A CASE STUDY OF A BILATERAL FEMTOSECOND LASER INJURY

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Abstract

An Air Force laboratory student scientist sustained a bilateral laser injury from a 100 femtosecond Ti:Saph laser. The accident victim's immediate report was small spots in his vision. His visual acuity was 20/20 acuity for each eye, but he reported he needed to fixate slightly eccentrically to read 20/20 letters. Damage was apparent centrally in both eyes with OCT. At one month after the injury, he reported that he did not see the blurry spots unless he thought about them. His visual acuity was right eye 20/15 and left eye 20/13. However, when reading the eye chart he reported the blurry spots to be about the same size as the 20/15 letters. The ocular findings of visual acuity, fundus images, and OCT are reported. In addition, the details of the accident from a laser safety officer's perspective will be reported, including laser energy, root cause, contributing factors, and corrective measures. Ultrashort lasers have an especially low damage threshold compared to longer pulsed lasers. The plasma flash induced by a focused femtosecond laser has been reported to cause retinal injury. This case highlights that special vigilance in safety practices is necessary when working with ultrashort pulsed lasers.

Introduction

Laser technology continues to rapidly advance. Small handheld lasers are increasingly powerful and easily available to hobbyists and require diligent adherence to safety principles to avoid eye injury[1]. Ultrashort lasers, lasers with a pulse duration of less than a nanosecond (nsec), are increasingly available and are in widespread use by laser professionals. Titanium:sapphire lasers, or simply Ti:Saph lasers are tunable ultrashort lasers which emit red and near-infrared light in the range from 650 to 1100 nanometers (nm). These lasers are being used in scientific research because of their tunability and their ability to generate ultrashort pulses.

The high peak power of these lasers and the capability of causing optical breakdown and super continuum generation make these lasers more hazardous than longer pulse duration lasers. Special vigilance in safety practices is necessary when working with ultrashort pulsed lasers. This paper reports on the case of a bilateral laser injury from a 100 femtosecond Ti:Saph laser.

Case Report

A 34 year old, Asian/Caucasian male graduate student, working in the Air Force laboratory sustained bilateral laser injuries while aligning an infrared (IR) TiSaph, ultrashort femtosecond laser. His initial symptoms were that he saw intense white flashes of light, and then had "tracers" in his vision, "the sort of thing if you look at a light bulb and then blink your eyes you can still see the bulb for a while." He described what he was seeing as "like looking at the flash of an arc welder for a short amount of time, and having my eyes saturated (intensity wise) at a tiny spot in the center of my vision." That perception persisted for a few days. He did not feel any pain. Prior to working on this laser system he was working on a visible laser and wearing the appropriate laser eye protection (LEP) for that laser system. When he moved to the IR laser, he did not change to the appropriate LEP. He was not protected from the IR laser with the LEP he was wearing. He reported that he has frequent migraine headaches, associated with an aura. He reports that he had a migraine the night before the accident, and that he was starting to get his aura a little before starting to help with the alignment.

His visual acuity was 20/20 acuity for each eye, but he reported he needed to fixate slightly eccentrically to read 20/20 letters. OCT (SPECTRALIS® Tracking Laser Tomography) revealed thin columns of damage, approximately 40 µm in width, through the retinas at each fovea (Figure 1).

Fundus examination and color fundus photography revealed small yellowish spots at the foveas of both eyes (Figure **2**).

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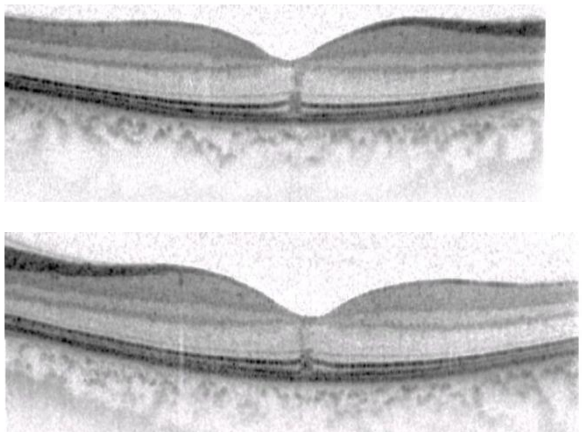
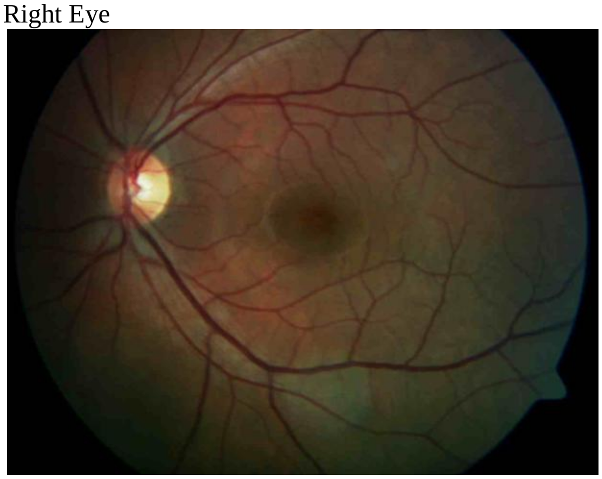


Figure 1. OCT images of the right eye (top) and left eye (bottom). Both eyes show damage through the retina at the foveas.

Right Eye



Left Eye

Figure 2. Fundus photographs of the right eye (above) and left eye (below) revealed small yellowish spots at the foveas that are barely visible in these photographs.

He was examined the day after the incident, 3 days after the incident, and 15 days after the incident. At 1 days after the incident his acuity with his glasses was right eye 20/20 and left eye 20/20. His visual acuity and his awareness of the small defects in his vision showed slight improvement with time after the accident. At 15 days with his spectacle correction his acuity was right eye 20/15 and left eye 20/13.

At one month after the injury, he said that his vision seemed to be improving. He did not even notice the blurry spot unless he thought about it. He said there was still some blurriness around the edges of letters but that blurriness was described as outside of his very central vision and that it did not affect his ability to read at a distance. When reading the visual acuity chart, he reported that he could read the 20/15 and 20/13 letters but they were blurry. He could notice the blurry region in the center of 20/20 and larger letters.

The retinal specialist commented at his exam 15 days after the injury that if he did not know there was an injury, he would have overlooked the spots on the foveas. The impression on the first two exams was that the lesions appeared to be solar injuries.

He has another exam scheduled for a 6 months follow-up. At 4 months, he felt his vision was still improving. At had noticed some diminished night vision at 1 month post injury that he no longer noticed. The blur spots in his vision were very small, near his visual resolution limit. He described the blurry spots as about the size of the width of ink on the letters on the lower left corner on a $20 dollar bill, "Treasurer of the United States," at a distance of 16 inches. The height of those lowercase letters subtends about 5 min of arc, equivalent to 20/20 acuity.

Laser Energy

The MPE for pulse durations are unchanged from 1 nsec to 18 microseconds (μsec), but decrease below 1 nsec [2, 3]. The biological exposure experiments with ultrashort lasers show that very low less pulse energies cause retinal damage [4, 5] compared to longer pulsed exposure. Ultrashort lasers can produce optical breakdown and plasma formation that causes super continuum generation over a wide range of wavelengths. Longer pulse widths do not generally result in optical breakdown.

The laser wavelength in this case was 800 nm and the pulse width was 100 femtoseconds. The Maximum Permissible Exposure (MPE) for that short pulsed laser

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is a very low 24 $nJ \cdot cm^{-2}$ at the cornea or 9.15e-09 J total intraocular energy. The output of the laser was 40 mJ.. Assuming the beam was circular, Gaussian, 0.5 cm in diameter, with a 0.5 mrad divergence, the Nominal Ocular Hazard Distance (NOHD) was a very long 29,293 meters, assuming no atmosphere. The diffuse reflection hazard zone distance for this laser was 7.0 meters, assuming the laser was 1 meter from the reflecting surface, the surface was 90% reflective, and the viewing angle was 0 degrees. For the diffuse reflection, an optical density (OD) of 1.2 was needed assuming the observer was 1 meter from the reflecting surface. Those numbers show that the reflected beam has enough energy to cause ocular damage and that, if viewing the reflection, both eyes would be damaged because of the divergence of the energy from a diffusely reflecting source. Obviously wearing the wrong LEP contributed to this accident. Looking over the LEP to see the reflection on IR paper could also be a source of injury with these ultrashort lasers.

Discussion

There have been a number of other ultrashort laser injury cases that have been reported over the last several years [6-10]. The presentations of these cases are all similar. The damage is typically bilateral, caused by reflections, and LEP is either not worn or the wrong LEP is worn. The damage to central vision is visible with OCT and causes a very small scotoma. There is only a small reduction in visual acuity (20/20 – 20/40). Remarkably, a yellow or whitish spot similar to the appearance of solar retinopathy, which occurs when a person intentionally stares at the sun, has been described in most of these cases on initial presentation.

Similar to solar retinopathy, ultrashort laser injuries are commonly bilateral, and the damage location is near the foveal center. The mechanism of injury is different with solar retinopathy however. The area and extent of the injury in solar retinopathy is small, on the order of 100 µm, but these laser injuries are smaller, roughly 25 µm or less. In the case of an ultrashort laser injury, for the injury to occur bilaterally at the foveas, the person has to be looking at the laser and the laser injury energy is reflected or the person is observing optical breakdown which results is a laser energy from a small source being spread toward the person from a spot that the person is fixating. Thus the injury is to both foveas. The person does not need to have a prolonged exposure, one pulse, occurring in 100 femtoseconds or in picoseconds is enough to cause damage.

Laser Injury Evaluation and Treatment

A Patient's history of the length and type of laser exposure is important. A significant direct eye exposure to a laser, persistent after images, and decreased visual acuity should initiate urgent referral to an eye care specialist for further ophthalmologic testing. Brief laser exposure or indirect exposures with complaints of headaches or blurry vision often are not the result of ocular injury and require other diagnostic explanations [11]. The laser parameters, energy and pulse width, and distances involved, should be part of the history to determine if a laser injury makes sense. Ideally, a Laser Safety Officer should conduct an investigation whenever a suspected overexposure occurs to determine event characteristics, root cause, contributing factors, and corrective measures.

Early evaluation and treatment are of course appropriate to establish the initial conditions of the injury. OCT has proven to be very helpful in imaging the extent of laser injury. Spectral Fourier OCT has higher resolution and is less affected by eye movements and is a more preferred technology to evaluate laser lesions at the fovea[7]. Fundus imaging should also be done.

Standard treatment for laser injuries has not been established. The appropriate treatment depends on the type of injury and extent of the injury. Steroids have often been used, but the benefit of steroids has not been definitively established. Clinical and animal studies for treatment are equivocal. A number of laser pointer injuries have been treated with intravitreal injections of anti-VEGF drugs. Anti-VEGF medicines can slow the vision loss associated with age-related macular degeneration (AMD)[12]. Use of the anti-VEGF drug, Ranibizumab, has been associated with good visual outcomes in some cases of laser injury and may have helped recovery[13]. NSAIDS have also been advocated and have had proved beneficial in some animal studies for some types of lesions [14].

Contributing Factors to the Accident

There were a number of contributing factors to this accident. The use of the wrong LEP was partially the cause of this injury. More redundant checks to assure the right LEP is in use when using this and any laser should be implemented. In this particular lab, a better choice LEP would have been one with enough OD for the 532 green laser as well as the IR laser. Then there would not have been a need to change LEP when moving from one laser to another.

The migraine aura may have distracted this worker from thinking about his LEP. Procedural controls can fail because of distraction. Engineering structural hardware to prevent access of the laser beam and its reflections would be the best solution to prevent injury. Video could be used to align the beam and prevent ocular exposure from the actual laser beam. Protective barriers and curtains should be used. Extra training and precautions, because of the dangerous nature of ultrashort laser pulses, is warranted.

Laser Safety

Per ANSI Z136.1[2], employers have a fundamental responsibility for the assurance of the safe use of lasers owned and/or operated in facilities under their control. For Class 3B and Class 4 lasers and laser systems the employer "shall" provide safety programs and employee training programs. A trained Laser Safety Officer (LSO) with the authority to implement appropriate laser control measures is designated. Obviously, the proper LEP should be available, and there should be procedures to assure that the appropriate LEP is worn.

Following this accident the Chief of Safety had a mandatory safety down day. All laser workers who used IR laser cards received instruction on the use of lasers and safety precautions. One obvious instruction was to use the right LEP.

Laser Eye Protection for ultrashort lasers may in some cases may not provide the OD that is specified by a manufacturer and requires special care in selection. [15, 16] There are 3 special considerations with ultrashort lasers and the selection of laser eye protection; (1) the high pulse density may cause saturation of the absorption and a reduction of the optical density, (2) femtosecond laser pulses have a large bandwidth and a broadband filter may be required, and (3) the fluence that produces damage of the laser protection materials drops with decreasing laser pulse duration [17]. Unfortunately, laser eye protection is not generally provided by manufactureres for ultrashort lasers and measuring their OD requires special techniques.

Following the accident, the laboratory was shut down to be moved to a new location. New procedures and precautions, as well as procedural controls to make sure that the proper eye protection is being worn should be implemented.

Members of the 711th Human Performance Wing Optical Radiation Bioeffects Branch, USAFSAM Ophthalmology Consult Service Branch, along with Army and Navy partners maintain the Tri-Service Laser Safety Hotline for reporting of laser injuries and incidents. This hotline is maintained in order to provide the most appropriate evaluation and treatment for DoD personnel who receive laser injuries. Consultation was provided in this case. The Tri-Service hotline contact information should be made conspicuously and easily available in all DoD laboratories. Lessons are learned from these laser accidents and the lessons should be disseminated to laser workers.

Summary and Conclusions

Laser safety principles are generally observed and laser eye injuries are still uncommon. However, ultrashort lasers, with their low thresholds for retinal damage are a newly developing concern for injury. Ocular damage can occur from these lasers from reflections and cause bilateral injury. Laser Safety Officers should be monitoring ultrashort lasers and assure that lasers are operated safely. People working with ultrashort lasers should receive additional laser safety training and extra control practices should be implemented. This case highlights that special vigilance in safety practices is necessary when working with ultrashort pulsed lasers.

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Meet the Author

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