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Personal risks posed by LEDs used in everyday devices

Industrial Hygiene

The use of LEDs as lighting sources is growing exponentially, not only as domestic lighting but also in terms of personal devices such as smartphones, computer screens, household appliances, etc. The main drawback of white-light emitting LEDs, however, is their high content of blue wavelength radiation, which is harmful to the visual system. This project involves the design of a lighting device formed by LEDs of different spectral characteristics to check if they cause retina damage, especially in retinal pigment epithelium cells. Our experiments have shown that light exposure from all LED sources increases the percentage of light-induced cell death, especially in cells exposed to white and blue light, which record a 92% and 94% cell-death increase, respectively, in comparison to a non-exposed control group. The study concludes that exposure to high intensity LED light during light/dark cycles harms retina cells.

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Introduction and historical background

The first Light-Emitting Diode (shortened to LED) was created in 1927 by Oleg Vladimírovich Lósev (1903- 1942), but LEDs were not taken up commercially until 1962, when a relatively low-intensity red LED with an emission frequency of about 650 nm was developed. In the seventies new spectrum colours were brought in (green and orange), as well as infrared LEDs. It was not until 1993, however, that blue LEDs were developed thanks to the research work of the scientist Shuji Nakamura, who discovered a cheap blue-LED manufacturing process based on the compounds gallium nitride and indium nitride. This discovery paved the way for the subsequent development of the white LED from blue LEDs with a phosphorous coating.

LEDs were initially used in remote controls for television sets, hi-fi systems, etc. Their use steadily took off and is now widespread in electronic devices, household appliances, remote controls, detectors, mobile phones, signage, information panels, liquid crystal display screens of mobile phones, calculators, electronic agendas, among others. For domestic lighting purposes white LEDs have been developed as an alternative to traditional light bulbs, on the strength of their undoubted advantages like low energy consumption, low voltage, low temperature, quicker response capacity and longer useful life. A recent article by Behar-Cohen et al (2011) predicts that incandescent lighting sources will be phased out by LEDs in coming years, disappearing completely in Europe by September 2016 [1]. Nonetheless, the main, unresolved problem posed by white-light emitting LEDs is their high content of blue wavelength light (the most energetic) and high luminance.

It has been scientifically proven that blue light (short wavelengths) has a negative effect on the eyes (retina). Light-induced injuries have traditionally been broken down into three types: photomechanical (light wave shock effect), photothermal (local wave-induced heat) and photochemical (change in the macromolecules). Light-induced retina changes are by now understood with a fair amount of precision [2,3].

LEDs have been widely taken up for use in electronic devices, household appliances, detectors, mobile phones, signage, calculators and electronic agendas, among others

Recent publications have weighed up the toxic effects of light on retinal pigment epithelium cell cultures [4,5]. The main aim of these studies has been to ascertain the cell survival rate after light-radiation exposure. To date, however, there have been no studies to assess the harmful effect of LED light on ocular structures. This is of great interest, however, due to the sheer number of hours that people are exposed throughout their lifetimes to light sources of this type. There would therefore seem to be an urgent need for studies of human organs exposed to this light, i.e., the eye and especially the retina, which is the most vulnerable zone of the eye and is essential for the power of sight.

The main aim of this study is therefore to determine the light-induced harm (phototoxicity) caused by LEDs on the retina in vitro to find out the repercussion on the human visual system.

Materials and methodology

Emitter: LED lighting device

A lighting device has been designed comprising five differentiated zones separated off from each other by discriminating barriers of a white material. Each one of the zones contains a LED producing light of irradiance 5mW/cm2 but with different spectral characteristics: blue LED (468 nm), green LED (525 nm), red LED (616 nm), white LED with a colour temperature of 5400ºK. The last zone was made up by a control group of cells that had not been exposed to any light (Figure 1).

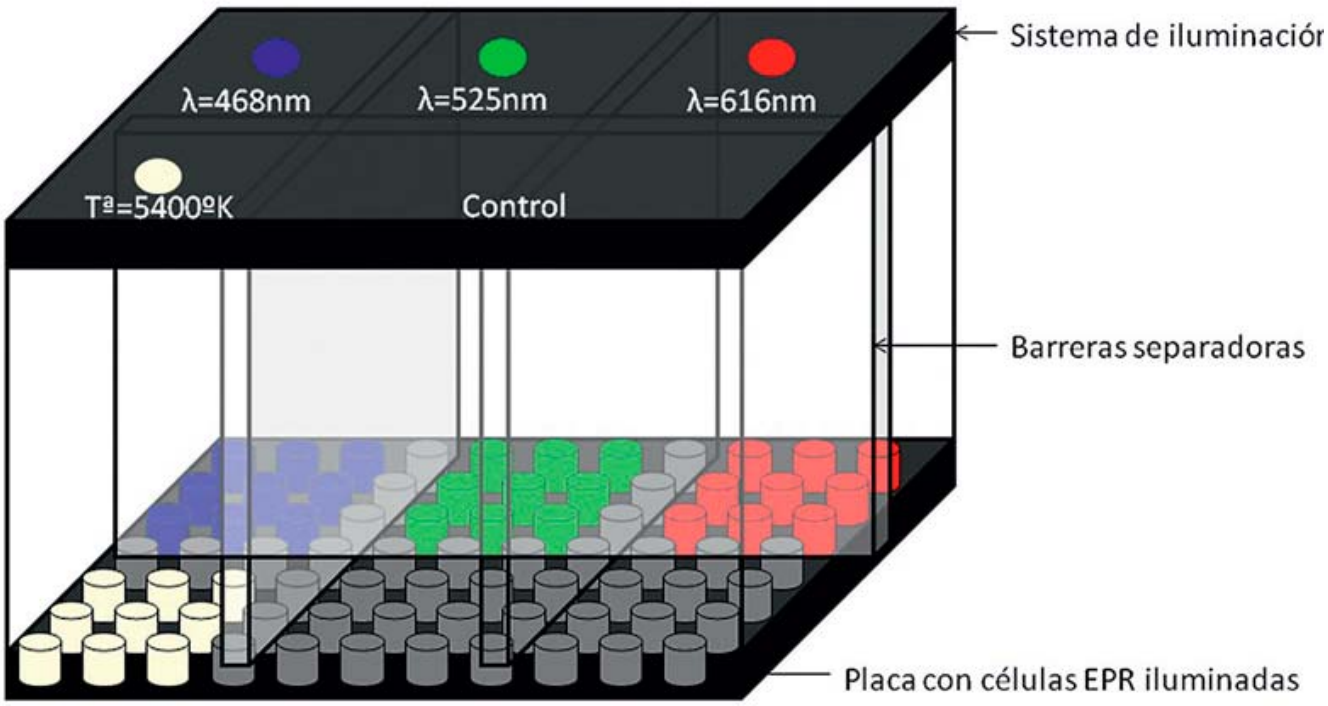

Figure 1. Outline of the LED lighting scheme used in this study.

Receptor: human retinal pigment epithelium cells

Retinal pigment epithelium cells from healthy human donors were grown in a culture medium, a sine qua non for *in vitro* cell culture. The cells were sown in 96-well plates at a density of 5000 cells per well. The culture medium was replaced every 24 hours to pre-empt evaporation from the heat given out by the light. The retinal pigment epithelium is a hexagonal layer of cells that is essential for the power of sight; alternation thereof produces retinal degeneration, impairment of the visual function and even blindness.

Phototoxicity experiment

The retinal pigment epithelium cells were exposed to the different light sources during 12 hour/12 hour light/dark cycles. After the exposure the cells were treated with specific toxicity-assessment procedures and observed by fluorescence microscopy (BD Pathway 855, Becton, Dickinson and Company).

DAPI staining was used to quantify cell survival; this technique, ideally suited for the cell count, involves a colorant that stains the cell nuclei and is excited with ultraviolet light to produce strong blue fluorescence when joined to the DNA.

The indicator used to evaluate the light-induced cell death (apoptosis) was caspase-3 and -7 activation, since these enzymes are involved in apoptosis regulation and execution.

Statistical treatment

Each experiment was repeated at least twice. The values are given as mean ± standard deviation. The data were analyzed by Student's t-test using the statistical software Statgraphics Centurion XVI.I (USA). P-values of less than 0.05 were considered to be significant.

Results

Cell survival

After the exposure period during three 12 hour/12 hour light/dark cycles the cell nuclei of the retinal pigment epithelium were DAPI-stained to count the number of cells per well.

The non-irradiated cells grew well in the plate wells but irradiation with LED light inhibited cell growth. Blue light produced a very significant reduction in the number of cells, although there was also an observable phototoxic effect for green and white light. In the case of red light no statistically significant differences were observed (Figure 2).

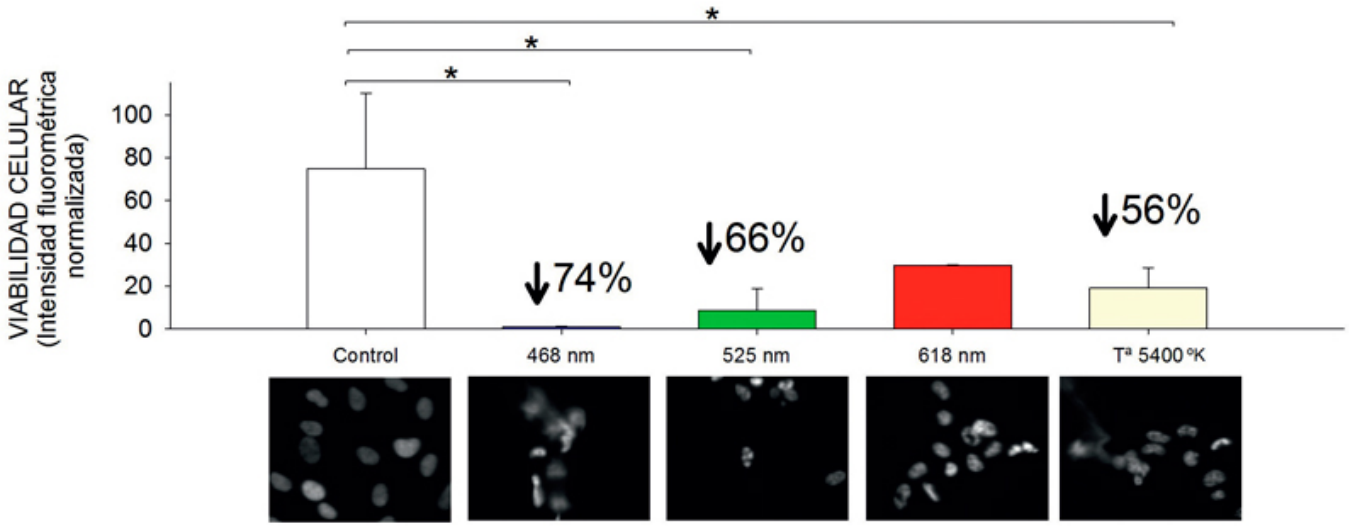

Figure 2. Cell survival of the retinal pigment epithelium cells. Graph showing the mean ± standard deviation of n=2-5 experiments. Representative images obtained from fluorescence microscopy. The asterisk (*) shows statistical differences when compared with the control group ($p<0.05$, Student's t).

Apoptosis (light-induced cell death)

Caspase-3 and -7 activation was the indicator used to assess light-induced cell death, since these enzymes are involved in the apoptosis process. The experiments showed that light exposure increases the percentage of apoptotic cells for all LED light sources, especially in the cells exposed to blue and white light, in which there was a 92% and 94% increase, respectively, of apoptotic cells (cell death). Microscope images show caspase activation as a pinkish colour around the blue DAPI-stained nucleus (Figure 3).

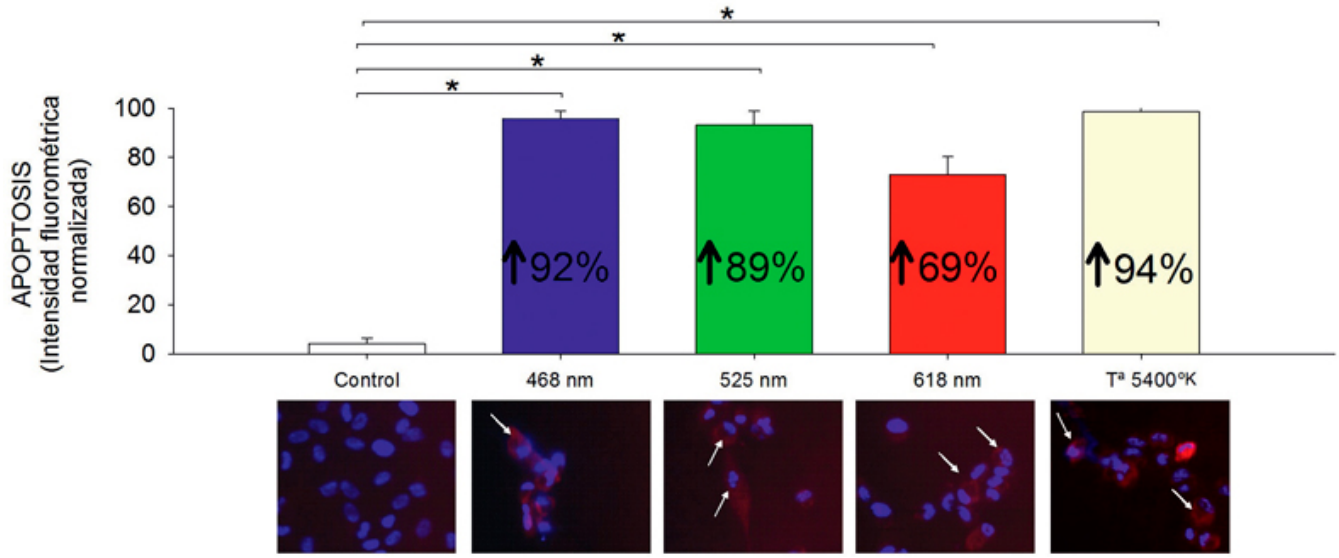

Figure 3. Light-induced cell death determined by caspase 3 and 7 activation. Graph showing the mean ± standard deviation of n=2-5 experiments. Representative images obtained from fluorescence microscopy. The asterisk (*) shows statistical differences when compared with the control group ($p<0.05$, Student's t).

Discussion

The first evidence of light damage to the human retina dates back to 1912 in Germany when thousands of people suffered retina lesions after watching a solar eclipse [6]. Two wavelengths of the visual spectrum have traditionally been blamed for phototoxic damage: class I damage coincides with the absorption spectrum of rhodopsin whereas class II damage peaks in the short wavelength region (accounting for the concept of violet-blue light hazard). Two mechanisms of photochemical retina damage have therefore been proposed: one put forward by Noell in 1965 and the other by Ham in 1976. Table 1 shows the main distinguishing features of both [7-9].

Werner *et al* (1989) described different degrees of RPE cell damage in patients scheduled to undergo enucleation who voluntarily looked at the sun. No significant photoreceptor alterations showed up, however, accounting for the sound vision after exposure [10]. The retinal pigment epithelium regenerates rapidly whereas photoreceptors begin to degenerate, sometimes even disappearing completely after light exposure [11].

In recent years diverse publications have focused on evaluating the phototoxic effects of light on pigment epithelium cell cultures. The main objectives of these studies was to assess cell survival of epithelial cells after light exposure. Some studies also looked at other factors such as mitochondrial activity, DNA damage, levels of the endothelial growth factor and other salient aspects.

Our study shows an appreciable reduction in cell survival and concomitant increase in light-induced cell death

For example, in the study of Godley et al (2005) cell cultures were irradiated with light comprising wavelengths from 390 to 550 nm, with an irradiance of 2.8mW/cm2, the exposure time ranging from 0 to 9 hours. Results showed no differences in cell survival after three hours of light exposure; after 6-9 hours, however, there was an appreciable reduction in mitochondrial respiration. Another finding of this study was an increase in the production of oxygen reactive species after one hour of light exposure and also DNA damage after three hours of exposure, falling away at six hours, indicating the start of DNA repair (adaptive response) [4].

Table 1. Distinguishing features of the mechanisms of photochemical retina damage put forward by Noell in 1965 and Ham in 1976.

Type I or blue-green type or Noell type	Type II or blue-UV type or Ham type
Produced after long exposure to low light intensities (<1mW/cm^2)	Produced after short exposure to high light intensities (>10mW/cm^2)
Initial damage found in photoreceptors	Initial damage found in retinal pigment epithelium cells
Most harmful wavelengths: equivalent to the absorption spectrum of the visual pigment (rhodopsin)	Most harmful wavelengths: short wavelengths of the visible spectrum (violet-blue)

To date, however, no studies have looked into the phototoxic effect of LED-emitted radiation on retinal cells. Our study has evaluated cell survival and cell death of the retinal pigment epithelium produced by medium-intensity LED light (5 mW/cm2). The results of our experiments show an appreciable LED-light-induced reduction of cell survival and concomitant increase in cell death, the phototoxic damage being greater at shorter wavelengths.

It should be pointed out here that the EN 62471 standard classifies lighting sources according to the phototoxic risks (from ultraviolet to infrared radiation), establishing four risk groups according to the maximum permitted exposure time:

- 0 risk (no risk). When the maximum exposure limit is higher than 10,000 seconds.
- Risk 1 (low risk). When the maximum exposure limit falls between 100 and 10,000 seconds.
- Risk 2 (moderate risk). When the maximum exposure limit falls between 0.25 and 100 seconds.
- Risk 3 (high risk). When the maximum exposure limit is less than 0.25 seconds.

The study concludes that exposure to LED light during light/dark cycles harms retinal pigment epithelium cells

On the basis of this standard, Behar-Cohen indicated that a blue LED with an intensity of over 15 W belongs to risk group 3; if the light intensity is 0.07 W it belongs to group 1. LED lighting sources of everyday use for the general public are classed as risk group 2 (in comparison to conventional lighting sources that belong to group 0 or 1). He also found that the amount of blue light emitted by a white LED is 20% higher than daylight of the same colour temperature [1].

Conclusion

Exposure to LED light during 12 hour/12 hour light/dark cycles, especially in the shorter wavelengths, harms retinal pigment epithelium cells. Future studies are now needed to ascertain which intensities, wavelengths and exposure times of LED lighting devices are lethal and non lethal for retinal tissue.

ACKNOWLEDGEMENTS

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TO FIND OUT MORE

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