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Laser and Its Hazard Potential

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Abstract

Laser-induced eye injuries have been reported more and more often in the past years, yet the laser is not a modern invention. Based on stimulated emission, the wavelength, energy dose and pulse duration of the laser are the determining factors for its possible hazard potential. The eye, which is the most vulnerable body part for laser radiation, can be affected. As medical treatment is discussed controversial, a great demand has been put on developing laser protection gear. The present review summarizes the physical basics, clinical findings and therapeutic options of laser-induced eye injuries.

Keywords: Laser; Radiation; Eye injuries; Therapy

Introduction

Laser- (Light Amplification by Stimulated Emission of Radiation) induced eye injuries have increased in the last years. Accidental, as well as targeted injuries have been reported not only in private, and occupational settings, but also in the military. The basic concept of absorption and emission of light was reported for the first time in 1917, when Einstein talked about "the quantum theory of radiation" [1]. This was the fundament for the development of modern laser technologies. Several years later the first MASER (Microwave Amplification by the Stimulated Emission of Radiation) was developed by Townes et al. [2]. Collaboration between Dr. Townes and Dr. Schawlow provided first recommendations for the extension of MASER in the range of visible light [3]. It was finally in 1960 that Maiman et al. [4] published the first laser, using ruby. Since then, several investigations have been done to expand its application in research, clinical therapy, and industry and for human entertainment. It is anticipated that the use of laser will be extended in the next years, thus the exact mechanisms of the laser effect on diverse structures (e.g., ocular tissue) are of great interest. Concurrent to the increased interest in laser applications, is also a rise in developing protection against potential laser-induced injuries.

Laser-physical characteristics

Laser technology is based on the principle of simulated emission: an atom is excited by an external energy source to a higher energy level. If a photon with the same energy level as the difference of the excited electron and the lower energy level, contacts this excited electron, the latter one will drop on the lower energy level and emit a further photon. This emitted laser light is monochromatic, coherent and collimated [5]. The dimension of the laser-induced damage is dependent on three different factors: the wavelength, energy dose and pulse duration of laser radiation.

Radiation with short wavelength (ultraviolet) is absorbed in the cornea and could thus potentially damage the surrounding tissue via photochemical processes [6]. Visible light (380 nm to 1400 nm) passes the ocular structures until the retina, whereas only radiation above a special level can cause severe injuries [7]. Radiation of longer wavelength (far-infrared) in comparison is absorbed by water with consecutive thermal damage of the cornea, even until corneal perforation [8,9].

Pulse duration and energy level are interconnected when inducing eye injuries. Radiation with continuous-wave pulse duration emits constant radiation over a defined time period. Modulation of the pulse duration is possible, as "Q-switched" mode (i.e. short pulse duration with high energy levels) and mode-locked mode, which represents a series of short pulses [10]. Both of them can cause severe eye injuries due to their high energy level even at a long distance [11]. It is well known that radiation with high energy levels can induce severe injuries, however, radiation with low energy levels can also generate the same damage pattern when released in short pulses [12].

The pattern of injury is dependent on pulse duration and energy level. Radiation with low energy and long pulse duration (>several seconds) induce photochemical reactions [13], whereas shorter pulse durations (<seconds) will generate thermal damages in the surrounding tissues. If the pulse duration is even shorter (<nanoseconds), mechanical injuries can be caused due to a rapid release of heat [14].

Laser-induced eye injuries

Laser-induced eye injuries occur, regardless of the availability of safety glasses. Often they are caused accidentally, such as during a laser show [15] or by a cosmetic laser [16]. Accidental injuries by laser pointers with consecutive retinal affection were reported even after an exposure time of about 10 seconds [17]. Some reports of laser injuries were self-inflicted [18,19]. Unfortunately, the majority of the cases published in the past months have been tightly focused by strangers [20,21].

The use of laser in industry and research has caused several industrial accidents [22,23]. Additionally, laser-induced injuries were reported in military misadventures [24-26]. In most of the cases the eyes were hurt during exercises or caused by inappropriate handling. Data from the US Army Safety Center, the US Army Center for Health

Promotion and Preventive Medicine, and the Walter Reed Army Institute of Research showed that most of the victims were affected by a Q-switched, Neodymium:YAG (Nd:YAG) laser (1064 nm) [27]. Due to the high repetition of short pulse duration (time periods of nanoseconds) of military lasers, the retinal is often affected multifocally [28].

Laser-induced eye injuries – morphologic findings and therapy

Laser radiation is graded into different groups according to its risk exposure. Laser until class 2 are known to be "safe", due to the sufficient protection by the normal lid closure. In higher classes, the normal ocular protection mechanisms fail and serve eye injuries can be induced (accident prevention regulation BGV B2, [Laserstrahlung], 01.04.1988, version 01.01.1997 with instructions from April 2007 status: January 2010 (print: 2011-01)). The victims of laser injuries typically report decreased visual acuity and visual field defects [19]. Corneal structures can be disrupted, reaching form photokeratitis until perforation [8,29,30]. The extent of intraocular damage however, is dependent on pupil size [31]. Vitreous [32], subretinal [33] or chorioretinal hemorrhages [32], as well as retinal edema or scars can also occur [34], and hypopigmentation [35], pigment clumps [36] and choroidal neovascularization [37] can develop. Even one month after an injury, macular holes may arise [38]. Macular pucker or epiretinal membranes were observed in some patients [39,40]. Beside the testing of visual acuity, measurements of the visual field (e.g., with perimetry, Bagolini test [41,42]) should be performed by clinicians. Additional information can be received by measuring of the Spectralis Domain OCT, as it offers the possibility to visualize the exact retinal damage [19,20]. Spectralis Domain OCT measurements are also recommended in clinical follow-up examinations.

The therapeutic procedure for laser damage has been discussed controversially. Administration of local and systemic anti-inflammatory drugs (e.g., glucocorticoids, indomethacin) [43,44], as well as Nd:YAG hyaloidotomy or victrectomy [45] have been the medical or surgical options, yet recovery of visual acuity has not been consistent. Reports of an increase [46] as well as a missing of visual acuity after vitrectomy [47] can be found in literature. Even laser-induced macular holes do not require an immediate operation as they can close spontaneously [48]. However, there is no evidence-based recommendation for the treatment of laser-induced eye injuries. Several approaches were done using growth factors [49,50] or neuroprotective substances (e.g., MK-801 in animal model [51]; PN-277 in animal model [52]), however some of them are toxic for humans. Research on new medical treatment is ongoing with a focus on the aforementioned target structures.

Conclusion

Although there is a guideline of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for the exposure of laser [5], several accidents were reported accidentally or even tightly focused. It is recommended that laser radiation is totally encased. If this is not possible, a restriction of entrance, laser protection glasses and specific training courses should be offered. It is also recommended that the civil international trading of laser equipment via the internet be restricted for laser (≥ class 3) to prevent any inappropriate use.

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