



WHITE PAPER

Use of Light Emitting Diodes in Dental Operator Lighting

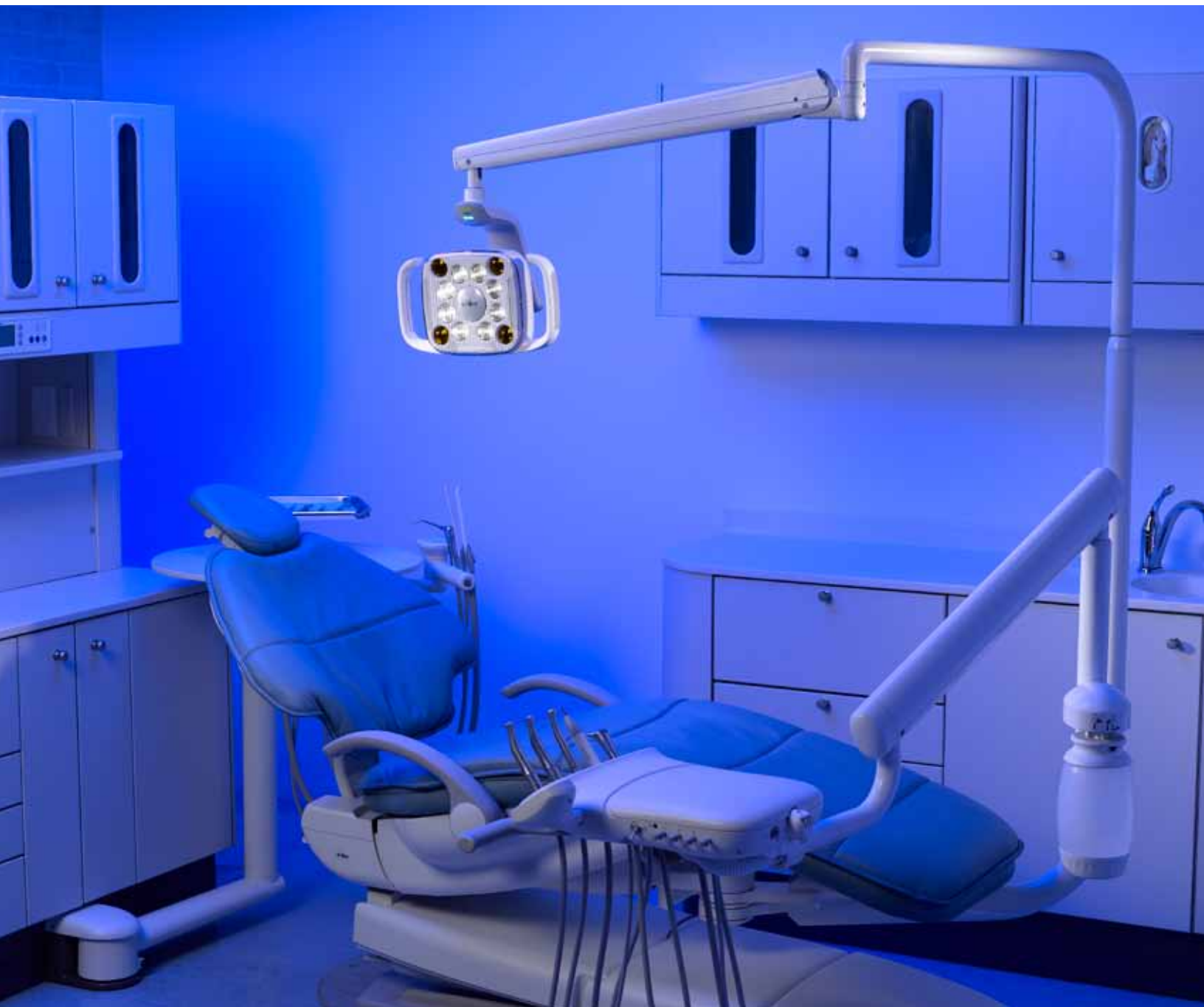


TABLE OF CONTENTS

Background	3
Purpose of This Paper	3
Critical Components of Dental Task Lighting.....	4
Light Quantity.....	4
Light Quality	4
Color	5
Correlated Color Temperature	5
Chromaticity	6
Color Rendering Index.....	6
Light Consistency and Uniformity.....	7
Shadowing.....	7
Compatibility with Light-cured Composite Materials.....	8
Other Important Components of a Dental Light.....	9
Ergonomic Considerations of the Dental Light.....	9
Visual Acuity and Proper Illumination.....	9
Light Positionability.....	10
Easy and Intuitive Operation of Light Controls.....	11
Infection Control	11
Hassle-free Ownership.....	11
Aesthetics.....	11
LED Basics, Advantages and Disadvantages	12
Advantages of LEDs in Dental Task Lighting.....	12
Disadvantages of LEDs in Dental Task Lighting.....	13
Bibliography.....	14

BACKGROUND

Over the past two decades, Light Emitting Diode (LED) technology has been rapidly displacing more traditional lighting technologies (i.e., incandescent bulb, fluorescent, etc.) across a broad range of industries and applications. The potential advantages inherent in an LED-based light—high light output, flexibility in color and spectrum and intensity, low radiant heat, longer life, compact size, and lower power consumption—make the technology very attractive.

In the past five years, the quality and performance of higher-end LEDs has improved to the point that the technology is now suitable for adaptation into dental work light applications. To date, there are a number of dental equipment manufacturers that develop and market dental task lights using LEDs.

Critical evaluation of the competitive products shows manufacturers have not yet overtaken the best-in-class halogen bulb-based lights. However, there is clear momentum for LED technology developing within the dental industry—from both manufacturers and dental practitioners. LED technology will enable improvements and innovations that will displace, if not replace, halogen bulb-based lights over the next 5–10 years in the dental light market.

PURPOSE OF THIS PAPER

The purpose of this paper is threefold: First, it seeks to educate professionals within the dental community on the basic requirements of dental task lighting. Second, it describes how the application of LED technology relates to these requirements in terms of benefits and tradeoffs. Third, and most important, the information should enable well-supported recommendations or decisions on the acquisition of quality dental light solutions for the dental practice.

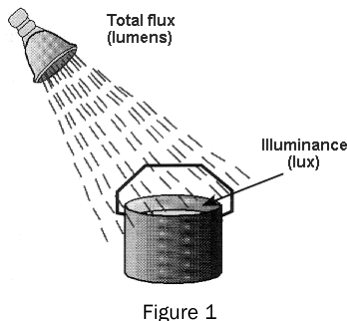


Figure 1

**First and foremost,
it's about the
performance of the light
in the oral cavity.**

CRITICAL COMPONENTS OF DENTAL TASK LIGHTING

First and foremost, any dental light must enable the dental practitioner to deliver the best quality dental care with maximum productivity. To achieve these goals, the dental light must deliver light of sufficient quantity, quality, and consistency. These terms are somewhat qualitative and therefore can be subjective, so it is useful to describe lighting performance with more objective parameters.

Light Quantity

For oral cavity illumination, it is useful to think of light quantity as the amount of light incident on a given area (Figure 1).

It is described in terms of “illuminance”¹ and is typically measured in lux (lumens/m²) but may also be represented in foot-candles.

A good light typically covers an area 90–100mm high by 150–160mm wide in order to fully illuminate the oral cavity without the need to reposition the light, plus illuminate the periphery in order to reduce eye fatigue. Illumination levels for most dental applications may range from less than 8,000 lux (e.g., white light being used during light-cured composite restorations) to as high as 30,000 lux during procedures in the posterior of the oral cavity that employ indirect vision techniques and water cooled drills (e.g., cavity preparation on a second molar in the upper arch).

While this range of illuminance is relatively high compared to most other office applications, it is appropriate for more challenging procedures like the example above. However, it is important to note that not all applications require this amount of light, and the dental team should take care to use only the amount of light necessary for the procedure to support long-term eye health. ([See Ergonomic Considerations of a Dental Light for more information on proper selection of illumination levels, pg. 9.](#))

Light Quality

Growing public awareness of the importance of oral health diagnoses and treatment, as well as strong demand for cosmetic restorations that are natural and highly aesthetic, have made quality performance of dental lighting one of the most demanding.

¹ ISO 9680 describes an area of 50mm x 25mm that must be at least 75% of maximum illuminance, however, the patterns of most dental light manufacturers produce larger patterns to more effectively illuminate the patient's mouth and cheeks.

The light reflected (i.e., perceived) from the patient's mouth can only be as good as the light delivered from the source.

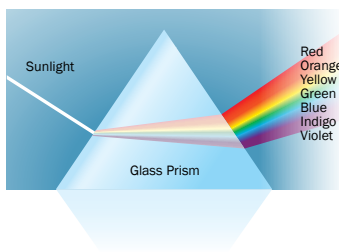


Figure 2

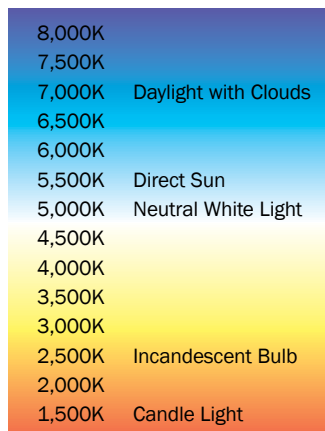


Figure 3

For decades, the dental profession and industry have generally agreed that oral cavity lighting should be a neutral white in color to best enable the practitioner to diagnose oral health and discern healthy tissues from diseased or damaged tissue.

For these reasons, dental light manufacturers have sought to design products that mimic natural sunlight as closely as possible. This is because natural sunlight provides a broad, well-balanced color spectrum, or spectral power distribution, that the human eye regards as the ideal illuminant for perceiving the “true” color of an object. The more closely a light source matches the quality of sunlight, the greater likelihood that the dental practitioner will accurately perceive the condition of the oral cavity. Simply stated, the light reflected from the patient’s mouth and perceived by the practitioner can only be as good as the light delivered from the source.

Color

Subjectively, one of the chief goals of a dental light is to render tissue in a natural way, and this is best achieved by using a white light. It is important to note that what the human eye perceives as white light is actually light that contains a balance of all colors (i.e., wavelengths) of visible light. This balance of colors is represented by the spectral power distribution of the light produced by a source.

The spectral power distribution (Figure 2) is like a fingerprint for the color characteristics of a light source. While it contains complete information about the color content of a light source, it does not serve as a simple, easy-to-interpret way of communicating the overall color appearance or the ability to discern colors when using the source. To more conveniently describe the color quality characteristics of a light source, several metrics are commonly used in the illumination industry: correlated color temperature, chromaticity and color rendering index.

Correlated Color Temperature

The perceived color of a light source is often described by Correlated Color Temperature (CCT). The concept of color temperature is based on the phenomenon that when mass is heated to a high enough temperature, it emits light. The color of the light depends on the temperature measured on the Kelvin scale (K), thus the relation between temperature and color. Figure 3 illustrates this correlation for what is referred to as an ideal black body radiator. In reality, most light sources do not perfectly match the colors of the ideal black body radiator, but a nearest match can be determined, which is referred to as correlated color temperature to emphasize that it is not necessarily the exact color of an ideal black body at the specified temperature.

Neutral white light has a CCT of 5,000K which is why most dental manufacturers offer lights at or near this value.

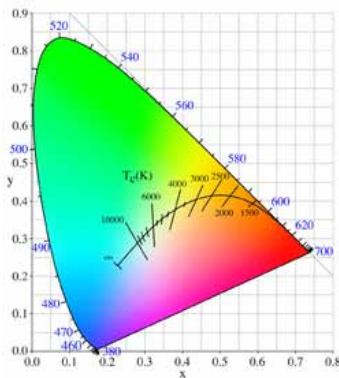


Figure 4

There are a few important points to note with respect to color-temperature as this method can be confusing for a couple of reasons. First, it is fairly common for individuals to conclude that the light actually operates at this temperature. This is not necessarily the case (Tungsten has the highest melting point of all metallic elements at 3,695K). Second, people often describe red colors as “warm” and blue colors as “cool.” Paradoxically, blue light corresponds to a higher CCT than red light.

CCT is a useful metric for characterizing how warm or cool a light appears, but by itself, it doesn’t provide complete information about the color quality of a light. This can be especially true for light sources, including LEDs, that are not based on heating a filament until it glows since the color may deviate substantially from the colors produced by the black body radiator.

Chromaticity

Since LED lights do not behave in the same way incandescent sources do, it is insufficient to fully describe the color of white light in only the dimension of CCT. It is therefore useful to use chromaticity coordinates.

Unlike CCT, which is limited to the colors emitted by a black body radiator, chromaticity spans all colors. There are a number of systems for showing two dimensional plots of chromaticity, where each coordinate pair defines a unique color. One widely used example is the (x, y) chromaticity coordinate system, depicted in Figure 4. By specifying a value for x and a value for y, a color may be precisely characterized.

Notice that this illustration also includes a curved line representing the colors generated by the ideal black body radiator. The short, straight lines represent lines along which the CCT remains constant. It also demonstrates how CCT can be insufficient for describing color quality. Consider the 6,000K contour line. At the point it intersects the black body radiator curve, the color is nearly white. Moving upward along the 6,000K line yields a greenish light, while pinkish light emerges along the 6,000K line.

Chromaticity coordinates enable the color of a light source to be more fully described than with CCT. A limitation of chromaticity coordinates is that it is not readily apparent to most people what color a particular chromaticity coordinate pair represents without a plot, such as the example in Figure 4.

Color Rendering Index

While CCT and chromaticity aim to characterize the color appearance of a light source, color rendering index (CRI) provides a measure of how well a light source reproduces the colors of various objects compared to an ideal or natural light source. As mentioned earlier, sunlight contains all colors of light



High CRI Source Lower CRI Source
Figure 5

(i.e., wavelengths of light) at sufficient levels such that it accurately renders all colors reflected by an object. That is to say, the red component of light in the white sunlight allows us to perceive all the subtleties of tone, whether it's all the reds found in gum tissue or the wide range of color perceived from something as common as a smile (Figure 5).

Sunlight is considered to have perfect color rendering and has a CRI of 100. It follows, therefore, that a dental light should have as high a CRI as possible (along with correct color and appropriate illuminance) to provide the best opportunity for accurate perception of the condition of the oral cavity.

Traditional light designs, such as the A-dec 6300 Light, with a Quartz-Halogen bulb and dichroic reflector can consistently achieve a CRI of 95+. LED-based dental task lights, however, have typically not been able to achieve an equivalent CRI. To be certain, there are a growing number of products available that are at or above 90, but there are also lights on the market that fall below 80 CRI at 5,000K.

Given the high adaptability of the human eye, the clinical effect of using a light with lower CRI is not entirely clear, but research confirms that light with higher CRI (i.e., ~90 or above) renders tissue within the oral cavity more completely and accurately.

Light Consistency and Uniformity

The overall consistency of a light pattern (Figure 6) further differentiates light performance. With respect to illuminance, the light pattern should have a clear and uniform central region that consistently illuminates the targeted region of interest.

At the edges of the pattern, illuminance levels should drop gradually with a feathered edge to limit eye fatigue due to refocusing between areas of sharp contrast. ([Also see Ergonomic Considerations of a Dental Light, pg. 9.](#))

As an additional note, the pattern produced by the light should effectively control the amount of glare in the patient's eyes. The ISO Standard, ISO 9680, specifies that the light directed or scattered at the line 60mm from the center of the pattern (i.e., the approximate distance from the mouth to the horizontal centerline of the eyes) must not exceed 1,200 lux. A good dental light should perform well below this threshold; however, it is important to note that not all lights, including some LED-based lights, meet this requirement.

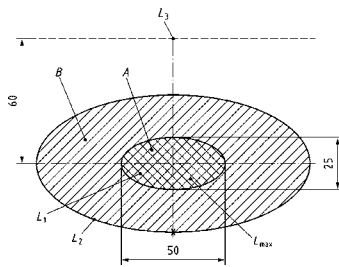


Figure 6

Lighting Pattern According to the ISO 9680:2007

- A Inner area of illumination
- B Outer area of illumination

Shadowing

A dental light must exhibit excellent shadow performance to support good dental team posture and enhance productivity. The light head must be designed such that partially obstructing the light field will not cast excessive

The light source should span at least 150mm to achieve a “stadium” effect with the light pattern.

shadows or substantially reduce lighting that cause the dental team to have to slow down, reposition the light, or assume a poor ergonomic posture.

To achieve good shadow performance, the dental light head must be wide enough in both the horizontal and vertical directions to ensure obstructing objects (such as an instrument or hand) do not cause obtrusive shadows. At the standard distance of 700mm from the light head to the oral cavity, the light source should span at least 150mm to achieve a “stadium” effect with the light pattern. This can be achieved with either a sufficiently large reflector or a broadly distributed array of light cells.

Compatibility with Light-cured Composite Materials

Modern dentistry has seen an explosion in the use of photo-initiated dental materials. Most notably, light-curable composite resins have become extremely popular due to their natural cosmetic appearance, improved ease of application, and improved strength and durability without the concerns of mercury-based amalgam.

Camphorquinone is the most common photo-initiator used in light-curable dental materials (composite restorations, sealants, orthodontic bracket adhesives, etc.). Since camphorquinone cures in the blue range (visible light below a wavelength of 500nm), a bright white dental light may cause premature curing. This is because the white light naturally contains light in the blue spectrum. The consequence of premature curing may result in a poor restoration (one with voids or defects) or may require the dentist to remove the material and start again.

Given the popularity of light-curable dental materials, it follows that a dental light should be highly compatible with these types of applications. Traditionally, manufacturers of halogen-style dental lights have offered some form of intensity adjustment to allow the user to reduce light power. While this approach can extend the time a practitioner has to apply and cure a light-cured resin, it does not fully eliminate the potential for premature reaction. The result is that many dentists prefer to simply turn the light away or off and work without a task light rather than take the risk.

LED-based technology is particularly suited to address this issue. While any white light, including LED, will introduce blue light that can initiate curing, the fact that multiple LEDs can be used in one light head makes it possible to offer a mode that either reduces (by mixing multi-colored LEDs) or completely eliminates (by using filters or non-white LEDs) all of the blue light in the pattern. Of course, the pattern will not be white in this case, but it allows the dentist to work with full illumination in the oral cavity during critical steps of the restoration.

OTHER IMPORTANT COMPONENTS OF A DENTAL LIGHT

Of course, performance of the light in the oral cavity is the most important component of any dental light, but to qualify as truly successful, the dental task light must also address a number of other requirements of the dental team and environment. When done well, ergonomics, infection control, hassle-free ownership, and aesthetic appeal all serve to multiply the value of a dental light.

ERGONOMIC CONSIDERATIONS OF THE DENTAL LIGHT

Modern dentistry has come to recognize the vital impact that ergonomic practices have on the dental professional. In efforts to deliver excellent dental care and treatment, practitioners will routinely sacrifice good posture to achieve better vision in the oral cavity. The consequences of poor ergonomics result in chronic pain, reduced productivity, and a shortened career. The dental light plays an important role in this regard, so its design should foster good vision and posture to the highest extent possible.

Visual Acuity and Proper Illumination

As discussed earlier, the light pattern should first fully illuminate the oral cavity. This in turn fosters good posture and minimizes the need to reposition the light. Once these conditions are established, the dental light must deliver proper illumination to meet the needs of the particular user and the application.

Proper illumination levels for dental lights have been the subject of much research and debate. It is a fairly common perception among many dental clinicians that more light generally provides better visual acuity (that is the ability to accurately perceive the condition of various tissues in the oral cavity). However, more light does not necessarily correlate to better visual acuity since the human eye will naturally adapt to the light level (Calleja & Hernandez, 1998).

Factors such as age, gender, and ethnicity can affect a user's preference regarding "proper" illumination. Concurrently, the specific dental procedure affects desired illumination levels as well. For example, brown-eyed male dentist age 60, working in the posterior area of the mouth may require substantially more illumination than a blue-eyed female dentist age 35, using direct lighting performing a restoration in the anterior. Of course, the use of lighted loupes, a lighted handpiece, and/or lighted suction devices also contribute to the light reflected or directed to the user's eyes.

It is therefore essential that the dental light provide the ability to adjust illumination to deliver only the amount of light necessary based on the needs of the user and the procedure.

It is also worth noting that LED-based dental lights have a distinct advantage relative to traditional bulb-based lights when it comes to adjusting illumination. Because they require different methods of control and power regulation, the illumination level can be adjusted without changing the color of the light pattern. Bulb-style lights, on the other hand, will change in color as the illumination level varies. The benefit for the user is that, when a lower level of light intensity is appropriate, color is not compromised.

In summary, the dental light must enable easy selection of the lowest level of illuminance to meet the user's preference and demands for the specific procedure. This will serve to reduce eye fatigue and improve productivity.

Light Positionability

Gross Positioning of the Light The light should be easy to move to and from a stowed position. The dental light should be easy to position with a sufficient range of motion to accommodate illumination of either the upper arch or lower arch for all foreseeable procedures. These procedures would certainly include having the patient in the supine or seated position, but should also allow for special cases such as treatment for a patient in a wheelchair that cannot be moved into the chair.

As a final note on gross positioning of the light: Range of motion and positionability should allow the operator to position the light from 15 degrees past vertical (i.e., in line with the operator's line of sight) to reinforce ergonomic positioning when loupes, indirect lighting, and indirect vision are employed.

Fine Positioning of the Light with Three-axis Positionability While some practitioners will accept a light with two axes of rotation, a light with three axes of positionability is preferable from an ergonomic point of view. The third axis allows the light to be positioned obliquely relative to the centerline of the patient. This is necessary to have shadow-free lighting in the mouth and to make it possible for the dentist to move with his or her head during treatment without forming shadows. The result is better posture and better vision while avoiding shadowing.

Ultimately, a dental light should perform well enough that positionability is not often required, and when it is, the motions are intuitive—nearly effortless. While LED technology has made it possible to develop a dental light with truly superior positioning, not all light designs have realized this opportunity.

To reduce eye fatigue and improve productivity, a dental light must enable easy selection of the lowest level of illuminance while still meeting user preference and assuring optimal performance for the specific procedure.

It should be possible to activate the light without touching it or causing the primary user to look away from the oral cavity.

Easy and Intuitive Operation of Light Controls

As discussed above, LED technology enables modes that better support dental procedures (e.g., levels of illumination, cure-safe lighting). Yet dental clinicians rightly want to stay focused on the oral cavity and will not necessarily take the time to change a lighting mode.

Ideally, it should be possible to activate the light without touching it or causing the primary user to look away from the oral cavity.

Infection Control

While LED technology has clear potential to improve dental lighting, it's important to keep in mind that any new design must still meet the rigorous cleaning and disinfection protocols of modern dental environments.

Touch surfaces must be minimized wherever possible without compromising intuitive activation and positioning. Ideally, the shapes and contours of the light should be easy to wipe or protect with simple barriers to enable quick and thorough operatory turnover.

Hassle-free Ownership

The product design must be reliable and robust with minimal need for repair. A well-designed LED-based light will never need replacement of the lighting elements. The most robust design will achieve performance requirements without the need to employ components such as fans, thermal limit switches, and bulbs that may cause premature failure.

Repairs and adjustments must be simple, straightforward and inexpensive.

Aesthetics

To the patient in the chair, few objects in the treatment room are more prominent and imposing. It is therefore essential that the design of the light projects a professional image. Simple shapes and thoughtful lines communicate a sophisticated, high-tech appearance, which impact the overall treatment room experience. And because a quality dental light should last between 10 and 20 years, the design must retain its appeal over time.

Additionally, the visible surfaces, particularly components such as a lens shield or reflector, should be easy to clean or barrier-protected without apparent streaks or smudges that might create a less than favorable perception in the mind of the patient.

LED BASICS, ADVANTAGES AND DISADVANTAGES

As with any new technology that seeks to displace an incumbent technology, there are always advantages and disadvantages to consider. The transition to LED-based dental lighting from more traditional quartz-halogen bulb-style lights is no different.

Advantages of LEDs in Dental Task Lighting

More Light with Less Power Consumption. LEDs are far more efficient at producing light. Technology has advanced to the point where it is possible to get substantially more light from a lot less power. A typical bulb-style dental light operates at approximately 100W to deliver ~24,000 lux. By contrast, an LED-based light can deliver 25% more light at one-fifth of the required power. Further, the trend toward more efficient LEDs will continue into the foreseeable future. While dentists are unlikely to sacrifice light performance simply to reduce energy consumption, dentists appreciate the reduced energy expenses as well as the sustainability benefits.

Long Life with No Bulb Replacement. Even the best bulbs have a limited life and will eventually fail—often during a procedure. The result is a recurring cycle of lost productivity and expense. LED-based lights, by contrast, offer the very real potential of operating without failure over the entire life of the product, an estimated 40,000 hours of use over 20 years. This is especially true when the light is designed with robust thermal management and balanced power regulation ([see “Thermal Management” in Disadvantages, pg. 13](#)). Additionally, light emitting diodes are inherently more robust than incandescent bulbs.

No Radiant Heat. LED-based lights do not produce radiant heat, which means there is no “heat lamp” effect. This helps prevent the dental team from perspiring while working in their personal protective equipment, such as gloves, glasses, mask, and gown. The result is a more comfortable and productive work environment.

This is particularly significant in larger clinics or institutional settings where many lights are operating in close proximity. The BTUs produced by halogen-style lights can significantly raise room temperature.

Advances to Further Dental Lighting Applications. As noted in earlier sections, LEDs offer the potential to deliver more light more efficiently, improve ergonomic positionability, and more effectively support applications such as lighting during application of composite restorations.

If the heat of the LED junction isn't engineered to dissipate, the life of the LED may be dramatically shortened.

Disadvantages of LEDs in Dental Task Lighting

Thermal Management. While LEDs do not produce radiant heat (or infrared light) outside the visible spectrum, heat *is* produced at the LED junction. If this heat is not dissipated, the life of the LED may be dramatically shortened as overheating causes the diode junction to fail.

Clustering multiple LEDs together (a method some manufacturers have chosen) exacerbates the problem of thermal management which may require active cooling such as a fan and over-temperature sensors, which in turn limit robustness and reliability.

LED-based lights that maintain low junction temperatures by avoiding close clusters of LEDs and active cooling are more inherently robust with respect to thermal management.

Color Rendering Index. While CRI for LED-based lights is benefitting from technological advances, the performance edge still goes to the quartz-halogen bulb/dichroic reflector-style (which can reach CRI values greater than 97). However, some LED lights are now close enough in performance that many clinicians will not be able to discern a practical difference. Nonetheless, the dental professional should assess prospective dental lights first-hand and make a decision based on his or her own preference.

Initial Price. LED-based lights capable of performing on par with (or beyond) their bulb counterparts require a much higher degree of technology and sophistication. The LED components themselves must be mounted to a circuit board and electronically powered by a driver board. Additionally, light performance requirements drive either more sophisticated optics or thermal management.

LED light engine replacement (if required) is much more costly. LEDs have received a great deal of well-deserved praise with respect to their longevity. However, it is worthwhile to note that if there is a failure, such as thermal overheating, the cost and effort to repair the light will be substantially more than a simple bulb replacement.

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