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LED operating lights in dental practice

By Professor Laurence J. Walsh

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In recent years, there have been dramatic developments in the technology and performance of light emitting diodes (LEDs), to the point that arrays of LEDs are now suitable for replacing conventional operating lights. Such lights have been used in head mounted lights for some years and this author uses both Heine and Orascoptic high intensity LED headlights in clinical work. There are now LED arrays which replace operating lights (Figure 1) and this article explains their operation and contrasts aspects of their performance with conventional light sources.

The long life of high intensity LEDs and the corresponding reduction in maintenance costs explains why they are now used routinely in traffic lights, emergency lights, aircraft cabin lighting, automotive lighting and the like. A 12 Watt Luxeon™ array fully replaces a 150 Watt bulb in a traffic signal, reducing maintenance costs over their 10-15 year lifetime, as well as giving a saving in energy costs of 50%. Because of the low total cost of ownership, high intensity LED street lighting is now being introduced, with 50% less power consumption than mercury vapour lamps and 6-10 times longer life for the same level of illumination.[1-3]

Conventional halogen lights

Quartz tungsten halogen (QTH) lamps are the standard lighting component found in a dental operating light. These lamps are driven by the low voltage (12 volt) circuit of the dental unit. Most units offer adjustment of the drive current using a variable resistor arrangement or via software control. There is an inherent problem in adjusting the intensity of the light. As the current to the lamp is reduced and its output dims, the colour temperature reduces and the light shifts from white to orange-red, rather than remaining white.

Figure 1. The Pelton & Crane Helios 3000 LED light is a replacement for halogen operating lights.

Inside the halogen lamp itself, a tungsten filament is encased inside a quartz envelope, with an outer glass envelope. The envelope protects the glass from melting because of the very high temperature of the filament. The gas inside the envelope is a halogen gas (such as xenon) which combines with tungsten atoms as they evaporate from the filament, and redeposits them back onto the filament. All the components inside the lamp operate at very high temperatures.

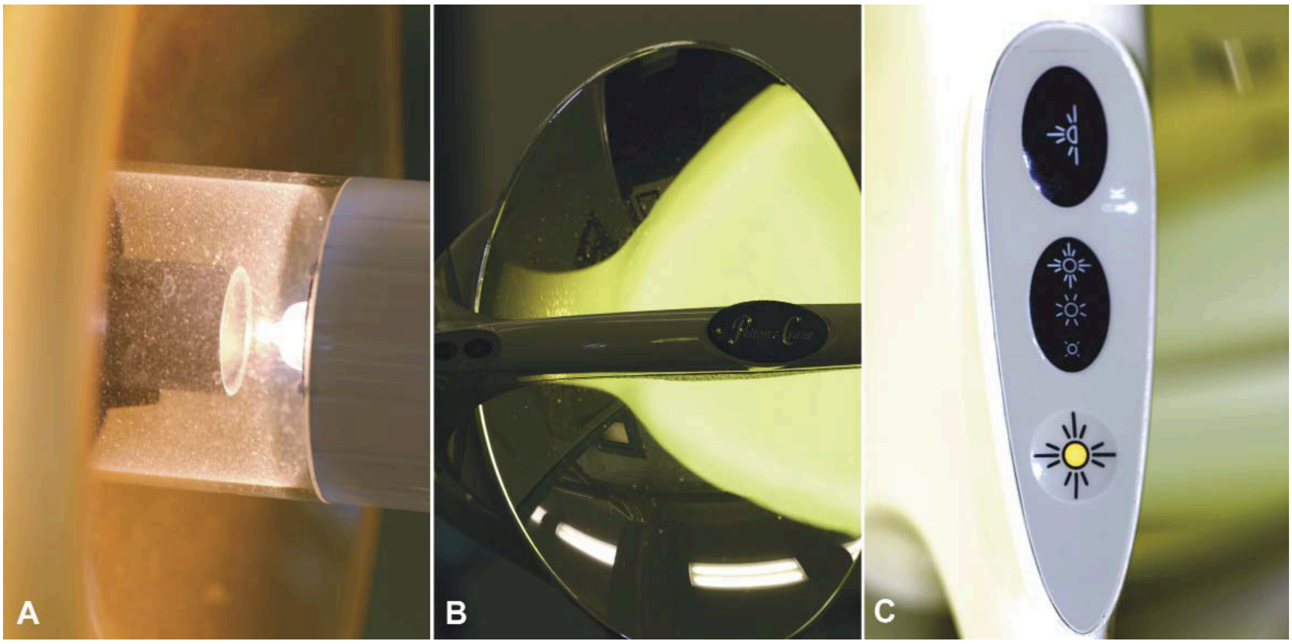

Figure 2. Operating lights. Panel A shows the lamp and reflector of a conventional quartz tungsten halogen lamp. The reflector absorbs infrared wavelengths and becomes hot during use. Some light is also transmitted through the rear of this glass reflector. Panel B shows the highly reflective and completely non-transmissive surface of the reflector in the Pelton & Crane Helios 3000 LED light. Panel C shows one of the dual control panels of the Helios 3000, which control intensity, safe non-curing mode, and colour temperature. Each light is factory calibrated to deliver the specified colour temperatures of white light.

The light is emitted from the single tungsten filament in the lamp in all directions and despite the action of a parabolic lens (Figure 2), the light is brighter in the middle and dimmer at the edges of the focussed spot. QTH lamps generate a broad range of wavelengths, from ultraviolet through to infrared, requiring the use of expensive filters in the reflectors to prevent the long (infrared) wavelengths being shone onto the patient's face. These same wavelengths also cause heating and degradation of components in the operating light made of plastic and other materials.

The conversion efficiency of these units, calculated from the useful visible light divided by the electrical energy input, is relatively low, at some 5-10%. In practical terms, this means that much more of the energy is dissipated into the reflector and frame of the light and into the operatory environment as heat, than onto the patient's face.

LEDs as a light source

LEDs can generate coloured visible light, which is spectrally narrow and near coherent (i.e. pure in colour) (Figure 3). A range of colours from LEDs are available, ranging from ultraviolet, violet, indigo,

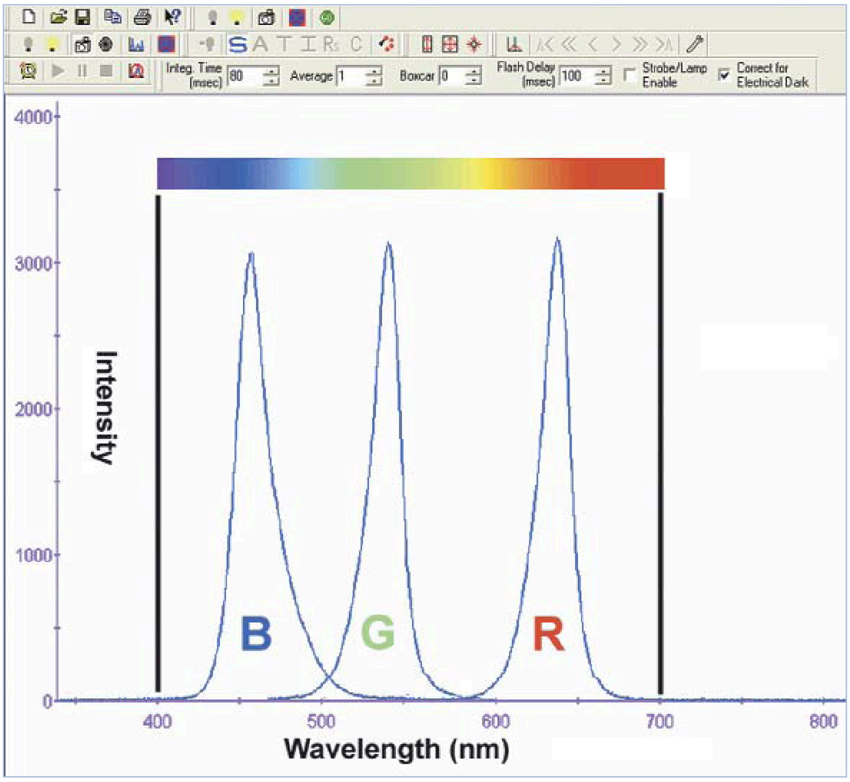

Figure 3. Emission spectra of blue, green and red LEDs recorded on a high resolution Ocean Optics spectrophotometer in the author's laboratory. The graph shows their normalized optical intensities (not their apparent intensities to the human eye, which is much more sensitive to green) versus wavelength. The visible spectrum from 400-700 nm is also indicated.

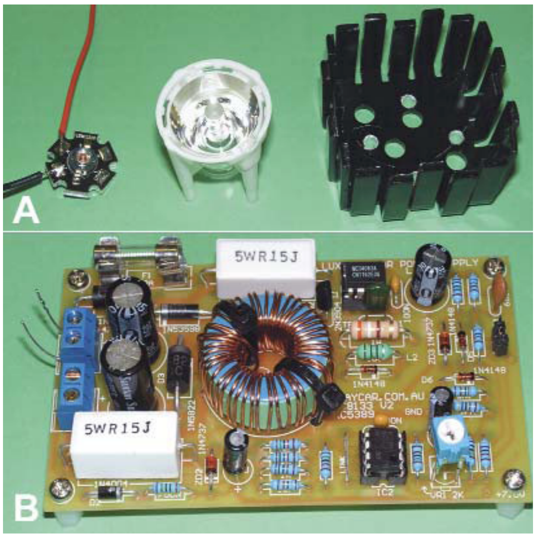

Figure 4. Components of a typical high intensity LED unit constructed by the author. A, from left, Luxeon high intensity LED, lens, and heatsink. B, Pulse width modulation controller, used to vary the light output of the individual Luxeon LEDs.

Figure 5. Three high intensity Luxeon LED lights assembled as in Figure 4 with lenses and heatsinks, and driven with identical current. Note how the simple combination of one red, one green and one blue does not give white - much more green is required. Note also how the apparent brightness of the red LED is greatest, despite the same drive current.

Figure 6. Digital lux meter used to measure light intensity levels. The reading shown is taken when the Helios 3000 light was operated at its highest intensity, giving 29,900 lux.

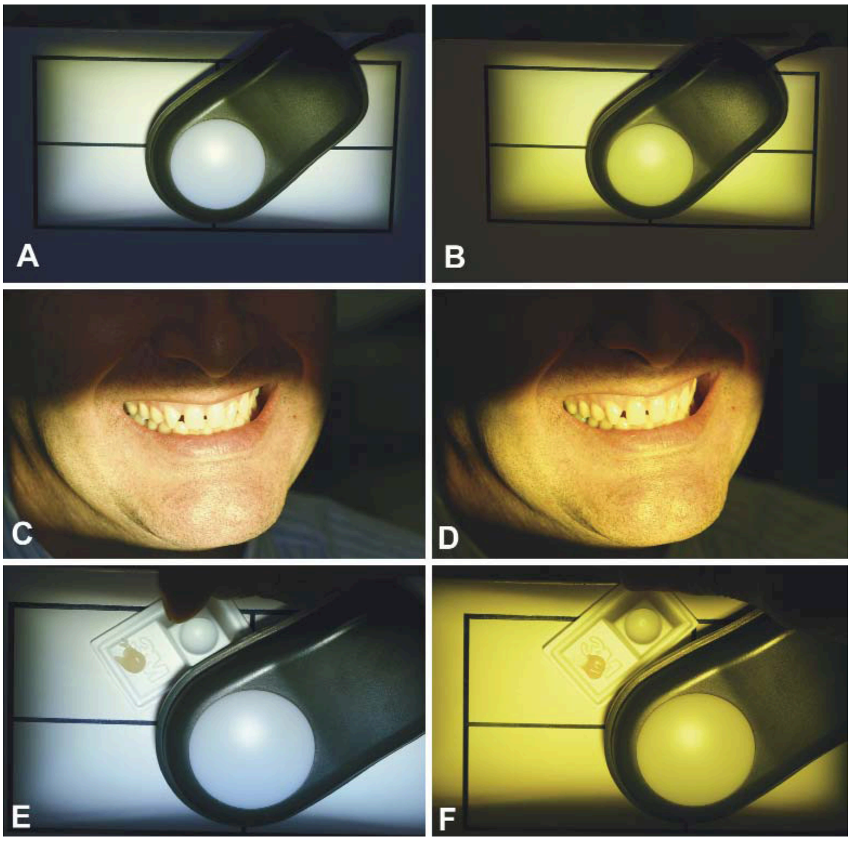

Figure 7. A comparison of the Helios 3000 light operated in its normal mode (left hand images) and safe non-curing mode (right hand images). Panels A and B show the distribution of light onto the target grid of 150 X 75 mm, onto which is placed the sensor of the light meter shown on Figure 6. Panels C and D show the sharp boundaries of the light and how even the illumination is, without stray light shining into the patient's eyes. Panels E and F show testing of composite resin samples (3M ESPE Z-100 resin, shade B3) for spontaneous curing under the lights.

blue, turquoise, cyan, aqua green, yellow, amber, orange and red-orange through to several varieties of red. The emitted colour depends on the configuration of the semiconductor junction, for example whether it is indium gallium nitride or aluminium indium gallium phosphide. As the nature of the junction changes, so does the drop in energy as electrons move from the N-type area of the semiconductor to holes in the P-type area and fall to a lower orbital state, releasing the energy of the transition in the form of photons. The larger the energy difference, the shorter the wavelength, thus larger energy transitions mean that the emitted light will be at the blue-violet end of the visible spectrum.

Conventional LEDs comprise a small semiconductor chip mounted into an epoxy package. The limited dissipation of heat from the LED chip in this design gives them a high thermal resistance and limits the intensity which can be gained. Self-heating, which occurs in a conventional 5 mm diameter LED, limits the drive current to approximately 20 milliamperes. In contrast, high intensity LEDs such as Luxeon LEDs from Philips Lumileds use a different packaging approach, mounting a larger semiconductor chip onto a large heatsink slug. This reduces problems from self heating and allows the LED to be driven at much higher currents (such as 350 milliamperes), without exceeding the threshold internal junction temperature of 120 degrees Celsius (Figures 4 and 5). The chip design used in high intensity LEDs can also be packaged at higher density than regular LEDs, so more emitters can be packaged into a smaller space. Being much smaller, the quality of light from the parabolic reflector is improved as it is free of shadowing. Multiple LEDs can be combined into arrays with individual optics or combining light-guides so that uniform lighting is achieved without central hot spots and peripheral glare.

LEDs have a much higher conversion efficiency than incandescent and halogen light sources, typically 35% and above. They produce light in a directional fashion, meaning that losses from absorption of energy into the frame of the light are almost eliminated. Unlike a halogen lamp, the turn-on time of an LED is in the microsecond range, meaning that the light is instant-on, without flickering or warm up.

LEDs can be dimmed over more than a 500 fold range without altering the colour temperature of the light, by using the technique of pulse width modulation (Figures 6 and 7). This means that once the colour temperature is selected, the intensity can then be adjusted independently to suit the ambient lighting conditions and optimize the difference between ambient surgery lighting and the illuminated intra-oral area. This feature is found on commercial LED units such as the Pelton and Crane Helios 3000™ (Figure 8).

High intensity LEDs last at least 10 times longer than other light sources. Because they have no glass or filaments, there is nothing to break or shatter. LEDs are not subject to sudden failure or burnout. Thermal stresses in the base of the LED caused by different coefficients of thermal expansion can stress the solder joints and electrical connections, so much work has gone into redesigning this aspect, particularly for industrial applications.

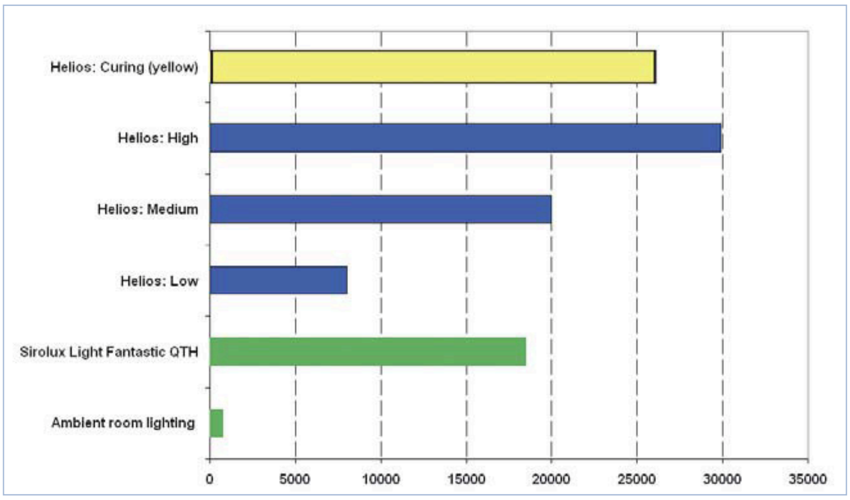

Figure 8. Performance assessment using a digital light meter, showing measured light levels in lux on the horizontal scale. From bottom to top, the bars represent readings for ambient room lighting, a conventional quartz tungsten halogen lamp, the Helios 3000 light operated at low, medium and high intensities, and the Helios in its safe non-curing mode where there are no blue light emissions.

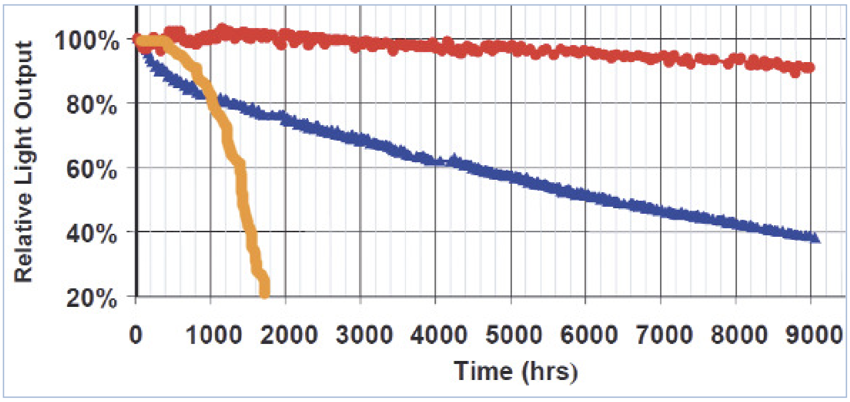

Figure 9. Stability of light output over time from a baseline level of 100% for an incandescent lamp (orange curve), a conventional 5 mm expoxy-packaged LED light (blue curve) and a high intensity Luxeon units (blue curve). Data from References 1 and 2. Note that the incandescent lamp failed at 1500 hours.

The light output of high intensity LEDs changes gradually during their lifetime, typically with a slight increase in light output for several hundred hours after their first use, followed by gradual logarithmic degradation over time thereafter. The rate of degradation is in proportion to the forward current through the LED, and is not affected by ambient (room) temperature. It is, however, influenced by the junction temperature inside the LED, which is why selecting the correct drive current and providing sufficient heatsink capacity to the base of the LED are important design features. The typical light degradation of a high intensity LED is only 10% after 10,000 hours of operation. This equates to 5 years of continuous use at 40 hours per week. In contrast, conventional LEDs show 60% degradation at 10,000 hours (Figure 9).

The widest variety of high intensity LEDs, Luxeon LEDs from Philips Lumileds, are expected to deliver 70% of their initial intensity after 50,000 hours of operation. The 70% figure is used widely in the industrial lighting industry to compare the longevity of light sources because this is the threshold at which the human eye can detect a reduction in light output. The author has a panel of high intensity Luxeon LEDs in a solar-powered test rig in his home workshop. These LEDs have been operated automatically during daylight hours every day for the past 4 years, with less than 5% change in their output over that time.

Invention of dental surgery lighting with LEDs

Credit for inventing LED lighting which replaces a conventional halogen operating lamp in dental practice must be given to Michael Mandikos, a Brisbane prosthodontist. Michael's original concept and design used a plurality of LEDs to generate white light. Selected LEDs were turned off so that the light produced lacked the blue and UVA wavelengths from 350-500 nm, and so would prevent premature photo-polymerization of dental restorative materials.[4-6] This wavelength range took into account the absorption spectra of initiators such as comphoroquinone, phenyl-propanedione and Lucerin TPO. Michael's design was patented in January 2005, and included configurations both for conventional LED packages and for high intensity LEDs such as Luxeons.

His work also identified the appropriate ratios for combining LEDs of the same intensity to produce white light. This is not a simple matter because of the variable sensitivity of the human eye to colour, being more sensitive to green-yellow and less sensitive to red. There are a number of workable combinations - for example 10 green plus 5 red and 2 blue LEDs.

White LEDs also exist, which are single blue Indium-Gallium-Nitride (InGaN) LEDs with a phosphor coating exited by the blue light to create "white light". If used in an operating light, these LEDs would need yellow filters to remove blue light from the phosphor emission to make them "safe" for restorative work with photo-polymerizing materials. Such filters are fitted routinely as "flip-down" elements of Heine and Orascoptic high intensity LED headlights for the same reason.

The latest developments in LED lighting for dentistry

Recent work from Pelton & Crane in the United States has led to the development of a purpose built LED operatory light, the Helios 3000, which is based on an array of high intensity red, green, blue and amber LEDs, similar to 3 Watt Luxeon III LEDs. These are positioned in a novel optical design with an acrylic light guide which directs light onto a concave aspheric reflector.[7-9] The light is then focussed onto the plane of the patient's face. This optical design gives a sharp rectangular footprint of 150 X 75 mm at normal working distances, such that no stray light reaches the patient's eyes (Figure 7). A further interesting attribute is the shadow-free nature of the illumination, which is due to the arcuate positioning of the LEDs. An object which blocks the light emitted by one LED does not cast a shadow onto the oral cavity, because each takes a slightly different optical path.

By using high intensity LEDs, the system uses 60% less energy than a halogen operatory light.[7] The light intensity has three settings, to reduce visual fatigue when switching vision from the oral cavity to the operatory and then back again. The user can also adjust the colour temperature from 4200 to 5000 Kelvin (a cloudy day to full sunlight).

The Helios unit includes the ability to turn off the blue component, to provide the "safe non-curing" mode (Table 1, Figure 8).[9] This was evaluated in the author's clinic by testing the curing time for samples of composite resin samples (3M ESPE Z-100 resin, shade B3). Under full normal "white light" illumination from the Helios 3000 light, resin setting occurred at 60 seconds, whereas under the "safe non-curing" mode, samples which were checked over a period of 5 minutes continuous exposure showed no evidence of setting. As a contrast, when resin samples were placed under normal illumination from a halogen lamp, setting occurred at 45 seconds.

A key issue in using high-power LEDs is managing the heat emitted from the LED semiconductor chip, particularly when LEDs are operating at high junction temperatures. LEDs such as Luxeons use thermal heatsink slugs to draw heat away from the chip. The design of the Helios light incorporates a heat pipe which moves heat from the LEDs to the rear of the unit, where a small fan operates to move air across heat sink fins to dissipate heat. Because of this arrangement, the reflector remains cool to the touch.

It seems that the phrase "the future is bright" certainly applies to LED lighting for the dental operatory. While progress over the past 5 years has been nothing short of spectacular, further increases in the optical performance of LEDs are expected in coming years. This will likely mean the wider use of LED environmental and room lighting in both clinical and domestic environments.

Table 1. Different colour mixes from LEDs

Mode	Intensity (%)			
	Blue	Green	Amber	Red
Cool white 5000K	72%	70%	75%	100%
Warm white 4200K	100%	80%	75%	100%
Curing-safe yellow	0	30%	60%	100%

Adapted from data in reference 9.

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About the author

Professor Laurence J. Walsh is the technology editor of Australasian Dental Practice magazine. He is also a noted commentator on and user of new technologies and is the Head of The University of Queensland School of Dentistry.