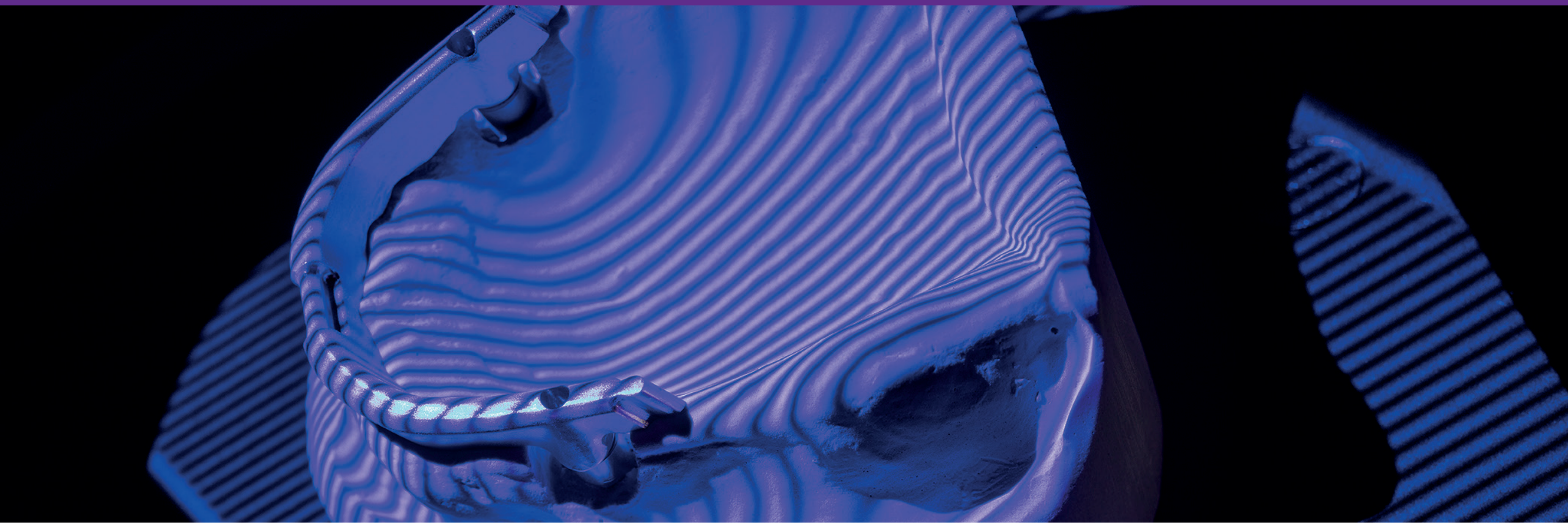

Dental 3D Scanner - A Risk Factor?

Dr. Christoph Prall, Dipl.-Ing. Jörg Friemel

While blue light has long symbolized technical innovation, the focus is increasingly shifting to its harmful effects on the human eye. This is also of significance in everyday dental laboratory work, where 3D scanners with intense blue light sources are increasingly used. Here, the onus is on manufacturers and laboratory owners to ensure health and occupational safety.

Modern artificial light sources, such as light-emitting diodes (LEDs), can generate light in the visible spectral range and thus the blue spectral range very efficiently and with high power [1]. With wavelengths of 400 nm to 490 nm (nanometers) [2], blue LEDs are not far from ultraviolet light (UV light), which starts at a wavelength below 380 nm or 400 nm, depending on the standard considered [3, 4]. It should therefore come as no surprise that blue light is potentially hazardous to the human eye. The harmful effects of UV light on the eyes and skin are well known [5, 6]. However, the photochemical retinal hazard of blue light—photoretinitis—is often overlooked because the human eye perceives blue light as less intense compared to green or yellow light of the same intensity [7]. This deceptive perception of hazard potential is also known as the blue light hazard [2, 4, 8, 9].

Potential hazards of visible and invisible optical radiation

The wavelength of light (i.e., its color) is an essential determining factor for the effect of optical radiation on the eye and whether it may pose a hazard (see Figure 1). For example, the different spectral ranges—from UV to visible to infrared (IR) light—affect the eye differently [4, 6, 8] because light penetrates the eye to different depths depending on the wavelength. For one, UV light is mainly absorbed in the anterior region of the eye (the cornea) or in the eye lens and barely penetrates to the retina [4, 8, 9]. Depending on the radiation intensity, irradiation with UV light can lead to temporary painful inflammation of the cornea (photokeratitis) and, in the long term, irreversible clouding of the lens of the eye (a photochemical cataract) [3, 4]. Such eye damage is also known to result from snow blindness or from looking into a welding arc unprotected. In contrast, IR irradiation of the eye may thermally induce damage (i.e., burns on or in the eye), depending on the intensity of the radiation [4, 8, 9]. The retina can be damaged by the near IR range (NIR), and the cornea can be damaged by the far IR range. Blue light, however, is part of the visible spectrum and thus reaches the retina, where it is absorbed and further processed as blue light information [7]. However, thermal or photochemical damage to the retina may also occur, depending on the wavelength, radiation intensity, and exposure time [2, 3]. High radiation intensities (e.g., from laser light) can lead to thermal retinal damage (i.e., burns) [2, 3, 6]. At lower radiation intensities, the risk of photochemical retinal damage predominates. The hazard potential is highly dependent on the wavelength of the incident light [9]. In particular, light with a wavelength between 380 nm (bordering on UV light) and 550 nm (yellow light) can lead to photochemical retinal damage. However, this effect is most pronounced in blue light and reaches maximum impact at a wavelength of 435 nm to 440 nm [6, 9]. Photochemical retinal damage is therefore referred to as the blue light hazard. Molecules of the retina can absorb the energy of incident blue light, potentially leading to the formation of reaction products (e.g., free radicals) [2, 10]. These reaction products are highly reactive and can damage the retina through chemical reactions. The quantity of reaction products arising from this process is proportional to the product of irradiance and exposure time. **In other words, strong irradiation over a short period of time can have the same effect as weak irradiation over a longer period of time.** The effect of prolonged irradiation is cumulative and can therefore add up [6, 10]. While thermal damage to the retina is usually immediately apparent through blindness of the affected areas, photochemical damage occurs insidiously as the result of a cumulative effect [2, 10]. Retinal damage is usually irreversible and can lead to reduced acuity, impaired color vision, defects of the visual field, and, in extreme cases, blindness.

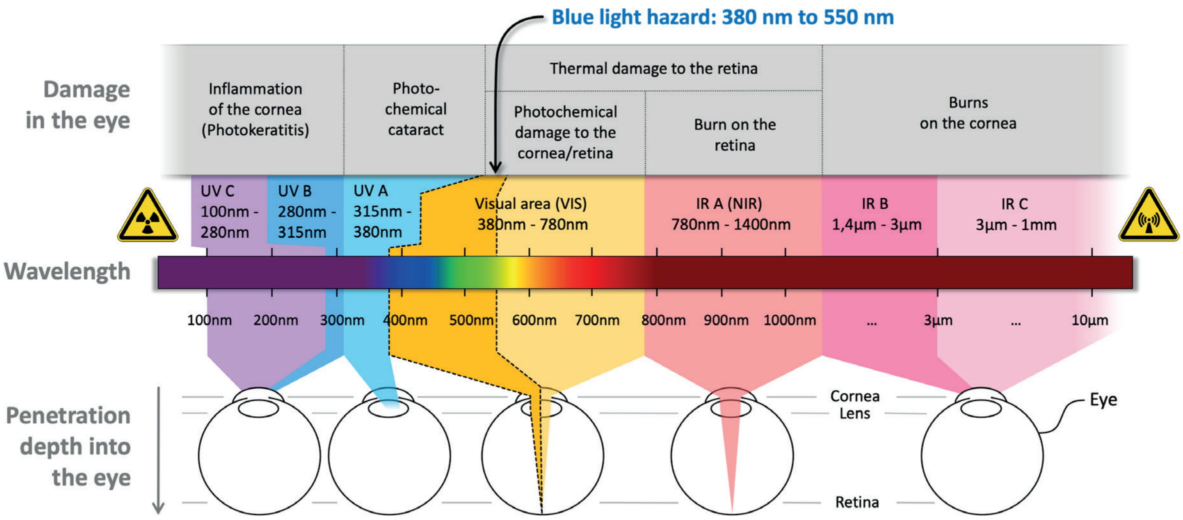

Figure 1: Graphical representation of the eye damage that can be caused by intensive exposure to optical radiation, depending on the color and wavelength of the light
Graphic: C. Prall, smart optics Sensortechnik GmbH, basic data: [4, 9, 15]

The potentially harmful effects of blue light on vision have only shifted into focus in recent years with the advent of LED technology. While the light spectrum of classic incandescent lamps includes a higher red component and a lower blue component, the exact opposite is the case with most modern white LEDs, as these light sources are based on blue LEDs that excite a dye to glow and create the impression of a white color [1, 2, 11]. The LEDs used for room lighting generally remain below critical limits. However, this may not be the case for powerful, narrowly focused light sources, such as blue stage spotlights or blue image projectors. Depending on the eye's adaptation to daylight or night vision and the wavelength of the light, the human eye can only perceive blue light 10–20 times weaker than green or yellow light [7]. Therefore, personal risk assessments can be deceptive, as high-intensity blue light can be perceived as much weaker than green or yellow light of the same intensity. Potential hazards should be considered at the latest in the glare effects on the eye caused by blue light.

Use of blue light in dental 3D scanners

In recent years, pure blue light has been widely used in dental technology to digitize 3D dental objects. The technical reasons for this are the lower chromatic aberration and reduced diffraction effects of the images captured by a 3D sensor [12, 13]. These optical effects, which can lead to blurring, are less pronounced with blue light. Additionally, 3D scanners are increasingly manufactured with an open design to improve operating convenience and ensure that the scanned object can be changed out quickly. During the scanning process, this may increase the blue light exposure experienced by the operator and the surrounding workstations.

Technical framework conditions

To minimize hazards from optical radiation (e.g., blue light), certain guidelines, standards, and legal regulations must be observed. The IEC 62471 standard, in particular, deals with the photobiological safety of (incoherent) light sources and especially the hazards of blue light. Furthermore, LEDs were explicitly included in the latest revision of this standard. The IEC 60825 standard, on the other hand, deals with laser light (coherent radiation).

The most important legal and normative framework conditions relating to optical radiation, using the examples of Europe and Germany

Legal and normative framework conditions
DIRECTIVE 2006/25/EC: Protection of workers from the risks associated with exposure to artificial optical radiation
OStrV: German ordinance on the protection of employees from the hazards of artificial optical radiation
TROS (technical rules in Germany for incoherent optical radiation): Technical rules for the occupational health and safety regulations on artificial optical radiation
TROS (technical rules in Germany for laser radiation): Technical rules for the occupational health and safety ordinance on artificial optical radiation
IEC 62471: Photobiological safety of lamps and lamp systems
IEC/TR 62778: Technical rule for the application of IEC EN 62471
IEC 60825: Safety of laser products

How can laboratory owners assess the potential hazards of artificial optical radiation, particularly blue light?

The following insight of the physician and philosopher Paracelsus can be applied here: "The dose alone decides that something is a poison" [14]. The decisive factors for the hazard potential of a light source include its:

- **Brightness** (intensity),
- **Color** (spectral distribution of artificial optical radiation), and
- **Time** (duration of exposure).

For a laboratory owner, comparing these three factors of the dose principle with what is found in a typical 3D scanner using a blue light source is not easy in practice. However, the maximum possible exposure time per working day can still be evaluated easily based on the duration of 3D scanner use. Evaluating the intensity dependent on the spectral component of the respective light source is not an easy matter. Essential factors beyond this include the radiating surface and the direction of the radiation. If operators or other persons can look directly into the light source of the 3D scanner (e.g., in a dental laboratory), there is a higher risk potential than if the emitted direct radiation is shielded. If no direct radiation can be emitted, the proportion of scattered light intensity must be investigated.

Occupational safety is also important for 3D scanners

The aforementioned assessments are not readily available to the laboratory owner, who is responsible for the occupational health and safety of his/her employees. These assessments require specialized knowledge of physics and photometrics, special measuring equipment, and an understanding of the relevant standards and regulations. Ultimately, the laboratory owner should have the manufacturer of the 3D scanner confirm that operation of the scanner is safe with regard to protections against artificial optical radiation and particularly against blue light. Ideally, the manufacturer will identify the respective risk group for the product at a referenced distance from the light source according to IEC 62471 or (in the case of laser light) identify the respective laser class according to IEC 60825. These classifications indicate the degree of hazard involved, the resulting safety measures, and the maximum duration of exposure. Light sources classified in the free group do not pose any photobiological hazard [2, 9]. Furthermore, light sources assigned to Risk Group 1 do not pose any hazard, given normal human behavior [2, 9]. For Risk Group 2, hazards are minimized only if the eye's defense reaction functions correctly during direct irradiation and the eyelid closure reflex works properly with a maximum of 0.25 s (seconds) [2, 9]. Irradiation longer than 0.25 s may pose a hazard for Risk Group 2. For Risk Group 3, the highest risk group, even short-term irradiation is dangerous. Similar considerations apply to 3D scanners that use laser light. These are considered safe in Laser Class 1, given normal human behavior. For Laser Class 2, hazards are minimized only if the eye's defense reaction functions correctly during direct irradiation and the eyelid closure reflex works properly with a maximum of 0.25 s [15]. If a longer duration of exposure is to be expected in Risk Group 2 or Laser Class 2, one possible protective measure is for the user and all other persons at risk (e.g., in a dental laboratory) to wear special protective goggles.

A well-designed 3D scanner can be expected to operate safely without any need for the user to wear protective goggles, posing no risk to the user. A manufacturer cannot shirk its responsibility by affixing warning labels and transferring responsibility to the operator (see Figures 2 and 3). Rather, a manufacturer is generally obliged to ensure the safety of the products it places on the market. This includes all known or foreseeable hazards that may emanate from a product, including the hazards of blue light.

According to the central basic standard ISO 12100 "Safety of machinery," the very first stage of risk minimization is to implement an "inherently safe design." This means that all hazards must be reduced as far as possible by technical measures. Only residual risks, which cannot be further reduced by technical measures, may then be countered with supplementary measures, such as safety instructions, warning signs, or prescribing personal protective equipment.

Figure 2: Warning sign against optical radiation (left) and arning sign against laser radiation (right)
Graphic: C. Prall, smart optics Sensortechnik GmbH

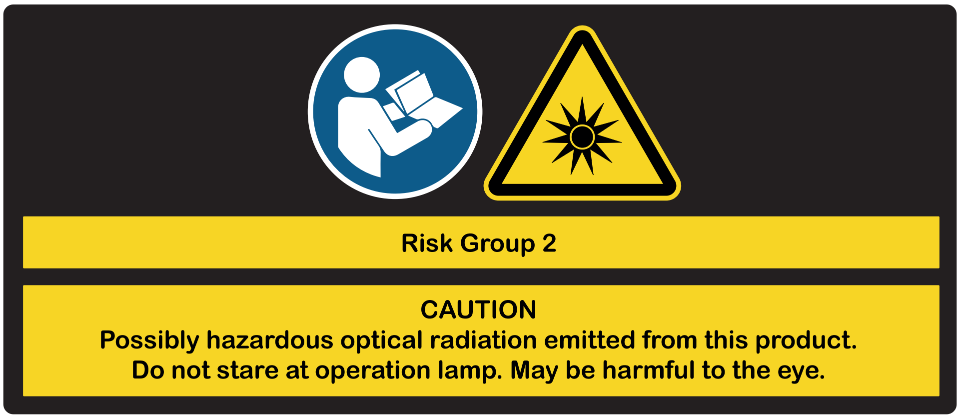

Figure 3: Example of labeling a product with Risk Group 2 optical radiation
Graphic: C. Prall, smart optics Sensortechnik GmbH

What is the situation for artificial optical radiation, laser light, and blue light in dental 3D scanners currently on the market?

Nearly all manufacturers offer 3D scanners with pure blue light. The light sources used in these scanners fall within the described wavelength range of 380 nm (bordering on UV light) to 550 nm (yellow light) and can lead to photochemical retinal damage. At the same time, the design of these devices is becoming increasingly open. Most devices now lack a hood that can be closed during scanning and reliably shield all light effects, including those that are dangerous or disturbing. From a purely metrological perspective, an open design means that more ambient light (e.g., sunlight) can enter. Countermeasures, such as increasingly powerful light projectors, must be taken for metrological capture, which is increasing the hazard potential. The aim is to capture the object at increasing speed, meaning that the 3D sensor has less time to collect the measurement light from the scanner. To detect sufficient light in a shorter amount of time, the use of even more powerful projectors is necessary.

Conclusion

Less shielding and more powerful light projectors: this is the exact opposite of inherent safety with regard to the hazards of artificial optical radiation and particularly blue light. Most manufacturers of dental 3D scanners consider the aforementioned potential hazards when designing their scanners. However, it is still important to engender sensitivity to this matter. If one takes a look at contemporary dental 3D scanners in the context of an open design, in which increasingly intense blue light is emitted horizontally into the room (sometimes even at the eye level of the seated operator), the question arises as to whether the hazard posed by blue light has been considered or whether the manufacturers are evading their responsibility. At the end of the day, the laboratory owner is liable for occupational health and safety as an employer. Therefore, before purchasing a dental 3D scanner, laboratory owners should have the respective manufacturer confirm safe operation with regard to protections against artificial optical radiation, laser radiation, and blue light. If still in doubt, advice should be sought from appropriately qualified persons in the field of occupational safety, light safety, or laser safety. Professional associations or accident insurance companies are other points of contact for support. This article was also published in German in May 2021 [16].

References

[1] R. Dohlus, Lichtquellen. De Gruyter, 2014.
[2] L. Udovičić, F. Mainusch, M. Janßen, D. Nowack and G. Ott, "Photobiologische Sicherheit von Licht emittierenden Dioden (LED)," German Federal Institute for Occupational Safety and Health, Vol. 1, 2013.
[3] C. Schneeweiss, J. Eichler and M. Brose, Leitfaden für Laserschutzbeauftragte. Springer Spektrum, 2017.
[4] "Technische Regeln zur Arbeitsschutzverordnung zu künstlicher optischer Strahlung - TROS Inkohärente Optische Strahlung - Teil: Allgemeines," Gemeinsames Ministerialblatt (GMBI), No. 65–67, p. 1302, 2013.
[5] W.T. Ham, H.A. Mueller and D.H. Sliney, "Retinal sensitivity to damage from short wavelength light," Nature, Vol. 260, No. 5547, p. 153–155, 1976.
[6] E. Sutter, Schutz vor optischer Strahlung – Laserstrahlung inkohärente Strahlung, Sonnenstrahlung. VDE Verlag, Vol. 3, 2008.
[7] A. Freiding, Untersuchungen zur spektralen Empfindlichkeit des menschlichen Auges im mesopischen Bereich. Herbert Utz Verlag, 2010.
[8] "Non-binding guide to good practice for implementing Directive 2006/25/EC 'artificial optical radiation,'" European Commission, Directorate-General for Employment, Social Affairs and Inclusion, 2011.
[9] IEC 62471 "Photobiological safety of lamps and lamp systems."
[10] A. Berke, "Teil 2: Blaues licht – Gut oder schlecht?," DOZ, Vol. 2, p. 54–59, 2014.
[11] C. Prall, "Photoluminescence at high temperatures from epitaxially growing nitride-semiconductor layers for in-situ material characterization," Dissertation, University of Duisburg-Essen, 2018.
[12] J. Eichler and H.J. Eichler, Laser – Bauformen, Strahlführung, Anwendungen. Springer, Vol. 6, 2006.
[13] W. Demtröder, Laserspektroskopie: Grundlagen und Techniken. Springer, Vol. 17, 2007.
[14] W.-E. Peuckert, Theophrastus Paracelsus Werke Band II: Medizinische Schriften. Wissenschaftliche Buchgesellschaft, 1965.
[15] IEC 60825 "Safety of laser products."
[16] C. Prall and J. Friemel, "Risikofaktor dentaler 3-D-scanner?," dental dialogue, Vol. 22, No. 5, p. 54–59, 2021.

Background

Dr. Christoph Prall received a diploma in laser technology in 2009 and a Master of Science in Applied Physics in 2011, both from the University of Applied Sciences, Koblenz, Germany. During his work as a research associate at the Institute for X-Optics (IXO) in Remagen, Germany, from 2009 to 2010 and at the Institute for Measurement Engineering and Sensor Technology at the University of Applied Sciences Ruhr West, Mülheim a.d. Ruhr, Germany, from 2011 to 2017, he gained many years of hands-on experience in an international research environment through his involvement in various projects in the field of photonics and LED technology. In 2018, he earned a doctorate (summa cum laude) from the University of Duisburg-Essen for his work on "Photoluminescence at high temperatures from epitaxially growing nitride-semiconductor layers for in-situ material characterization." Since 2018, he has been working at smart optics Sensortechnik GmbH, Bochum, Germany, initially as a product developer and then as head of the research and innovation department. Since 2021 he was additionally appointed as the head of development. Furthermore, he has many years of practical experience as a multi-certified laser safety officer in the field of laser and light safety for industrial and scientific applications as well as technical applications.

Jörg Friemel is a graduate engineer (Dipl.-Ing.) in the field of electrical engineering. He worked in sales of optical inspection systems for quality assurance from 1991 to 1995. He co-founded smart optics Sensortechnik GmbH in 1997 and has acted as a managing partner ever since.

Contact

Dr. Christoph Prall
smart optics Sensortechnik GmbH
Lise-Meitner-Allee 10
44801 Bochum, Germany
www.smartoptics.de

Jörg Friemel (Dipl.-Ing., graduate engineer)
smart optics Sensortechnik GmbH
Lise-Meitner-Allee 10
44801 Bochum, Germany
www.smartoptics.de