The possible ocular hazards of LED dental illumination applications

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The Possible Ocular Hazards of LED Dental Illumination Applications

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continuing education TDA JOURNAL EXAM #50

ABSTRACT

The use of high-intensity illumination via Light-Emitting Diode (LED) headlamps is gaining in popularity with dentists and student dentists. Practitioners are using LED headlamps together with magnifying loupes, overhead LED illumination and fiber-optic dental handpieces for long periods of time.

Although most manufacturers of these LED illuminators advertise that their devices emit "white" light, these still consist of two spectral bands - the blue spectral band, with its peak at 445 nm, and the green with its peak at 555 nm. While manufacturers suggest that their devices emit "white" light, spectral components of LED lights from different companies are significantly different.

Dental headlamp manufacturers strive to create a white LED, and they advertise that this type of light emitted from their product offers bright white-light illumination. However, the manufacturing of a white LED light is done through selection of a white LED-type based on the peak blue strength in combination with the green peak strength and thus creating a beam-forming optic, which determines the beam quality. Some LED illuminators have a strong blue-light component versus the green-light component. Blue-light is highly energized and is close in the color spectrum to ultraviolet-light. The hazards of retinal damage with the use of high-intensity blue-lights has been well-documented.

There is limited research regarding the possible ocular hazards of usage of high-intensity illuminating LED devices. Furthermore, the authors have found little research, standards, or guidelines examining the possible safety issues regarding the unique dental practice setting consisting of the combined use of LED illumination systems. Another unexamined component is the effect of high-intensity light reflective glare and magnification back to the practitioner's eyes due to the use of water during dental procedures.

Based on the result of Dr. Janet Harrison's observations of beginning dental students in a laboratory setting, the aim of this review is to raise awareness of the potential risk for eye damage when singular or combinations of LED illumination are used.

What is a Light-Emitting Diode (LED)?

A LED is basically a semiconductor diode.[1] Unlike incandescent and fluorescent lamps, LEDs are not inherently white-light sources. Instead, LEDs emit light in a very narrow range of wavelengths in the visible spectrum, resulting in virtually monochromatic light.[2]

The most common method used today to produce high brightness white-LEDs is based on the fact that complementary wavelengths ("short/blue" and "long/green") arriving simultaneously on the human eye will produce white-light sensation. Importantly, a blue-light component is always present in the LED spectrum.[3]

Also, it should be noted that all white-light sources have a blue-light component, but the blue-light component of all natural light is weaker than the green-light. The main safety issue of LED headlights is that the blue-light component of most LED headlights available today is too strong, compared with the green-light component.[4] Using narrow-band blue (403 nm) and green (550 nm) light adjusted to the same energy, exposure to blue-light (in animal studies) was found to severely damage rod photoreceptors, while green-light did not.[5,6]

Visible Light and Harmful Effects to the Eyes

Visual perception occurs when radiation with a wavelength between 400 and 700 nm reaches the retina.[7]

Ultraviolet radiation (UVR, with a wavelength of 100-400 nm), visible radiation (visible light; 400-700 nm), and infrared radiation (IR, 700-10,000 nm) are known as optical radiation. Visible light is referred to as short- (blue), medium- (green), and long-wavelength (red) radiation.[8] (**See Figure 1**)[9]

Thus, human eyes have the peak sensitivity at 555 nm and near zero below 400 nm and above 700 nm.[4]

The retina, however, is vulnerable to damage by light, a liability that has long been recognized.[7] Photoreceptors may be damaged by light, but the type of injury is modified by several factors, such as intensity, duration, intermittence of exposure to light, and spectral distribution.[10] It was recognized more than forty-five years ago that light, particularly blue-light, could induce retinal damage by a photochemical processes.[11]

The principal retinal hazard resulting from viewing bright-light sources is photoretinitis.[12] Only in recent years, it has become clear that photoretinitis results from exposure of the retina to shorter wavelengths in the visible spectrum, i.e., violet- and blue-light.[12, 13]

The radiant power of individual LED chips and LED light sources continues to increase. Application of multiple LED light sources that may be used in the dental setting has created a concern over the increased potential risk of eye damage due to the blue-light component always present in the LED illumination sources.

LED and Blue-Light Hazard

It is often emphasized that LED-based light sources are different from traditional lamps in that they contain higher proportions of blue wavelength light and are thus more likely to cause problems such as blue-light hazard.[14]

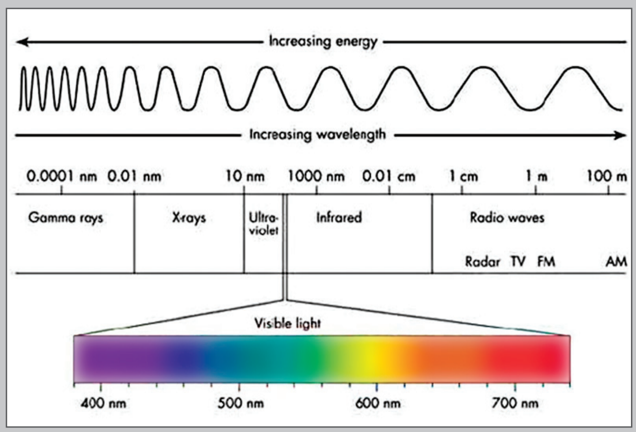
"Blue-light hazard" (BLH) is defined as the potential for retinal injury due to high-energy short-wavelength light. At very high intensities, blue-light (short-wavelength 400–500 nm) can destroy the photopigments which then act as free radicals and cause irreversible, oxidative damage to retinal cells, potentially including blindness.[14] The potential phototoxic retinal damage is thus expected to occur with wavelengths in the blue-light spectrum between 400 and 460 nm (blue-light hazard).[15, 16, 17]

When evaluating the risk of blue-light hazard posed by LED (and other) light sources, two fundamentally different cases require clarification and consideration: 1) looking at an illuminated scene, and 2) direct view into light source.[14]

Irradiance refers to the radiation of a surface by a light source,[14] which is indirectly viewed by an operator, not directly gazing into the light source.

In a LED, although the chip that emits light is very small, the brightness (expressed as radiance or luminance) may be extremely high.[3] Moreover, with the expected increase of luminous efficacy of LEDs, increased luminance could result.[3]

Figure I – Wavelength Chart from Qlaser Solutions of Stone Oak[9]



Age-Related Macular Degeneration

Age-related macular degeneration is a condition of visual impairment of the central visual field (macula) predominantly in elderly people.[14] It is the predominating cause of legal blindness among those aged over 65.[18, 19]

Commonly discussed hazards affecting the eye are blue-light hazard and age-related macular degeneration, which can be induced or aggravated by high intensity blue-light. Furthermore, UV (ultraviolet) may affect the eye, causing cataract or photokeratitis (sunburn of the cornea).[14] Some researchers are more certain: Ham et al., after conducting studies on animals, suggested "long-term, chronic exposure to short wavelength light is a strong contributing factor to senile-macular degeneration."[20]

Long-term exposure to visible light particularly predisposes the eye to AMD.[21] The difficulty of assessing lifelong exposure to light in epidemiological studies, however, prevents clear conclusions from the data, and the correlation remains controversial.[22, 23, 24]

Protective Mechanisms of the Eye

Eyes have two protective mechanisms: absorption of harmful wavelength and adjustment of the pupil size (from less than 1 mm to 8 mm).[4] Wavelengths under 400 nm are absorbed by the lens of the eye and cannot reach the retina, but more blue spectrum radiation can reach the retina in the young eye than in the aged eye,[7] because in the young eye, ocular transmittance is high, reaching close to 90% at 450 nm.[17]

If the blue-light is separated from the green-light, eyes cannot protectively limit the blue-light reaching the retina because eyes are not sensitive to the blue-light.[4] But if the blue-light is mixed with the green-light, the pupil of the eye can adjust according to the brightness of the green-light component and thus limit the blue-light which reaches the retina.[4]

Recovery from light-induced retinal damage has been shown in a number of studies.[25, 26, 27] Other information suggests that damage to the young and adult eye by intense ambient light is avoided because the eye is protected by a very efficient antioxidant system, however, after middle-age there is a decrease in the production of antioxidants.[28]

Cataracts are a disorder that develops over a lifetime. Due to natural aging and the absorption of UV radiation, the lenses of the eye turn opaque/yellow, obstructing the passage of light. The severe form of this age-related problem is called cataract.[13] As a side effect, when turning yellow, the lens serves as a blue-light filter, and, thus, as a kind of natural protection for the retina as we age. In severe cases, surgical removal or replacement of the lens may become necessary. Such patients, as well as children, are often more sensitive to blue-light than are healthy adults.[13] Therefore, dentists who have had cataracts removed may be susceptible to further damage of their eyes using LED illumination(s) in the dental setting.

Light Intensity and Exposure Duration

It has been believed that eye damage depends on the total wavelength dose received. This implies the light intensity and the duration required to cause a certain level of damage are correlated, and a longer light exposure can substitute for the use of a lower intensity.[7] Interestingly, red-light of a certain intensity is insufficient to induce retinal damage, whereas blue-light of the same intensity will cause retinal injury.[16]

O'Steen et al, have furthermore demonstrated that there are qualitative differences between the damage from low intensity and that from high intensity.[29,30,31] They showed that the rate of degeneration is directly related to the strength of the illumination and that the extent of retinal degeneration is greater with high intensity illuminants.

Cumulative Effects of Light

The cumulative nature of light damage has been observed in several investigations.[32,33,34]

Noell was the first to demonstrate the cumulative effect of light exposure in retinal damage.[10] He showed that a five minute exposure does not produce a significant effect, whereas three and four exposures, each of five minutes' duration and each followed by a one-hour dark interval, lead to significant damage. It is more surprising that dose fractionation can produce a more severe effect than the same total duration of illumination without interruptions.[10] This is a possible concern to dental practitioners using LED illuminations, who move from patient to patient during the work day.

Glare

Glare can lead to discomfort without impairing visibility, but it drives the observer to look away from the glaring source which increases if the light source is facing the observer. Disability glare is due to the light scattering which creates a veil that lowers any contrast and renders the task impossible to view.[3] High-luminance light sources generate a veiling glare. Lights with a relative high content of blue, such as LEDs, are liable to generate glare.[3]

In the dental setting, there is the contributing factor of the use of water which increases reflection and glare for the operator, particularly during the use of multiple illuminating sources.

Magnification

The Principle of Conservation of Radiance (brightness) means that the source radiance and retinal irradiance cannot be increased by the optical aid.[35] The optical aid permits the eye to bring into focus the source at the closer viewing distances. However, despite no increase in retinal irradiance, the increasing image size can increase the retinal hazard as a consequence of the spot-size dependence of retinal thermal injury.[35]

Properties of Dental Headlamps

It is interesting to note when one examines a manufacturer's specification sheet for LED dental headlamps, the "brightness" (expressed as either radiance or luminance) is often not given. Instead, the radiant intensity or luminous intensity is almost always specified. If one knows what the apparent source size is, then one can then calculate the LED radiance or luminance.[35]

Dental headlight manufacturers strive to create a pure white LED, and they advertise that this type of light emitted from their product offers bright white-light illumination. Some manufacturers offer a type of LED light selectivity i.e., neutral, warm, cool or bluish light.

Some dental headlamp manufacturers do give a warning regarding LED light. There are three styles of LED headlights available today: neutral LED, cool LED and extreme cool LED (strong blue enhanced LED). The blue spectrum of the neutral LED lights is similar to the green spectrum and the blue spectrum of cool LED is slightly stronger than the green spectrum, but the blue spectrum of extreme cool LED is much stronger than the green spectrum.[36] The use of elevated blue spectrum and extreme cool LED for long durations may be harmful to eyes. Also, elevated blue/extreme cool LED lights distort colors.[36] Indeed, it has been shown that cold white LEDs emitted about three to four times as much energy in the blue-light risk portion of the spectrum as warm-white LEDs did.[3]

The uniform beam without color dispersion generated by "achromatic multi-lens optics" is the safest, because there are neither bright spots nor color separation. The beam generated by reflector optics produces a bright center, but there is no strong blue spectrum separated. The most dangerous beam is a beam formed using single-lens optics because the strong blue spectrum is visible to the eyes.[36]

Guidelines—Safety Legislation Relating to LED devices

Multiple LED illuminators may potentially induce eye damage if not carefully designed and used.[37] The fact that LED light can have very high radiance and irradiance and is sometimes utilized without eye protection of any kind raises potential eye safety hazard concerns, particularly when multiple sources of high intensity LED illumination sources are used at the same time as in the dental setting described.

To the authors' knowledge, there are no mandatory standards or guidelines concerning the potential photobiological hazards of LED illumination in the dental setting in the United States.

According to the Tennessee Department of Labor and Workforce Development Division of Occupational Safety and Health (TDLWDDOSH), OSHA does not have a specific standard that addresses hazards associated with LED light sources.[38]

TOSHA addresses occupational safety and health hazards without a specific standard under the general duty clause, which requires the employer to provide a workplace free from recognized health or safety hazards that are likely to cause serious physical harm. This could potentially cover exposure to LED light sources, if they are likely to cause serious physical harm to an employee. Also, according to TDLWDDOSH,[38] an employer must evaluate the hazards to which employees are exposed and provide them with appropriate protection. Information on a specific exposure from the manufacturer of the equipment(s) in question should provide assistance in determining actual or potential hazards for employees and additional appropriate measures that can be taken to protect the employees from those hazards.[38] A well-known example of such is the warning on all dental curing lights to protect eyes using an orange filter.

International Standard IEC/EN62471 gives guidance for evaluating the photobiological safety of lamps and lamp systems. Specifically it specifies the exposure limits, including LEDs but excluding lasers, in the wavelength range from 200 nm through 3000 nm.[39] Another International Standard IEC/ EN 60598-1 on Luminaire Safety based on EN 62471 will be updated and available sometime in 2013.[40]

Private companies are available in the United States that test for photobiological safety of LED Lamps and lamp systems for a fee. Many of these companies use IEC/EN 6247 guidelines, however, as far as the authors could ascertain, there are no requirements in the United States that adhere to this standard.

The quantities to be measured and evaluated against exposure limit values are of irradiance and radiance, as summarized in **Table 1**.[39]

Conclusions

Data suggests that acute and chronic LED light exposure, through a combination of headlamps, operatory lights and fiber-optic handpieces, needs to be further investigated.

In the dental setting, the potential exists for light–induced retinal damage due to:

1. The blue wavelength component of the light (blue-light hazard)
2. The intensity of the light source or sources
3. The duration of use of the light
4. The magnification of light by dental loupes
5. The glare and/or reflection of light
6. Age of practitioner
7. Cataract removal

The use of high-intensity of LED illumination via multiple sources in the methodology of dental practice described raises important questions regarding photobiological damage to the eyes. There are possible undiscovered risks for chronic day-long, life-time exposure to the general population, and photochemical damage may cumulatively induce photoreceptor loss.[3] It follows that the possibility of greatly increased risk to the dental practitioner is an important concern that needs further research.

Regulatory guidelines are needed, including development of strategies for eye protection for dental practitioners. It is well-known that blue-light is detrimental to the retina. Although it is unclear whether blue-light predisposes an individual to the development of AMD or only exaggerates a property that is already present, the use of an additional blue-light filter should be considered.[7]

Manufacturers of dental illuminating devices should be encouraged to provide easily understood technical information

Table I - Photobiological Safety of Lamps, Overview of LED Product Safety, A European Perspective[39]

Hazard	Wavelength Range (nm)	Quantity	Bioeffect	
			Eye	Skin
Actinic UV skin and eye	200–400 (weighted)	Irradiance	*Cornea*-photokeratitis *Conjunictiva*-conjunctivitis *Lens*-cataractogenesis	Erythema Elastosis
UVA eye	315–400	Irradiance	*Lens*-cataractogenesis	
Retinal Blue-light	300–700 (weighted)	Radiance	*Retina*-photoretinitis	
Retinal Blue-light–small source	300–700 (weighted)	Irradiance		
Retinal thermal	380–1400 (weighted)	Radiance	*Retina*-retinal burn	
Retinal thermal–weak visual stimulus	780–1400 (weighted)	Radiance	*Retina*-retinal burn	
Infrared radiation eye	780–3000	Irradiance	*Cornea*-corneal burn	
Thermal skin	380–3000	Irradiance	*Lens*-cataractogenesis	Skin burn

regarding the spectral properties of the illumination source and the possible "blue-light hazard" associated with each device.

Academia needs to ensure that easy to evaluate information and detailed safety standards related to continuous exposure to LED light is made available through manufacturers and professional literature.

Guidelines for Selecting Safer LED Headlights and Using Them Safely

Eyes have protective mechanisms against wavelengths under 400 nm and bright light with strong green wavelengths, but eyes are virtually defenseless against blue-light (400 nm to 500 nm) if the blue-light is not mixed with green light or is stronger than green light.[4]

Protecting one's eyes is extremely important. If a light is too bright, your eyes are no longer able to reduce their pupil size and protect the retina. You should reduce the brightness and find an optimum/minimum brightness level. Too much light is harmful for your eyes and also reduces your visual acuity.[4]

In order to minimize potential risks from the use of LED headlights, you may follow the guidelines listed below[4]:

1. Avoid any LED headlight which has too strong of a blue-light component. Lights with too strong of a blue-light component are bluish and distort the color of objects, creating a yellowish cast to the white color.
2. Avoid any LED headlight which disperses colors.
3. Avoid any LED headlight with strong glare which may damage the patient's, operator's, or assistant's eyes.
4. Set the brightness of the overhead operatory light at an optimum/minimum brightness level which allows you to see detail.
5. Set the LED headlight at an optimum/minimum bright level which will allow you to see detail.

The lens of the eye can be replaced with artificial lenses, but no artificial retinas are yet available.[4] Dentists must be proactive in preventing potential risks to the eyes when using LED illumination.

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Questions for Continuing Education Article - CE Exam #50

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1. In the dental setting, there exists the potential for LED light–induced retinal damage to dentists due to:
   a. Cataracts which have not been removed
   b. The glare and/or reflection of light
   c. Lack of magnification by dental loupes when using a dental headlamp
   d. Specific standards provided by OSHA for dentists

2. Which of the following statements are true:
   Statement 1 – Visual perception occurs when radiation with a wavelength between 400 and 700 nm reaches the retina.
   Statement 2 – Green wavelengths of light are just as hazardous to the eyes as blue wavelengths of light
   Statement 3 – Visible light is referred to as short- (blue), medium- (green), and long-wavelength (red) radiation.
   Statement 4 –All LED light sources contain a blue wavelength component:
   a. 1, 2, 3
   b. 2, 3, 4
   c. 1, 3, 4
   d. all of the above are true

3. Which of the following is NOT true:
   a. Set the brightness of the overhead operatory light to a minimum brightness level which allows you to see details.
   b. Avoid any LED headlight which does not disperse colors
   c. “Cooler” white LED light has a higher blue-light component
   d. Avoid any LED headlight which has too a strong of a blue-light component

4. At very high intensities, blue-light (short-wavelength) can destroy the photopigments which then act as free radicals and cause irreversible, oxidative damage to retinal cells, up to blindness. What is the approximate wavelength range of blue-light on the wavelength spectrum:
   a. 300-400 nm
   b. 300-500 nm
   c. 400-500 nm
   d. 400-600 nm

5. *Statement 1* – Light intensity and the duration required to cause a certain level of damage are correlated, and a longer light exposure can substitute for the use of a lower intensity.
   Statement 2 – Red light of certain intensity is insufficient to induce retinal damage, whereas blue-light of the same intensity will cause retinal injury.
   a. Both Statements are true
   b. Both Statements are false
   c. Statement 1 is true and Statement 2 is false
   d. Statement 1 is false and Statement 2 is true

Answer Form for TDA CE Credit Exam #50:

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3.	a	b	c	d
4.	a	b	c	d
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