 5.0 mm away from the detector (blue line), and the effect of filter interposed between light and detector; C: Detector located between the upper central incisors, simulating a class III restoration in MARC-PS; D. Eye protection filter inserted between the light curing and the detector.

the first 3 seconds, light from the LCU triggered the MARC software to start recording the light from the LCU, then the protective filter was interposed between the LCU tip and detector for 4 seconds to evaluate the ability of the filter to block the light, then the filter was removed and the light output from the LCU was measured again. This sequence allowed the optical trigger (set at its lowest limit of 11 mW/cm^2) within the MARC-PS software to start the light measurement. Three repeat measurements were made for each LCU in combination with each protective filter.

The irradiance that was delivered through the eye protective filters was converted to a percentage of the irradiance that reached the detector when there was no filter present. The data were analyzed for normal distribution and homoscedasticity using the Shapiro-Wilk test and Levene's test, respectively. Two-way ANOVA was used to compare the outputs from the 2 LCUs without the filters versus the light transmitted through the 15 different protective filters. The irradiance values delivered through the eye protective filters for both LCUs and thickness of the protection filters were analyzed using Pearson correlation test. All tests were performed at a significance level of α=0.05, and all analyses were performed using the Sigma Plot version 13.1 statistical package (Systat Software Inc., San Jose, CA, USA). The emission spectra (nm) were analyzed descriptively.

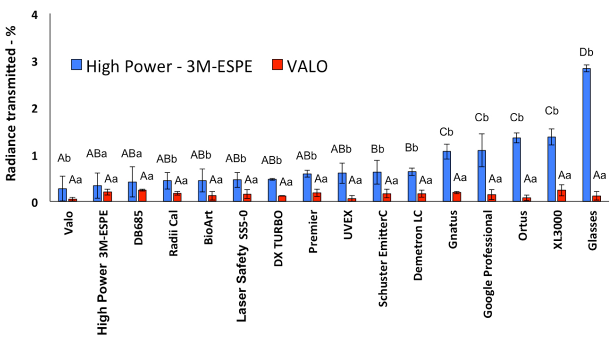

Figure 3. Percentage values of the initial irradiance values that were delivered through the 15 different eye protection filters.

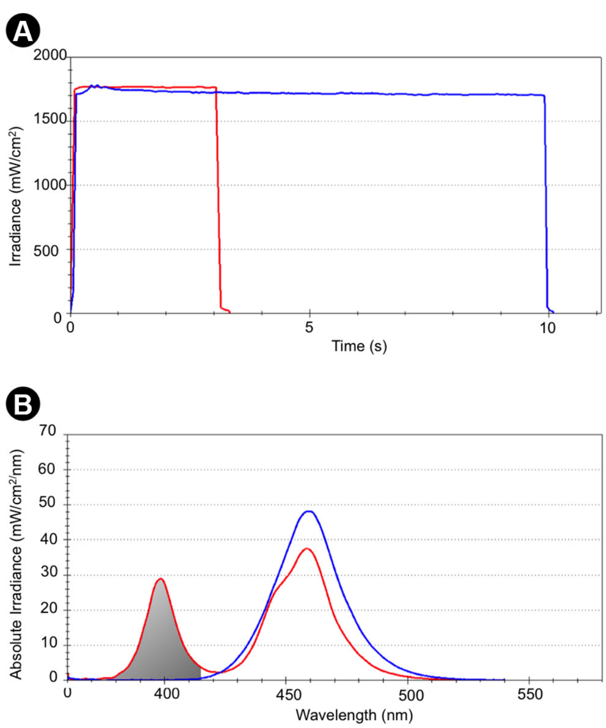

Figure 4. A: Irradiance of the light emitted by the Valo (Red line) and HP-3m-ESPE (Blue line) LCUs; B: Emission spectrum of the light emitted by the Valo (Red line) and HP-3m-ESPE (Blue line) LCUs; the gray area below the red line means the irradiance emitted bellow 415 nm.

Results

The irradiance values (% of maximum) that were delivered through the eye protective filters for both HP-3M-ESPE and the Valo are reported in Figure 3. The

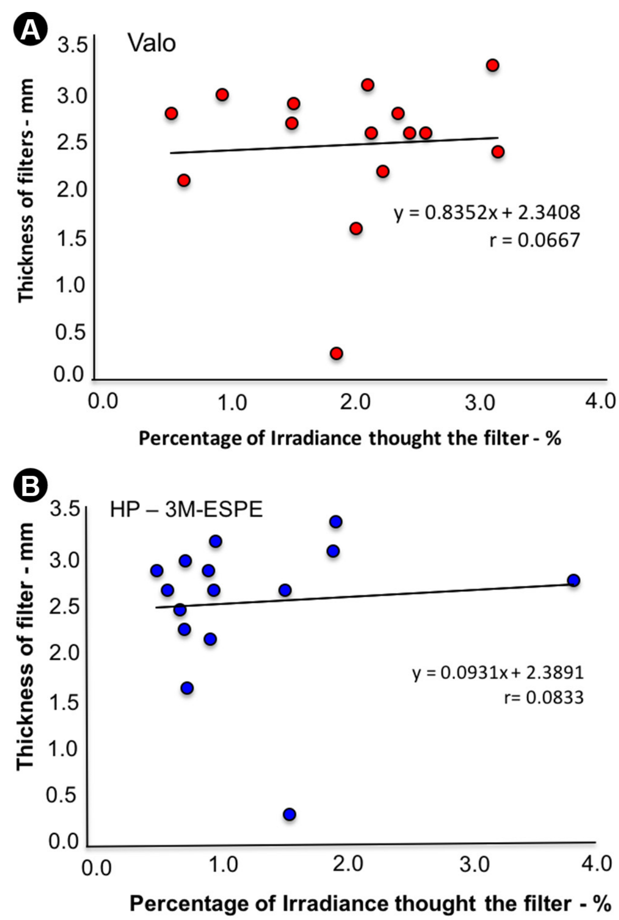

Figure 5. Pearson Correlation between the irradiance values delivered through the eye protective filters for both LCUs and thickness of the protection filters showing that the filter thickness had no impact the blocking ability of the filter.

irradiance and the spectrum of the light emitted by Valo and HP-3M-ESPE are shown in Figure 4A. As shown in Figure 4B, the Valo spectral emission delivered light below 415 nm compared to the mono-peak spectrum of the HP 3M-ESPE. Two-way ANOVA showed that the protective filters ($p<0.001$), the LCUs ($p<0.001$), and the interaction between protective filters and LCUs significantly influenced the amount of light that was transmitted through the filters ($p<0.001$). Tukey's test showed that the amount of light transmitted through the protective filters from the HP-3M-ESPE LCU was significantly greater than from the Valo LCU, irrespective of the protective filter tested. No difference was detected among the light curing transmitted through the protective filters when emitted by Valo LCU. When using the HP-3M-ESPE LCU, the Laser Safety Glasses filter transmitted significantly more light, followed by XL 3000, ORTUS, Google Professional and Gnatus filters. The Valo protective filter transmitted the least amount of light. No correlation was found between the overall irradiance values delivered through the eye protective filters for both LCUs and thickness of the protection filters (Fig.s 5A and 5B). Although the irradiance was lower when the Valo LCU was used, some protective filters did not block the lower wavelengths of light delivered by this LCU (Fig. 6).

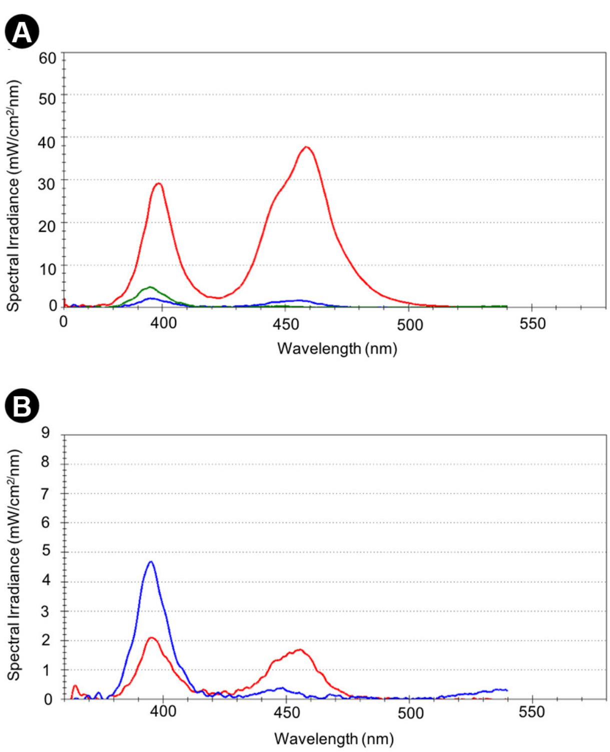

Figure 6. A: Emission spectrum of the light from the Valo and the light transmitted through the Laser Safety Glasses SS5-0 (Red line) and XL3000 (Blue line); B: Emission spectrum from the Valo (Red line) and the effect of the filter on the emission spectrum of light transmitted by the Laser Safety Glasses SS5-0 (Blue line) and XL300 (Green line). Note the ability of the filters to block the light from the Valo.

Discussion

The null hypothesis was rejected; the amount of light transmitted through the eye protection filters from the HP-3M-ESPE varied significantly among the eye protective filters that were tested. In addition, the eye protection filters behaved differently when used with the conventional (HP-3M ESPE) and multiple peak broad-spectrum (Valo, Ultradent) LCUs. When the Valo LCU was used, some protective filters did not block the wavelengths of light below 420 nm as well as other filters.

The long-term use of high intensity LCUs without protection has been associated with health risks (14,15) that may end a dental career. This cumulative effect of excessive exposure to blue-light use can cause photoretinitis, while the hazards of exposure to ultra-violet light are mostly associated with cataract, corneal injury and photokeratitis (16,17). The type of ocular injury is modified by several factors such as intensity, duration, intermittence of the exposure to light, and the emission spectrum (18).

In this study, the light emitted by the Valo LCU was less than 0.5% of the initial irradiance when it was viewed through the eye protective filters. The absolute irradiance of the blue-light component emitted by conventional LCU's such as the LED 3M ESPE can be higher than broad-spectrum LCU's such as the Valo because these lights also deliver light in the violet range of wavelengths (19-21) as can be see on Figure 6. The optical trigger of the MARC PS was only activated when the irradiance was at least 11 mW/cm^2 because of the noise when the signal is below 11 mW/cm^2. Althougth both lights had been adjusted to deliver the same irradiance, much of the radiant power from the Valo was delivered bellow 415 nm and the irradiance of the blue peak is lower (Fig. 6). The 3M HP delivered more light in the blue region than the Valo and this likely explains why the difference between the filters was only seen when the 3M HP light was used.

Using eye protective filters to block the UV and blue wavelengths of light from 380-500nm is important for professionals and patients who are exposed to the light in the dental office (22). However, the ability of the filter to block the harmful light is directly correlated with the design of the eye protection filters. The Laser Safety Glasses allowed the most amount of light to be transmitted when using the LED 3M-ESPE, suggesting that the red color plastic material used in this filter was not as effective as the orange plastic material used in the other filters. Interestingly, the thickness of the materials had no significant effect on the amount of transmitted light, regardless of the light source.

If the distance between the eyes and the light source is 30 cm, the maximum daily retinal exposure limit has been reported to be 61 seconds when using a low power curing light, and 28 seconds when using a high power curing light, ie, potentially less than one restoration a day (23). Thus, when using contemporary high power LCUs it should be mandatory to use eye protective filters when light curing, especially for the dentist and the dental assistant who are exposed to these high irradiance levels several times a day. However, the capacity to block the light emitted by the light that reach the eyes is not dependent only of the composition and color of the filter. The physical size and region covered by filter is also an important aspect. Unfortunately, the area of the eye protective filter attached to the light guide of most LCUs is not sufficient to protect, at the same time, both the dentist and the assistant. Therefore, it is proposed that the dentist, assistant and patient should use protective eyeglasses to provide the optimum protection. Using protective eyewear allows the user to have both hands free to manipulate the instruments and materials so that they can focus their attention on the tooth to which the light is directed, and deliver the intended amount of light to the resin (24).

All of the eye protection filters tested were able to significantly reduce the light exposure to a level where exposure is unlikely to cause harm during an average working day. Some new LED LCUs have multiple emission peaks that may include UV light and some of the filters evaluated in this study were not able to block the UV light component as well as other filters. This lack of protection may cause ocular damage (6,12) and clinicians should use the correct protective filter especially if they use a broad-band LED curing light. The maximum blue-light exposure of 1 min/day has been recommended to avoid retinal damage (2). Using any protective filter tested in this study that really cover eyes, such as the glasses or the paddle, the clinicians and assistant are adequately protected. It is essential for dental professionals to make sure that the wavelength range for the protective glasses as declared by the manufacturer is adequate for the intended function (6).

Within the limitations of this in vitro study, the following conclusions can be drawn: 1) The amount of light transmitted from the HP-3M-ESPE through the protective filters was significantly greater than from the Valo, irrespective of the protective filter tested; 2) No difference was detected between the 15 protective filters when the Valo was used; 3) When the HP-3M-ESPE was used, the 'Glasses' filter transmitted significantly more light, followed by XL 3000, ORTUS, Google Professional, Gnatus filters; 4) Not all of the protective filters were as effective at blocking the lower wavelengths of light below 415 nm; 5) Even in the worst scenario, the filters were still able to block more than 97% of the light from the LCU.

Resumo

A alta irradiância e diferentes espectros de luz emitidos por aparelhos fotopolimerizadores (Fp) podem causar danos oculares. Este estudo avaliou a capacidade de 15 filtros de proteção ocular em bloquear a luz prejudicial de um Fp convencional (HP-3M ESPE) e outro de largo espectro (Valo, Ultradent). Utilizando sensor anterior do equioamento MARC-Patient Simulator (BlueLight Analytics inc.) a irradiância que passou através dos diferentes filtros protetores foi mensuradas três vezes. Os valores médios da irradiância que passaram pelos filtros foram analisados usando Análise de variância fatorial e pelo teste de Tukey (α= 0.05). O espetro emitido dos Fps através dos filtros também foi obtido. A análise de variância mostrou que a interação entre os filtros protetores e Fps influenciou significantemente a quantidade de luz transmitida (p<0,001). O teste de Tukey mostrou que a quantidade que luz transmitida através dos protetores oculares quando usado o HP-3M ESPE foi significantemente maior quando comparado aos valores para o Valo, independentemente do filtro testado. Quando foi utilizado a fonte de luz HP-3M ESPE, o filtro de proteção ocular permitiu significativamente maior passagem de luz, seguido por XL 3000, ORTUS, Google Professional, e pelo filtro Gnatus. O filtro do Valo foi o mais eficiente ao bloquear a luz prejudicial. Alguns filtros foram menos eficazes ao bloquear menores comprimentos de onde (<420 nm). No entanto, mesmo no pior cenário dos resultados deste estudo, os filtros foram capazes de bloquear ao menos 97% da irradiância emitida pelas fontes de luz testadas.

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