Laser Eye Injuries in Military Occupations

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Introduction: Lasers (light amplification by stimulated emission of radiation) play an important role in our world and their use is increasing. They are powerful tools for good, but can also cause tragedy, especially in an aviation environment. Information about injuries associated with lasers is limited. This study highlights several laser eye injuries in the U.S. military and discusses issues pertaining to them. ***Methods:*** We gathered data from the U.S. Army Safety Center, the U.S. Army Center for Health Promotion and Preventive Medicine, and the Walter Reed Army Institute of Research. This paper describes ten representative cases of laser eye injury that occurred in the U.S. military between 1984 and 2000. ***Results:*** Patients suffered retinal damage, though no corneal injury occurred. Most were caused by accidental exposure to a Q-switched, Neodymium:YAG (Nd:YAG) laser at 1064 nm wavelength. The incidents occurred both on and off duty, indoors and outdoors, and from close and long ranges. None of the victims were wearing eye protection. Inadequate training and poor equipment design were major factors in at least six of the nine unintentional cases. The tenth occurred during military operations in the Persian Gulf. All of the victims needed several months medical care and follow up. Two received medical discharges as a result of their injuries. ***Discussion***: As illustrated by these cases, human and societal costs from unintentional laser eye injuries can be reduced by improving operator training, safety procedure compliance, and equipment design. In addition, intentional laser eye injuries are a growing concern and further research is needed to design appropriate protection, treatment and countermeasures.

Keywords: laser, eye, injury, mechanisms, military.

A REVIEW of military and civilian data sources in 1997 estimated that 220 confirmed laser (light amplification by stimulated emission of radiation) eye injuries have occurred between 1964 and 1996 (7). In this case series we reviewed military cases for which detailed information on the circumstances of the injury event were available. Our objective was to illustrate common features of laser eye injuries, discover frequently made mistakes committed by operators of laser devices, and highlight how flight surgeons, other health care providers, and other leaders can minimize these dangers in the future. Ten cases with unique circumstances are described.

More than ever before, lasers play a critical role in our world. Lasers scan data, assist in surgery, cut materials, measure distances, aid in research, and do a host of other important tasks. The first laser was produced in 1960 (2). Laser use rapidly spread throughout military, educational, and commercial laboratories, and beyond. For military purposes, lasers determine ranges, acquire targets, guide "smart weapons," destroy electro-optical sensors, aid training, and serve in many other areas (6).

Lasers are critical to military mission success, but incidents using lasers can instantaneously cause severe and potentially permanent eye damage. Unintentional laser eye injuries first occurred in the 1960s. In the late 1970s, Chinese physicians in the Sino-Vietnamese war first described wartime eye injuries from laser exposure (8). During the Gulf War, a U.S. soldier received a retinal burn from an Iraqi laser (2) and many Iranian soldiers developed eye injuries suspicious of laser exposure during the Iran-Iraq war (8). Soviet lasers were reportedly used against the Mujahadeen fighters in Afghanistan (8), and British warships allegedly employed laser systems to dazzle Argentine aircraft pilots during the Falklands War of 1982 (2). Additionally, there were reports of U.S. pilots flying missions over Bosnia being temporarily dazed by laser designators possibly used by the Yugoslavs (9). Enemy armies, terrorist groups, or criminals could use readily available lasers to blind a person or group and terrorize a population. As a result, several international groups have proposed banning laser weapons. The Geneva Convention in 1995 specifically regulates laser use to decrease the chance of deliberate injury.

As flight surgeons, the laser threat to pilots is our greatest concern. While a laser injury to an infantryman may impair his ability to fight, the same injury to a pilot could cause a crash, destroying the aircraft and killing its occupants. By highlighting these cases, we hope to make flight surgeons, pilots, administrators, and other leaders aware of these issues, and mobilize us all to find solutions.

Laser light is so dangerous because it is so concentrated. Light emitted from the laser is monochromatic, unidirectional, and coherent. This is why visible laser light is so bright despite using so little power, why it is only one color, and why it stays

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tightly collimated even from a great distance. Light in the near infrared and visible wavelengths is further concentrated by the eye and focused on the retina. Assuming clear environmental conditions, light emitted from a laser has nearly as much energy when it leaves the device as when it hits the cornea, but the cornea and the lens focus the light so much that the ratio of corneal irradiance to retinal irradiance is over 10,000 times (2). Binoculars and other magnifying optics may increase the exposure dose (2). The effect of the exposure depends on how much energy is transmitted to the retina, as well as the anatomical location and duration of exposure. For example, exposure in the fovea centralis of the retina (fine vision center) has the potential to cause a much more severe disability than a peripheral exposure.

Damage also depends on the type of laser. For example, a pulsed laser will cause more damage than a continuous laser of equal power. The U.S. military uses lasers of all classes from laser pointers (class 2 or 3A) to training devices, rangefinders, and target designators (class 4) (**Table I**)(11).

Almost any laser system, if it is powerful enough, can cause injury, regardless of the system's primary purpose. Rangefinder and target designation lasers can produce retinal lesions hundreds of meters from the source, and even farther if the victim is using magnifying optics. Even exposures that only briefly impair vision can cause tremendous damage; a pilot who has laser-induced flash blindness for only 20–30 s is likely to eject or crash (6).

Laser light causes eye injury by several mechanisms including thermal (pulse duration of microseconds to seconds), mechanical (picoseconds or nanoseconds), or photochemical (a few seconds). Thermal damage occurs when a chromophore, a wavelength specific light absorbing pigment, absorbs energy faster than the resultant heat can be dissipated. A temperature increase of 10°C can cause protein denaturation and coagulation, cell death, and scarring (2). Mechanical damage occurs when energy is deposited rapidly and heat builds up much faster, causing tissue disintegration. Combined with water vaporization, this process generates a "compressive pressure pulse (explosion), which travels from the site and disrupts the surrounding tissue" (2). Photochemical damage occurs when single photons directly break bonds in nucleic acids or structural proteins, even though energy is deposited too slowly to build up excessive heat. The body responds to excessive light energy on the retina by increasing choroidal blood flow to accelerate heat dissipation, and by cellular repair mechanisms to correct DNA, RNA, and protein damage, but these mechanisms can be overwhelmed if the energy or injury is too great.

Risk of injury also differs with human physical characteristics. People with ametropia (non-corrected vision) will focus the laser beam in front of or behind the retina, thereby decreasing energy deposited per unit area in the retina (2). Pupillary dilation in darkness allows more light to enter the eye, thus causing a more severe injury. Accommodation (close focusing) also focuses the laser beam anterior to the retina and therefore decreases the potential injury.

Clinical findings after a laser eye injury largely depend on the location of the injury, the energy and pulse duration of the laser, and the duration of exposure (especially for long pulse duration lasers in the visible spectrum). A foveal lesion will likely cause an immediate and significant loss of visual acuity. A parafoveal lesion may involve the fovea temporarily through inflammation and edema, resolving over days to weeks, or may spread to the fovea through secondary neuronal cell damage, causing permanent defects (2). Retinal burns further from the fovea may cause local scotoma (blind spots) or may be totally unnoticed by the patient. Higher energy lasers may cause nerve fiber layer damage, infraretinal vitreal hemorrhages, or subretinal hemorrhages. Laser exposures that are less severe may cause momentary distraction, flashblindness, or other mild symptoms, but these are unlikely to be reported or to be recognized as a laser eye injury if they are reported.

Because laser eye injuries often go unreported, no one knows exactly how many laser eye injury cases there have been. Since many laser beams are invisible, some patients may not realize they have been exposed. Conversely, many people have developed eye irritation or other symptoms due to other agents (sunlight, dust, etc) and blamed their symptoms on lasers. These factors make accurate diagnosis of laser eye injury and estimate of their incidence difficult.

TABLE I. LASER DEVICE CATEGORIES AND EFFECTS (11).

Class (Power)	Energy (W - watts, J - joules)	Effects
4 (High)	Continuous (CW): > 0.5 W Pulsed: > 0.125 J within 0.25 seconds	Direct and reflection viewing hazard. Diffuse reflection may be hazardous. May pose a fire hazard and may generate plasma radiation.
3 (3a & 3b) (Medium)	CW: < 0.5 W for 0.25 sec Pulsed: < 0.125 J within 0.25 sec.	Direct and reflection viewing hazard. Diffuse reflection is usually not hazardous.
2 (Low) Visible only	Depends on wavelength. For CW visible lasers, cannot exceed 1 mW.	Hazard comparable to looking at a projector or the sun; the eyes aversion response (0.25 sec) would normally prevent a person from staring into the light.
1 Non-hazardous	Depends on wavelength. A CW HeNe (632 nm) is below 0.0068 mW	Incapable of producing damaging radiation.

METHODS

The study population was active duty U.S. military members (Army and Marine) and Department of Defense civilians from 1980 through 2000. Investigators obtained the case information from existing databases in the U.S. military. Investigators initially searched U.S. Army Safety Center reports for the years 1980 through 1999 from the Total Army Injury and Health Outcomes Database at the U.S. Army Institute for Environmental Medicine in Natick, MA. Free text fields were searched to identify eye injury cases including the keywords "laser," "eye," and "injury." Investigators then cross-referenced details from these cases with data from the Laser Accident Incident Registry at Brooks City-Base in San Antonio, TX. More detailed information was obtained from accident investigation reports for three of the cases from the Laser/Optical Radiation Program at the U.S. Army Center for Health Promotion and Preventive Medicine at Aberdeen Proving Ground in Maryland. Lastly, we received information on the most recent cases through the year 2000 from the Walter Reed Army Institute of Research laser detachment at Brooks City-Base, TX. We selected these ten cases because they represent a wide variety of scenarios and have analyzed them with descriptive statistics.

RESULTS

These cases illustrate a wide range of mechanisms and outcomes of laser eye injuries, but there are many common themes. In 6 of the 10 cases, the victim noted a "flash" when the injury occurred, but in the remaining 4 cases, there was nothing. In 8 of the cases, scotoma was involved, usually as the presenting complaint. Though in some cases the history is unclear, the patients presented immediately for care in only half of the 10 cases. In the others, patients waited up to 3 wk for care. In 4 of the cases, worker mistake or "horsing around" contributed to the injury. Inadequate training and/or poor equipment design was a major factor in at least 6 of the 10 cases.

Case 1

After an airborne unit test jump using an AN/PAQ-1 laser target designator (LTD), the LTD was not returned to its secure storage area but rather was stored in a barracks room. Later that evening, another soldier in that room took the LTD off "safe," pointed it toward the door and pulled the trigger. Just then a 21-yr-old soldier who was walking in the hall outside noted that the door was partially open and looked into the room. The LTD beam (10 Hz Q-switched Nd:YAG at 1064 nm) hit him in the right eye at a distance of 8 ft. He immediately noticed a bright, strobe-like, pulsating white flash. He turned away from the light and noticed a red globular haze and a dark spot slightly below and to the right of fixation in his right eye (10). He tried to "wash the blood out" of his eye and then presented for care. Initial visual acuity (VA) was 20/400 in the right eye (oculo dexter; OD) and 20/20 in the left eye (oculo sinister; OS). There was a vitreous hemorrhage and three focal lesions in OD. Each lesion had an associated subretinal hemorrhage and the parafoveal lesion had a preretinal hemorrhage (10).

The patient was hospitalized and bolused with 10 mg of dexamethsone, followed by 4 mg every 6 h for 48 h. The vitreous hemorrhage cleared and the right eye vision improved to 20/30 by the second day after injury. Visual acuity peaked at 20/25 at 1 mo after injury but had deteriorated to 20/40 by 4 mo due to scarring and increasing macular pucker (10). This visual acuity persisted through the patient's last evaluation at 1 yr following injury.

Case 2

A civilian laser researcher for the U.S. Army in Aberdeen, MD, was adjusting a Nd:YAG pumped dye laser (wavelength 620 nm, pulse-repetition frequency 10 Hz) during a laser fluorescence experiment. He was not wearing eye protection because he needed to see the beam to adjust it. He saw a single orange flash, noticed a central reddish scotoma (blind spot) and presented for care (4). Initial exam showed a VA of 20/(not measurable) in the right eye and 20/20 in the left eye. Fundoscopic exam demonstrated a macular hemorrhage in OD and a normal OS (4). Ten percent of his visual field was obscured. The patient was treated with 60 mg of prednisone for 9 d and tapered. The hemorrhage gradually resolved and the VA improved to 20/60 at 7 wk and 20/30 at 11 wk. By 6 mo after the injury, his VA was 20/20. His VA was still 20/20 and he had no scotomas at 48 mo (5).

Though the prognosis in this case was very poor due to the extent of the injuries, the visual outcome in this patient was good. Ophthalmologists reviewing the case felt that this may have been related to two factors: 1) "the patient was accommodated (his eyes were focused for near vision), causing the laser energy to be focused anterior to the retina, resulting in decreased laser intensity at the retinal surface"; and 2) "the preretinal hemorrhage did not disperse into the vitreous, perhaps because of the limitation of the hemorrhage by the internal limiting membrane, or by the dense cortical pre-macular vitreous frequently found in young individuals" (5).

The outcome was also improved by a favorable lesion location. According to the incident investigation, many types of laser eye protection goggles would have prevented this injury (Franks J. Accident Investigation Report; 1987). Alternatively, laser workers can use a filter to attenuate the beam during alignment, thus preventing injury.

Case 3

A 19-yr-old soldier observing artillery projectiles unintentionally exposed his right eye to at least four pulses from the AN/GVS5 laser rangefinder. The soldier felt that the device was malfunctioning. He tried to check it by holding the Q-switched Nd:YAG device at arms length and looking into the beam aperture, not knowing that it was the exit aperture. He then depressed the switch and inadvertently shot himself. Since the beam is invisible, he did not realize what he had done. Shortly after the injury he noted significantly reduced monocular vision in the right eye. The following day he presented for care and the exam noted three retinal burns. Initial VA was 20/200 OD and 20/20 OS. There was a vitreous hemorrhage, deep retinal edema, and a significant central scotoma.

By 2 wk after the injury, both deep burns were scarred and the holes sealed. By one month, scar covered the central portion of the posterior pole of the eye, and contraction of the scar created retinal holes and traction lines (10). OD VA at this time was 20/200 viewing eccentrically (off center), and not measurable viewing centrally (10). The scarring progressed and by 18 mo after the incident, OD VA was "count finger" centrally and 20/400 with head turning. The central scotoma improved but did not resolve.

This case was especially tragic in that multiple burns produced an exceptionally bad outcome. The incident investigation discovered that the AN/GVS-5 was working correctly (Dudevoir S, Sliney D. Accident Investigation Report; 1990). However, this soldier was not properly trained to use it. The warning label was located on the bottom of this device, facing toward the ground and therefore impossible to see during normal use. There was no warning label at the laser exit aperture to alert the user of where the beam exited.

Case 4

While viewing a position about 3000 m away with his left eye through a 7x monocular scope during the Gulf War, a 24-yr-old soldier saw a bright "orange-red" flash come from the position. A ruby laser operating at 6943 nm was the suspected source. He presented for medical care and his VA was 10/400 OS and 20/15 OD. There was a subretinal hemorrhage within the center of macula involving the fovea, and the vitreous overlying the hemorrhage appeared to be detached (10). Three weeks after the incident, the edema decreased and examiners noted two areas of retinal pigment epithelial disruption (10). The patient had a central scotoma that persisted through 6 mo. The soldier was medically discharged (Franks J. U.S. Army laser accidents and incidents [Lecture notes]. Aberdeen Proving Grounds, MD: USACHPPM Laser/Optical Radiation Program; May 2000. Stuck B, et al. Laser accident and incident registry database [CD-ROM]. Brooks City-Base: Walter Reed Army Institute of Research, United States Army Medical Research Detachment; 2000).

This case occurred in an operational environment. Appropriate laser eye protection that could have prevented this injury is being developed.

Case 5

A 21-yr-old soldier was helping another soldier connect a power cable to an AN/GVS-5 laser rangefinder. He was holding the device wedged between his thigh and the door of a vehicle with the power switch "off" and the beam aperture facing him about 2 ft away. The soldier removed the beam portal lens cap and immediately saw a "bright flash." He noted eye irritation, blurry vision, and "splotches" in his view after the incident, but initially made no report (10). He was not wearing sunglasses or other protection. A battalion surgeon examined the patient 24 h after the incident and noted a VA of 20/50 OD and 20/200 OS. He was seen by ophthalmology and diagnosed with bilateral macular holes, bilateral vitreous hemorrhages, and a Snellen VA of 20/25 oculo uterque (OU; each eye) (10). His vision gradually worsened to 20/200 OD as epiretinal traction enlarged the macular hole. This hole encroached on the fovea and had to be surgically stabilized at 18 mo (10). Following the injury, the soldier received a medical discharge due to his eye injury. Four years after the incident, VA OS had stabilized at 20/15. Poor equipment design also contributed to this injury.

Case 6

A 21-yr-old soldier was performing a verification test on the G/VLLD AN-TVQ-2 laser target designator. Rather than looking into the eyepiece, she looked into the output port. The soldier pulled the trigger and saw an "orange-white flash." She received a bilateral intrabeam exposure that lasted approximately 2–3 s. She knew that she had been exposed and reported it immediately to her supervisor, who took her to optometry for evaluation. Visual acuity shortly after the incident was 20/50 OD and 6 h after the exposure, the patient was treated with solumedrol. VA decreased to 20/200 OD by day two, but improved to 20/20 by 55 d post exposure (13).

The incident investigation showed that this device was functioning normally and no extraneous beams were present (Sliney D. Accident Investigation Report; 1997). Somehow the safety shield had been pushed aside, and goggles were not required for this step in the verification process. The warning label was hard to read since the print was small and was black letters on a green background. A laser aperture warning label also may have helped, as would a greater differentiation between the design of the eyepiece and output port. The soldier did notify her supervisor immediately and appropriately. In this case, medical personnel were aware of the nature, injuries, and treatment of laser hazards (Sliney D. Accident Investigation Report; 1997).

Cases 7–10

The seventh case involved a 29-yr-old soldier who was accidentally exposed to a single pulse from a laser rangefinder at close range. He had one focal lesion which resulted in a VA of 20/50 at 5 wk post injury and 20/25 at 15 wk post injury (10). Case 8 was a 25-yr-old soldier who developed an edematous fovea and central serous retinopathy (CSR) during a training exercise. He had a pre-incident VA of 20/20, immediate post-incident VA of 10/400 and a final VA at 2 wk post injury of 20/20. However, he had regions of non-vision in the central 30° of the left visual field. The cause was never confirmed but was most likely a laser injury (10).

Case 9 involved a 44-yr-old soldier who accidentally placed himself in front of a friendly tank position 500 m away. He developed punctate macular lesions and CSR but had a VA of 20/20 only 2 wk after the incident (10).

The last patient was a 19-yr-old trainee who was "flashed" by others training on a PAQ-4 laser illuminator. He had a hypopigmented spot in the fovea, a pre-incident VA of 20/15, and a post incident VA of 20/200. The source is unknown as the PAQ-4 is a class 1 laser device and does not emit enough energy to cause a lesion in a brief exposure. The subsequent investigation was inconclusive.

DISCUSSION

Altogether, 70% of these cases were attributable to inappropriate use. Only one case was combat related, and that was the only one in which magnifying optics were used. In 2 of the 10 cases the patient received corticosteroids and in both cases the patient improved. Only one patient out of four whose initial VA was worse than 20/20 and did not receive steroids improved.

According to Army Regulation 40–501, a permanent vision worse than 20/20 (better eye) and 20/800 (worse eye) is adequate to justify medical retirement. This entitles the soldier to a permanent monthly pension, lifetime use of medical and other military services, and other retired military benefits.

The piece of equipment responsible for most of these injuries, the AN/GVS-5, has been replaced by the AN/GVS-6 and AN/GVS-8, which use a longer wavelength that is not in the retinal hazard region and has further differentiated the designs of the eyepiece and output port. However, the AN/GVS-5 is still used in some areas. Notably, the AN/GVS-5 is a Nd:YAG laser, the same type which caused over 25% of eye incidents in the review cited above (8).

There are many other things that can be done to protect against unintentional laser eye injuries. Devices should be engineered so that operators cannot inadvertently discharge them and also that they will not fire if the safety shield is pulled back. Goggles, face shields, and other gear and protocols minimize the risk of unintentional injury. The wavelength in the eye protection must match the wavelength of the laser being used (12).

Guarding against intentional injury is much tougher. Goggles and helmet visors for aviators have been used since the 1970s (3). However, protective lenses typically guard against only one or a few wavelengths. This is not adequate against tunable laser devices that operate over many wavelengths, but eye protection against all of these wavelengths would make it nearly impossible to see and fight (1). The U.S. Army has Ballistic/Laser Protective Spectacles (B-LPS) that protect against 1064 and 694.3 nm wavelength lasers, the most common used by the Army (4). Smoke on the battlefield can disperse and reflect the laser beam. Indirect viewing (such as with video cameras) can protect the eyes but are just as vulnerable as other electronic sensors, which means that they can be quickly damaged by laser light.

Pilots have significant risks of temporary glare or flash blindness and need to be protected. There are many other issues to be considered. If we have multiple laser eye injury casualties, whether in a civilian or military setting, will we have enough ophthalmologists to treat them? What is the most effective means of treatment? Surgery? Steroids? Something else? How can we train our medical officers and other primary care providers to screen for these injuries? What doctrinal changes do we have to make if anti-personnel laser use becomes a reality on the battlefield? All flight surgeons get laser training at Ft. Rucker and Brooks City-Base. Field Manual 8–50 exists and is taught to combat medics. What are the eye effects of chronic low-level laser energy exposure? How can we best involve leaders to make these protective measures happen?

This study has the significant limitation of being a descriptive case series and therefore uncontrolled. It is extremely difficult to get denominator data (how many people are at risk) for laser eye injuries since theoretically everyone in uniform (and many civilians) is at some (albeit minimal) risk. Many laser exposures and even injuries go unnoticed and unreported, especially if they are minor and are far from the fovea. Laser eye injuries (and probably even exposure) are rare enough that a cohort study would be impractical, and a case-control study would be difficult given the challenges regarding exposure assessment noted above. Unfortunately, it may take a major incident with multiple casualties to allow us to answer some of these questions.

Overall, laser eye injuries, though small in number, are a threat to the safety of U.S. military personnel. When they occur, they often cause devastating disability to the victim and significant costs to the military in terms of medical care and lost work time. Unintentional injuries can be reduced by continued improvement of training for laser operators, by improving labeling around laser output apertures, and by better engineering laser devices. Intentional injuries are likely to become a greater problem in the future, and the psychological effect of the threat of laser-induced blindness is potentially enormous.

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