Clinical Dentistry

Shedding light on a potential hazard

Dental light-curing units

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ABSTRACT

Background. Dental light-curing units (LCUs) are powerful sources of blue light that can cause soft-tissue burns and ocular damage. Although most ophthalmic research on the hazards of blue light pertains to low levels from personal electronic devices, computer monitors, and light-emitting diode light sources, the amount of blue light emitted from dental LCUs is much greater and may pose a "blue light hazard."

Methods. The authors explain the potential risks of using dental LCUs, identify the agencies that provide guidelines designed to protect all workers from excessive exposure to blue light, discuss the selection of appropriate eye protection, and provide clinical tips to ensure eye safety when using LCUs.

Results. While current literature and regulatory standards regarding the safety of blue light is primarily based on animal studies, sufficient evidence exists to suggest that appropriate precautions should be taken when using dental curing lights. The authors found it difficult to find on the U.S. Food and Drug Administration database which curing lights had been cleared for use in the United States or Europe and could find no database that listed which brands of eyewear designed to protect against the blue light has been cleared for use. The authors conclude that more research is needed on the cumulative exposure to blue light in humans. Manufacturers of curing lights, government and regulatory agencies, employers, and dental personnel should collaborate to determine ocular risks from blue light exist in the dental setting, and recommend appropriate eye protection. Guidance on selection and proper use of eye protection should be readily accessible.

Conclusions and Practical Implications. The Centers for Disease Control and Prevention Guidelines for Infection Control in the Dental Health-Care Setting—2003 and the Occupational Safety and Health Administration Bloodborne Pathogen Standard do not include safety recommendations or regulations that are directly related to blue light exposure. However, there are additional Occupational Safety and Health Administration regulations that require employers to protect their employees from potentially injurious light radiation. Unfortunately, it is not readily evident that these regulations apply to the excessive exposure to blue light. Consequently employers and dental personnel may be unaware that these Occupational Safety and Health Administration regulations exist.

Key Words. Bloodborne pathogens; dental bonding; light curing; resin-based composites; Centers for Disease Control and Prevention; adhesives; personnel; light; Occupational Safety and Health Administration; occupational exposure.

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Dental light-curing units (LCUs) are an integral component of modern dentistry. In the dental profession, LCUs are used widely to photopolymerize direct and indirect restorations, sealants, and bond orthodontic brackets. Consequently, the use of these lights is now vital to the practice of dentistry. The intense light emitted by modern LCUs can cause soft-tissue burns and eye damage, and exposure to high levels of blue light is referred to as the "blue light hazard." Although most ophthalmic research on the hazards of blue light pertains to low levels from personal electronic devices, computer monitors, and light-emitting diode (LED) light sources, the levels of blue light used in dentistry are much more concentrated and intense. Research on the effects of blue light in animals suggests that extended exposure to even low levels of light is cumulative and can result in

retinal injury, although this has not been tested or shown in humans.[1] Despite the lack of class I evidence of ocular risks associated with the use of dental LCUs, the aphorism made popular by Carl Sagan aptly applies: "Absence of evidence is not evidence of absence."[2]

LIGHT-CURING UNITS: THEN AND NOW

In October 1985, the American Dental Association Council on Dental Materials, Instruments, and Equipment recognized the dangers that dental lights curing units (LCUs) could cause and approved a statement that recommended using appropriate protective filtering eyeglasses.[3] It was recommended that these eyeglasses should transmit less than 1% of the light emitted below wavelengths of 500 nanometers. Thirty years later, the irradiance from dental LCUs has increased, in some cases by a factor of 10, and LCUs are now used extensively in almost every dental office for photopolymerization of restorations, adhesives, luting agents, and sealants; bonding orthodontic brackets; and tooth whitening procedures. For example, in 2000 it was estimated that dentists spent 240 hours per year light curing dental resins,[4] and in 2015 it was reported that Norwegian dentists spent on average 57.5% of their working days placing light-cured restorations.[5] In addition, a 2013 survey reported that at least 53% of dentists use LED headlamps, often on the brightest setting, for more than 5 hours every day and some are using operating microscopes.[6,7] However, it appears that many dentists are unaware that the light from white LEDs contains a large blue light component,[8] of the dangers posed by blue light, and of their possible use of inadequate protection.[5,9,10] Many dentists are also unaware that bright white, or "cool white," LED lights deliver more blue wavelength light than "warm white" LEDs and thus may pose a greater "blue light hazard."[11]

In 2004, it was reported that ophthalmic operating microscopes could pose a significant retinal photochemical hazard unless appropriate filters were used[1,12] and the maximum permissible exposure has been well described for ophthalmic devices.[13] As the power from dental LCUs and the use of magnification has increased, a need to prevent excess ocular exposure to blue light has also emerged.[12,14-19] Early LCUs delivered ultraviolet A (UVA) light.[20-22] Because of concerns about the poor penetration of UVA light into materials and the health risks from exposure to UVA light, the photoinitiator used in dental resins was changed, and blue light LCUs were developed.[22,23] The original source of this blue light was from broad-spectrum quartz-tungsten-halogen (QTH) bulbs that were heavily filtered to deliver a broad spectrum of blue light. Studies in the 1980s that assessed the ocular hazard from the early QTH lights used the maximum daily exposure levels and times proposed by the American Conference of Governmental Industrial Hygienists. The authors calculated that when using lights that delivered an irradiance of approximately 210 through 882 milliwatts per square centimeter from 400 through 700 nm, the maximum daily total exposure from reflected light ranged from 13 through 61 minutes[15] and from 2.4 minutes through 16.4 minutes when looking directly at the light from a distance of 25 cm.[14] In 2016 it was reported that when light from a plasma arc curing light was reflected from the buccal surface of a central incisor and then viewed at a 40-cm distance, the maximum cumulative exposure time in an 8-hour workday was approximately 11 minutes.[16] This limit would be reached by an operator placing 11 restorations a day and light-curing the adhesive and the resin in each restoration for a combined time of 60 seconds.

LCUs that use LEDs now dominate the market. The emission spectrum from LED lights is different and narrower than that from QTH units,[23-25] and most contemporary LED curing lights deliver at least 2 to 3 times the irradiance of QTH units. Manufacturers of some LED units now claim[26] their products deliver as much as 5,000 mW/cm^2 of irradiance, and most of this light is emitted in the blue wavelength region from 430 through 480 nm. The threshold during use of contemporary high-power LED curing lights is unknown, but it is known that these high-power LCUs can cause soft-tissue burns if misused.[27,28] To help prevent this from occurring, a recent development is a system that warns the user if the LCU tip moves away from a tooth and onto the soft tissues.[29] This technology also prevents the light from being shone directly into the eye.

ABBREVIATION KEY

EM: Electromagnetic.
IFU: Instructions for use.
LCU: Light-curing unit.
LED: Light-emitting diode.
OSHA: Occupational Safety and Health Administration.
QTH: Quartz-tungsten-halogen.
UVA: Ultraviolet A.

THE BLUE LIGHT HAZARD

The term "blue light hazard" refers to the photochemical damage to the retina caused by short-wavelength electromagnetic (EM) radiation from 400 through 500 nm, with the most damaging wavelengths from 420 through 455 nm.[8,30-34] These are the wavelengths of EM that are emitted by most dental LCUs.[22-24,35] Although blue light is present all around us and helps regulate our circadian rhythms,[8,36-38] animal studies suggest that chronic exposure to excessive amounts of blue

light can damage the light-sensing cells (photoreceptors) in the retina.[25,39-45] It is also known that the juvenile lens absorbs less blue light than the adult lens and that their retinas are more susceptible to the effects of blue light.[33,46,47] Based on numerous animal studies of acute exposure to blue light, daily exposure limits to protect the eyes of all workers have been set by many organizations, such as the International Commission on Non-Ionizing Radiation Protection,[30] the European Parliament,[31] and the American Conference of Governmental Industrial Hygienists.[32] As the use of electronic devices such as flat-screen televisions, computers, smartphones, tablets, and fluorescent and white light LED operatory lights has become more prevalent,[47,48] health-related concerns have arisen that all humans, not just dentists, are being exposed to excessive amounts of blue light.[25,38,49] A significant adverse association between touchscreen use and nighttime sleep, and sleep onset has already been reported.[8,36,41,50] A 2016 report from the American Medical Association[38] expressed concerns that the blue light from the LEDs in streetlamps might suppress melatonin production, disrupt the circadian rhythm, cause discomfort glare, and have detrimental environmental effects. The American Medical Association recommended that the blue-rich light from white light LEDs be minimized. In April 2019, the French Agency for Food, Environmental and Occupational Health & Safety warned that powerful LED lights are "photo-toxic."[49] The report recommended that the "maximum limit on short-term exposure to blue light should be reduced, only low-risk LED devices should be available to consumers, and the luminosity of car headlights should be reduced." Given these concerns, many manufacturers of electronic devices (cell phones, tablets, computer screens, and LED lighting) have already reduced the levels of blue light emitted by their products and some have optional settings that further reduce the amount of blue light emitted.[41,51] The blue light component from these devices is exponentially less than the blue light from contemporary dental LCUs, dental whitening lights, LED operatory lights, and LED headlamps.[11,16-19]

Dental personnel's exposure to blue light

The potential ocular harm that can occur when the eye is exposed to excessive exposure to light has already been published.[8,11-13,33,37,39-42,44-46] The maximum daily safe limits for exposure to blue light in an 8-hour workday are theoretical values based on animal studies.[30-32] Adding more light from powerful sources such as the LCU, the operatory light, the bleaching unit, or the operating microscope to the average daily exposure poses an additional risk of developing blue light—related injury.[16,18,19,34] Dental personnel have been trained to focus their stares on the bright light that is reflected from teeth, skin, and metal instruments for many hours every working day. Thus, they may not be protected by the natural aversion response of the eye to bright light that usually limits single exposures to less than a second.[11,30] The ocular exposure to blue light may be further enhanced when magnification loupes or operating microscopes are used without appropriate filters.[12] In these instances, the user is focused for an extended time every working day on small magnified areas that are very bright,[16] and the effects of the blue light component may be even greater.[11,52] This further emphasizes the importance of using the appropriate eye protection to reduce the amount of exposure to the additional blue light that is present in the dental office.[3,12,16,17,34,53]

PRIMARY AGENCIES THAT AFFECT EYE SAFETY IN THE DENTAL PROFESSION

There are many regulatory, advisory, and standard-setting agencies that address ocular hazards from blue light.[3,30-32,49,54] In addition to the recommendation made in 1985 by the American Dental Association Council on Dental Materials, Instruments, and Equipment to use appropriate, protective, filtering eyeglasses when using LCUs,[3] the European Parliament has published a directive[31] on the minimum health and safety requirements regarding the exposure of all workers to risks arising from artificial optical radiation. A standard from the Occupational Safety and Health Administration (OSHA) also contains a clause that explicitly protects all workers from potentially injurious light radiation.[54]

The 2 most widely read infection control safety-related documents in the United States—the Centers for Disease Control and Prevention Guidelines for Infection Control in the Dental Health-Care Settings: 2003[55] and OSHA Bloodborne Pathogen Standard[56]—provide recommendations for eye protection that focus on impact resistance and potential infection transmission from microorganisms in sprays and spatters, but they fail to make any specific recommendations to protect personnel from ocular risks related to curing lights. However, OSHA does have an overriding General Duty Clause that states that "Each employer shall furnish to each of his employees

employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employee," and "Each employee shall comply with occupational safety and health standards and all rules, regulations, and orders issued pursuant to this Act which are applicable to his own actions and conduct."[57] In addition, OSHA regulation 1926.102(a)(1) states, "The employer shall ensure that each affected employee uses appropriate eye or face protection when exposed to eye or face hazards from flying particles, molten metal, liquid chemicals, acids or caustic liquids, chemical gases or vapors, or potentially injurious light radiation,"[54] and "Eye and face personal PPE [personal protective equipment] shall be distinctly marked to facilitate the identification of the manufacturer."[58] Thus, OSHA regulations do cover blue light exposure, but they are often not readily evident or available and are not typically printed in commercially available infection control and safety compliance manuals for the dental setting. Consequently, the employer and employee may not be aware of the extent of the risk of exposure to blue light or the requirement to protect employees against potentially harmful light radiation. Previously many dentists were owner-operators and were responsible for their own actions. With the widespread introduction of corporate dentistry, however, many dentists are now employees, and their employers are responsible for ensuring that they are adequately protected from hazards in the workplace.[54,57]

Eyewear protection

The US Food and Drug Administration considers curing lights to be Class II medical devices (capable of posing a moderate risk to the patient, user, or both) that must meet approval standards before they can be sold in the United States. Although there are American National Standards Institute[59] and International Organization for Standardization[60] standards for protective eyewear, the protective eyewear or shields that are purchased after market (that is, not supplied with the LCU) are considered to be Class 1 (low risk to the patient, user, or both) exempt and not required to submit proof of efficacy and safety before being sold in the United States. Because not all dental LCUs emit EM radiation in the same wavelength range and there is a lack of regulation of aftermarket blue light protective filters, blue light–blocking eye protection purchased after market may or may not protect against all the EM wavelengths emitted from the LCU in use.[17,53,61,62] Thus, both the employer and the employee should ensure that they are using effective and adequate eye protection.[3,54]

Selection of curing light and eye protection

Those who purchase dental supplies and equipment are faced with numerous choices of commercially available products. Table 1 provides tips for selecting LCUs and eye protection, and Table 2 describes the advantages and disadvantages of each option.

Chairside safety for light curing

Despite the lack of Class I evidence of ocular risks in humans associated with overexposure to blue light, the aphorism made popular by Dr. Carl Sagan aptly applies: "Absence of evidence is not evidence of absence."[2] The use of white light LEDs has increased such that in just the past decade the entire population is now exposed to more blue light than ever before. It is too soon to know if this additional exposure poses a hazard to humans, but based on animal studies concerns have been raised that we are being exposed to excessive amounts of blue light.[1,8,15,31,32,34,38,49] Thus, the following recommendations should help ensure the safe use of LCUs in the dental office[35]:

- Do assess the patient for a history of cataract surgery, retinal diseases, or if the patient is taking medication that makes him or her more photosensitive. Such patients may be more sensitive to light exposure than the average person.[23,33] Infants and children are also more susceptible to the effects of blue light.[33,46,47]
- Do follow recommendations and ensure that all dental personnel use appropriate light-blocking eye protection during light-curing procedures.[3,54]
- Do check that your operating microscope has the appropriate filters against blue light.[12]
- Do read and understand the instructions for use (IFU) from the curing light manufacturer.
- Position the light shield to maximize eye protection when light curing.
- Do use appropriate barrier sleeves (US Food and Drug Administration–cleared plastic sleeves provided by the manufacturer)
- Follow the IFU regarding covering the tip of the light guide and the control buttons;

Table 1. Tips for selecting a light-curing unit and the appropriate eye protection.

TIP	COMMENTS
Ensure that both the LCU* and its charger are approved medical devices	The US Food and Drug Administration list of registered medical devices can be found at https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfRL/TextSearch.cfm. The precise name of the product in the US Food and Drug Administration database may differ from the name of the device (per the marketing department of the manufacturer).
Ensure that the curing light and eye protection meet photobiological safety standards	To be approved for use on patients, curing lights must undergo photobiological safety testing. The IEC† 62471[63] photobiological safety standard addresses the amount of light allowed in various ranges and requires warning labels for 3 different risk groups. Most lower-power curing lights fall into risk group 1, but some high-power curing lights modes may fall into the photobiological risk group 2.
Ensure that the photoinitiator systems of the dental material to be cured are compatible with the light emitted from the LCU	For resins that use only camphorquinone, a monowave light-emitting diode device delivering blue light (430-500 nanometers) is recommended. For resins that use additional photoinitiators that absorb almost exclusively < 420 nm and into the ultraviolet range, such as Lucirin TPO (BASF Formulation Additives) or phenyl-propanedione, a light delivering a broad spectrum of light from 380-515 nm.[64] is recommended.
Select appropriate eye protection	Eye protection should be covered by National Standards Institute/International Safety Equipment Association standard Z87.1[59] and International Organization for Standardization standard 12609.[60]
The best practice is to use the eye protection provided by the manufacturer of the curing light in use	Different curing lights may emit different wavelengths of light. Thus, eye protection provided with a specific LCU may or may not be compatible with another LCU.
If a third party manufactures the orange shields or glasses, ensure that they protect against the wavelengths emitted by the curing light in use	Good manufacturing practices guidelines stipulate that all claims on packaging and advertising can be proven.
Ensure that the curing light and its charger meet the required electrical safety standards	Required electrical safety standards (IEC 60601-1),[65] including standards that are specific to dental electrical devices and their accessories (IEC standard 80601-2-60[66]).

* LCU: Light-curing unit. † IEC: International Electrotechnical Commission.

- Avoid covering vents that may be blocked by a barrier sleeve.
- Do routinely test curing light output with a radiometer per manufacturer recommendations.
- Do follow the IFU (of the dental material and the curing light) for exposure times.
- To minimize heat development, cool the tooth and tissues with a flow of air.[23,67] Consider polymerization at intermittent intervals (for example, 2 exposures each lasting 10 seconds with a 5-second pause in between each instead of 1 continuous exposure lasting 20 seconds).
- Do not operate the curing light without using the correct eye protection.
- Do not look directly or indirectly at the light from the curing unit.
- Avoid prolonged exposure of unprotected eyes to reflected light.
- Do not just look away when light curing. You must watch what you are doing.
- Do not rely upon judging the heat output from the LCU by shining the light tip on the fingernail or on the back of the hand.
- Do not shine the light directly on unprotected oral mucosa or skin.
- To protect soft tissues, especially when light-curing Class V restorations, cover gingiva with a gauze[23,28] and avoid shining the light onto the mucosa.
- Do not expose oral tissues for longer times than recommended in the light manufacturer's IFU. Different shades of composite supplied from the same manufacturer often require different exposure times.
- Do not allow restorative materials to contact the end of the curing light (light guide, tip, or wand), as it will adhere to the tip and reduce light output.[23,68] Using a protective barrier (if recommended by the manufacturer of the LCU) will prevent this from occurring.

POSTPROCEDURE SAFETY TIPS

If after using the LCU your vision is blurred or you experience afterimages that persist, your eyes may have been exposed to an excessive amount of light.[1,15] If this happens, you should improve your standard of eye protection.

Once the light-curing procedure is complete, follow the manufacturer's IFU regarding methods for cleaning and disinfect the curing light and light shield, antiglare shield, cone, or other eye protection. To avoid damage, ensure that the disinfectant is compatible with the surface of the curing light and the shield used. The IFU will also state recommendations for cleaning, disinfection, and sterilization of the light guide and which US Environmental Protection Agency—registered

Table 2. Types of eye protection available for light curing.

TYPE OF EYE PROTECTION	ADVANTAGES	DISADVANTAGES
Orange round or oval shields attached to the light guide that are designed to protect against the wavelengths of light from the LCU* being used	■ Can be adjusted to provide best eye protection for the operator	■ The surface area of the protective eye filter of most LCUs is not sufficient to protect the dentist and the assistant at the same time ■ May restrict correct access of the light the restoration ■ If using this method, consider providing additional protective eyewear for the assistant
Orange goggles or glasses (especially those with side protection) that are designed to protect against the wavelengths of light from the LCU being used	■ Provide optimum protection, eliminate scatter irradiation ■ Allows for hands-free eye protection	■ If using loupes, may be inconvenient to change between the application of dental materials and light curing
Antiglare cones that fit on light guide or tip	■ Easy to use ■ Allows hands-free protection	■ May obstruct the view and may prevent ideal placement of the light tip over the restoration ■ Can increase the distance between the tooth and the light tip ■ May not provide sufficient eye protection in some light tip positions or if cone slips from the proper location
Paddles	■ May provide adequate coverage for both the dentist and assistant (depending on design and placement of paddle) ■ Curved paddles allow for better fit around the patient's face than a rectangular paddle	■ Requires an extra hand to hold the paddle in place. Does not allow hands-free protection
"Look away": In this method, the user places the curing light tip over the restoration to be cured and subsequently looks away when the LCU is turned on	■ None ■ This method is not recommended	■ This method does not provide adequate ocular protection ■ The user often glances at the operative field and is exposed to blue light ■ The user cannot monitor the location of the light tip if he or she looks away. This may result in soft-tissue burns, inadequate light curing, and a defective restoration

* LCU: Light-curing unit.

products can be used. If barrier sleeves are used, discard after each use to prevent cross-contamination; these are labeled as "single-use." The barrier sleeve should be removed before placing the light guide in the charger to ensure adequate electrical contact with the battery and avoid contaminating the charger.

The light probe should be inspected for damage or residue and cleaned before the next use. If visible resin remains, follow the manufacturer's IFU for removal. If cured dental materials are visible at the end of the light guide or light attachment lens, use an alcohol wipe and a plastic-edged instrument to gently scrape them away. To avoid scratching the tip or lens, do not use a sharp instrument to scrape off polymerized materials.

To ensure ocular safety after the dental procedure, carefully handle the LCU and do not accidentally turn the unit on while looking at the tip. To be prudent, remove the battery where possible to prevent accidental exposure.

ONGOING EDUCATION AND TRAINING

Ongoing education and training are paramount to ensure the safety of dental personnel and patients during light-curing procedures. All employers and employees should be educated regarding the need for eye protection that filters blue-violet and UVA light when using curing lights.[3,17,23,35,53] Educational topics may include a discussion of retinal damage that may occur after exposure to curing lights and with lack of or misuse of eye protection. In addition, the output from the LCU should be regularly assessed with a dental radiometer that is calibrated for the specific LCU per the manufacturer's IFU. Employers may also consider engaging in light-curing training with appropriate technologies to ensure that the intended amount of light is delivered to adequately cure the resin.[69-71]

CONCLUSIONS

The dental LCU has become an essential component of modern dentistry, and bright white LED lights that contain large amounts of blue light are now being used throughout the dental office. Research on the effects of blue light in animals suggests that extended exposure to even low levels of

irradiance can result in retinal injury.[1] Although this has not been tested or shown to occur in humans, dental personnel are exposed to much higher daily doses of blue light than the general public and thus may be at greater risk of developing ocular injury. Employers and employees may not be aware of the potential hazards or may not be familiar with regulatory documents that are meant to protect all workers from damaging exposure to light. Under OSHA, the use of protective eyewear is required, but readers must remember that if purchased after market, the blue light filter may be incompatible and not block all the wavelengths of light from the specific LCU in use.

Consequently, dental personnel may use inappropriate eyewear, may misuse the eye protection, or may choose not to use any eye protection during light-curing procedures. More research is needed on the effects of cumulative exposure to blue light in humans to better define the potential hazard from blue light to dental personnel and patients. Manufacturers of LCUs, government and regulatory agencies, employers, and dental personnel should collaborate to determine the potential additional ocular risks from blue light that exist in the dental office. ■

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Disclosure: Dr. Ferracane is listed on an external advisory board for BlueLight Analytics (Halifax, Nova Scotia, Canada). This appointment was made years ago, and he has not performed any duties for the company within approximately the past 5 years. The board position is an unpaid informal role. Dr. Mace is the inventor of an auto-positioning curing light eye shield designed to streamline the process of using filtration when curing. Dr. Mace is a majority owner of Ergocept (Washington, MO). Dr. Price is the inventor of the MARC-Patient Simulator that is used to teach light curing. The simulator is manufactured by BlueLight Analytics. Dr. Price is not associated with the company and has not performed any duties for the company since 2012. None of the other authors reported any disclosures.

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