Chapter 25

OCULAR LASER INJURIES

RODNEY D. HOLLIFIELD, MD*

**Vitreoretinal Surgeon, Retina Consultants of Nevada, Las Vegas, Nevada 89144; formerly, Lieutenant Colonel, Medical Corps, US Army; Chief, Vitreoretinal Service, Walter Reed Army Medical Center, Washington, DC*

INTRODUCTION

Laser use continues to proliferate on the modern battlefield. They are used routinely for target designators, rangefinders, and radar warning.[1] More ominously, the use of lasers as antipersonnel devices by enemy forces is a real and increasing threat. Given these facts, it is likely that healthcare providers will encounter individuals with possible ocular laser injuries. The ability of medical personnel to identify and properly manage suspected laser casualties is crucial to sustaining the fighting force.

In a combat situation, laser emissions by both hostile and friendly forces can lead to potential ocular injury. An unclassified list of known US Army lasers is provided in Table 25-1.[2]

With advances in solid-state electronics, frequency-doubled neodymium:yttrium-aluminum-garnet (Nd:YAG) lasers operating at a wavelength of 532 nm are commonplace and should also be expected in a battlefield environment. These lasers emit in the green color band. Potential threat lasers include, at a minimum, the lasers listed in Table 25-1, as well as the frequency-doubled Nd:YAG laser. Additionally, lasers that operate at multiple wavelengths are now available. These lasers offer the operator the ability to instantaneously choose and switch the operating wavelength, thus making the prevention of laser injuries more difficult.

Laser pointers, now commonplace in society, are also found in the combat environment. With their momentary exposure, most commercially available laser pointers have insufficient power to cause permanent retinal injury.[3,4] Nevertheless, the visible emission of the laser pointer can cause glare and dazzle (ie, flash blindness). Many individuals who are exposed to a laser pointer emission seek medical attention and will require reassurance. Proper diagnosis and management of these patients can prevent unnecessary loss of personnel and possible panic among otherwise healthy individuals.

Ocular injuries in military personnel have been reported[5] from friendly laser sources. Most of these incidents have involved exposure to target designators and rangefinders operating in a Q-switched (ie, rapidly pulsed) mode at 1,064 nm (infrared). Although the technology is available to produce antipersonnel lasers, no use of such a laser has been documented to date. Nevertheless, with increasing use of lasers, healthcare providers in future conflicts should be prepared to evaluate and treat ocular laser injuries.

LASER PHYSICS

The word "laser" is an acronym for *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation. The unique properties of lasers allow for the production of an intense, single wavelength of electromagnetic energy with minimal divergence. These properties allow the lasers to concentrate sufficient energy to destroy a target. Laser emissions are visible or invisible, depending on the wavelength of the particular laser.

The damaging effects of a laser on a target depend largely on the amount of energy delivered. At a constant distance, the total energy delivered by a laser is a function of three variables: power, exposure time, and spot size (diameter of the laser beam). For a constant exposure time and spot size, increasing the power increases the total energy delivered

TABLE 25-1

WAVELENGTHS OF COMMON US ARMY LASERS

Type	Device	Wavelength (nm)	Band
Helium-Neon	Tank, gunnery trainer	642.8	Visible (red)
Ruby	Rangefinder	694.3	Visible (red)
Gallium-Arsenide	MILES	905.0	Near-infrared
Nd:YAG	Rangefinder, target designator	1,064.0	Near-infrared
Carbon Dioxide	Rangefinder	10,600.0	Far-infrared

MILES: multiple integrated laser engagement system
Nd:YAG: neodymium:yttrium-aluminum-garnet
Adapted from Headquarters, Department of the Army. *Prevention and Medical Management of Laser Injuries.* Washington, DC: DA; 8 Aug 1990: 19. Field Manual 8-50.

to a target. For a constant power and spot size, decreasing the exposure time increases the energy delivered to a target. In this scenario, a rapidly pulsed (Q-switched) laser delivers more energy than a laser operating in a continuous wave mode. For a given power setting and exposure time, decreasing the spot size of the laser increases the total amount of energy delivered.

Mechanisms of Bioeffects

A laser interaction with tissue causes damage by one or more of the following mechanisms: (*a*) photochemical reaction, (*b*) thermal effects, (*c*) vaporization, or (*d*) optical breakdown.[6]

After laser exposure—usually with ultraviolet or visible light—chemical bonds are destroyed or formed because of photochemical reactions. Opacities or haziness of the cornea or lens, or both, may result from ultraviolet or visible light laser emissions.

Absorption of the laser energy results in a 10°C to 20°C rise in temperature of the affected tissue.[6] As a result, the absorbing tissue denatures. This thermal effect is most commonly encountered with visible or infrared laser exposure to pigmented areas of the eye, such as the layer of cells under the retina known as the retinal pigment epithelium (RPE). Clinically, the patient may present with an area of whitening of the RPE. Within days to weeks, many of these same areas may become heavily pigmented.

When the temperature of water within tissue rises above its boiling point, a microexplosion occurs and the tissue vaporizes. This type of injury might follow a particularly intense visible-wavelength laser exposure in the RPE, or an exposure to a carbon dioxide laser.

In optical breakdown, an extremely high-power laser exposure strips electrons from an atom, which results in the formation of plasma. The shock wave created by the plasma formation physically disrupts tissue, causing injury. Optical breakdown is independent of ocular pigment and can occur anywhere in the eye. Because of the eye's focusing power, though, these types of injuries are more likely to be encountered in the retina. Optical breakdown is most commonly seen with lasers operating with a pulse duration of 10^{-6} seconds or less.

Ocular Bioeffects

The human eye absorbs electromagnetic wavelengths between 400 and 1,400 nm. The greatest absorption occurs in the visible and near-infrared spectrum, 500 through 950 nm (Figure 25-1).[2]

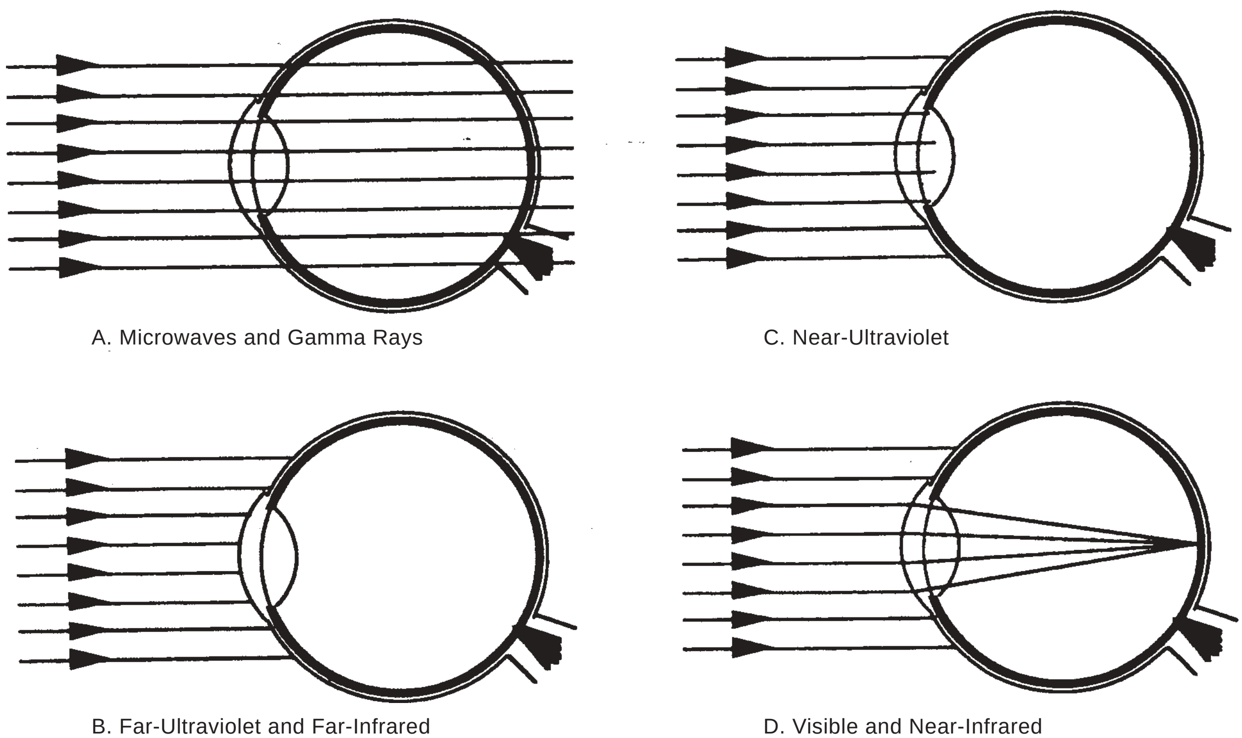


Fig. 25-1. Schematic diagram of the absorption of electromagnetic radiation in the eye. Adapted from Headquarters, Department of the Army. *Prevention and Medical Management of Laser Injuries.* Washington, DC: DA; 8 Aug 1990: 4. Field Manual 8-50.

TABLE 25-2

LASER ABSORPTION BY FUNDUS PIGMENTS

	XAN	HEM	MEL
Argon blue-green (488 nm)	+ + +	+ + +	+ +
Argon green (514 nm)	–	+ + +	+ + + +
Nd:YAG green (532 nm)	–	+ + + +	+ + + +
Dye yellow (577 nm)	–	+ + + +	+ + + +
Dye red (630 nm)	–	+	+ + +
Krypton red (647 nm)	–	+	+ + +
Diode (810 nm)	–	–	+ +

XAN: xanthophyll
HEM: hemoglobin
MEL: melanin
Adapted with permission from Bloom S, Brucker A. *Laser Surgery of the Posterior Segment.* Philadelphia, Pa: Lippincott-Raven; 1997: 7.

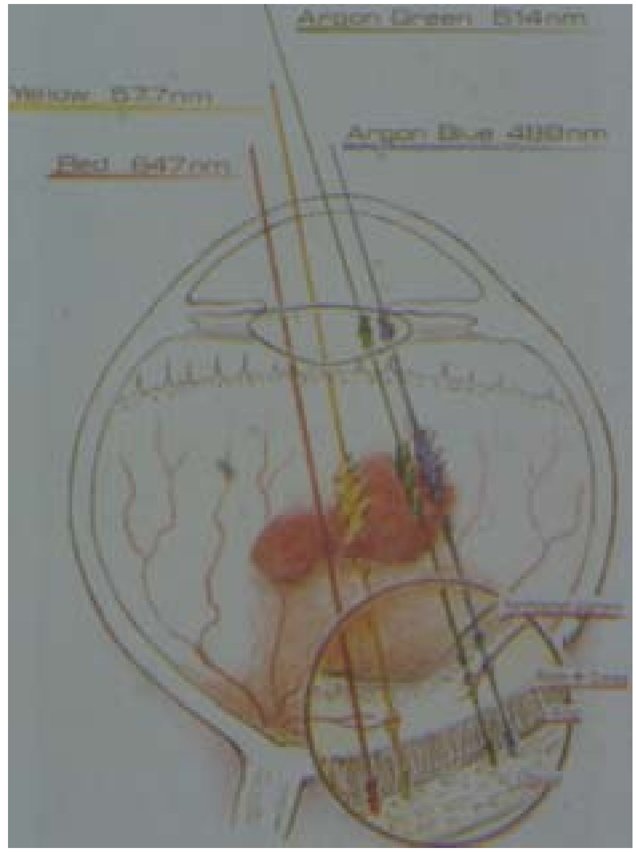


Fig. 25-2. Absorption characteristics of the major ocular pigments. Adapted with permission from Bloom S, Brucker A. *Laser Surgery of the Posterior Segment.* Philadelphia, Pa: Lippincott-Raven; 1997: Figure 1-4.

Because of the focusing power of the lens and cornea of the eye, energy transmitted to the retina can intensify by a factor of 10,000.[2] The use of optical sighting devices, such as binoculars or rangefinders, further increases the amount of laser energy delivered to the retina. Absorption of laser energy inside the eye depends on pigmentation. Pigments within the retina near the fovea (xanthophyll) and within blood vessels throughout the retina (hemoglobin) readily absorb laser energy (Table 25-2 and Figure 25-2). However, most absorption of laser energy occurs in the RPE. This layer of cells contains melanin, which readily absorbs laser energy. Laser energy absorbed in the RPE usually causes injury to the adjacent retina and choroid.

Depending on the laser intensity and wavelength, exposure to laser light may have temporary or permanent effects. With subthreshold laser emissions in the visible spectrum, most individuals experience glare and dazzle resulting from the saturation of the photoreceptors with light. This effect is similar to looking into the flash of a camera. Vision usually returns to baseline within several minutes. Nevertheless, during this refractory time, an exposed individual is visually handicapped. Tasks like firing a weapon, flying an aircraft, or driving a vehicle are severely hampered. Even minor tasks like map reading are affected. Laser emissions intense enough to cause ocular injury are known as threshold emissions. Threshold emissions in the visible spectrum usually cause glare and dazzle along with ocular injury.

SYMPTOMS

Individuals with ocular laser injuries experience a variety of symptoms depending on the type of laser and the location of the injury within the eye. Most individuals exposed to laser emissions in the visible spectrum present with complaints of glare or dazzle. Individuals with laser burns involving the cornea may complain of decreased visual acuity, pain, and tearing. Individuals with laser injuries involving the retina may complain of decreased visual acuity, blind spots (scotomas), or both in the visual field. Loss of contrast sensitivity and color vision may be presenting complaints. Lesions near or directly involving the fovea may result in metamorphopsia (distortion of straight lines) along with decreased visual acuity. Individuals who experience hemorrhage in the eye from a laser lesion may complain of floaters or a red discoloration to their vision. It is important to note that an individual presenting with laser burns to the peripheral retina may be asymptomatic.

DIAGNOSTIC MODALITIES

History

All suspected laser injury evaluations begin with a thorough history. In addition to aiding subsequent evaluation and treatment, the questions posed by the examiner are helpful for determining the possible threat laser wavelengths. These data are helpful when selecting appropriate laser protection to prevent subsequent injury. The following list of questions, developed by the US Army Medical Research Detachment of the Walter Reed Army Institute of Research, should be included in the history of an individual with a suspected laser injury:

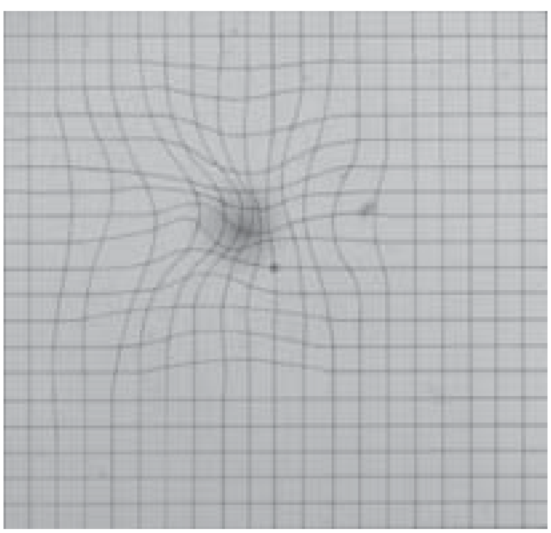
- What were you doing at the time of the incident?
- How long did the incident last?
- Can you describe the color of the light?
- Was the light continuous or interrupted?
- Was there an after-image?
- Did the incident impact the mission?
- Has there been any pain associated with the light?
- Did you rub your eyes?

Physical Examination

The physical examination begins with assessment of the patient's visual acuity. If available, Amsler grid testing is done to check for metamorphopsia and scotomas (Figure 25-3). The Amsler grid test is administered one eye at a time at the patient's normal reading distance. If reading spectacles are worn by the patient, they should be worn during the test.

Testing for color vision and contrast sensitivity should be documented. Most permanent laser injuries involving the retina have a decrement in one or both of these parameters. Color vision testing is done with each eye separately, at the patient's nor-

a



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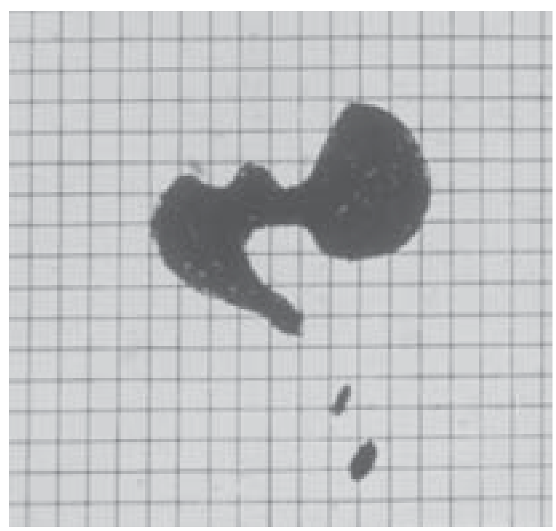

Fig. 25-3. (**a**) Metamorphopsia and relative scotoma on Amsler grid after laser injury to the retina. Test one eye at a time with the Amsler grid held 14 in. away. If the patient routinely wears spectacles, they should be worn for this test. (**b**) Absolute scotoma on the Amsler grid following a laser injury to the retina. Such a finding is suggestive of severe laser injury to the macula. The patient should be referred to an ophthalmologist for further evaluation. Photograph (a): Reproduced from Retina Research Fund. *For My Patient: Macular Degeneration*. San Francisco, Calif: Retina Research Fund; 1997; 18. Photograph (b): Courtesy of Bruce Stuck, US Army Medical Research Detachment, Walter Reed Army Institute of Research, Washington, DC.

mal reading distance and with spectacle correction, if needed. Pseudoisochromatic color plate (PIP) testing may be used to screen for color deficits. Detailed color tests such as the Farnsworth panel D-15 and the Farnsworth-Munsell 100 hue test are more sensitive for detecting color deficits but are not likely to be available in a combat environment. Contrast sensitivity testing requires the patient to look at a series of gratings at a fixed distance. The lowest amount of contrast to see the grating is known as the contrast threshold, and it is recorded for the various-sized gratings for each eye. Unfortunately, this test requires special equipment that may not be available in tactical environments.

The external adnexa and periorbital skin should be inspected. Swelling and erythema are findings consistent with possible carbon dioxide (10,600 nm) laser exposure. Attention is then directed inside the eye. Clouding and opacities of the cornea and lens are consistent with possible ultraviolet or far-infrared laser injury (Figure 25-4). Perforation of the cornea may be noted in high-energy exposures.

Injuries involving the posterior segment usually result from visible and near-infrared wavelengths. Laser injury to the retina can cause vitreous hemorrhage. In a combat environment, however, more common causes of vitreous hemorrhage (eg, blunt

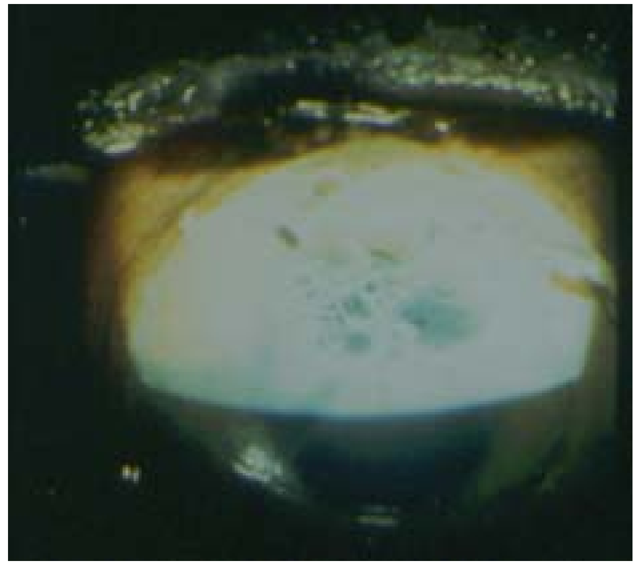

Fig. 25-4. Corneal opacification after an ocular injury with a high-energy infrared laser (laser operating parameters unknown). Acute corneal injuries without perforation should be treated with topical antibiotics. A pressure patch may be used to help make the patient more comfortable. Reproduced from Headquarters, Department of the Army. *Prevention and Medical Management of Laser Injuries.* Washington, DC: DA; 8 Aug 1990: Figure 6. Field Manual 8-50.

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b

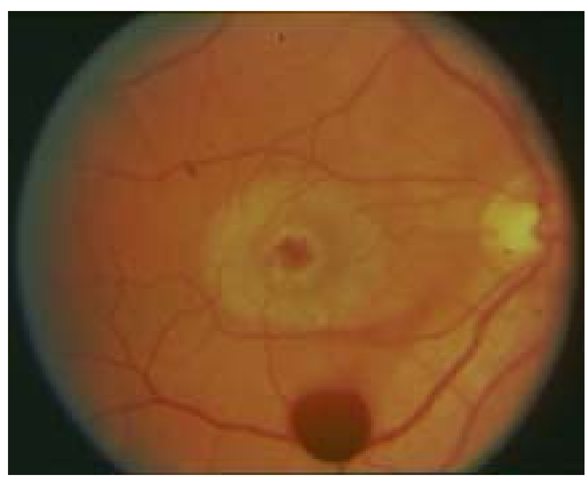

Fig. 25-5. (**a**) A full-thickness retinal hole after exposure to a neodymium:yttrium-aluminum-garnet (Nd:YAG) laser (1,064 nm) with pulse energy 150 mJ, frequency 10 Hz, and duration 10 nanoseconds. Some macular holes may be surgically closed with improvement of vision. (**b**) The retinal photograph shows preretinal hemorrhage, intraretinal hemorrhage, and retinal edema after exposure to an Nd:YAG laser. Photographs: Courtesy of Allen Thach, MD, Phoenix, Ariz.

a

b

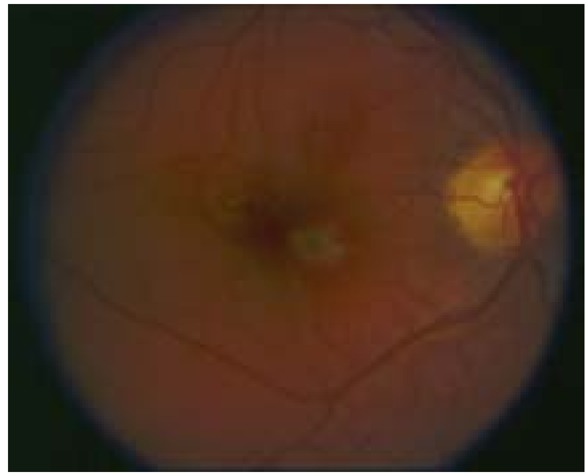

Fig. 25-6. (**a**) A retinal photograph made after the patient received multiple acute retinal burns from a Q-switched neodymium:yttrium-aluminum-garnet (Nd:YAG) laser (1,064 nm) rangefinder. (**b**) Several weeks after the laser injury, the same individual's retina was photographed again. Retinal striae and subretinal hemorrhage are present. Visual acuity is 20/200 with eccentric fixation. Photographs: Courtesy of Bruce Stuck, US Army Medical Research Detachment, Walter Reed Army Institute of Research, Washington, DC.

Fig. 25-7. Creamy colored retinal pigment epithelium changes after acute retina injury. Note the presence of preretinal hemorrhage. Reproduced from Headquarters, Department of the Army. *Prevention and Medical Management of Laser Injuries.* Washington, DC: DA; 8 Aug 1990: Figure 7. Field Manual 8-50.

trauma, penetrating trauma, retained intraocular foreign body) should be ruled out. If the visual axis is clear, the retina is inspected. The spectrum of retinal findings from a threshold laser exposure includes edema, necrosis, full-thickness holes, and retinal detachment (Figures 25-5 and 25-6). Hemorrhage may accompany retinal injuries and localize in front of the retina (preretinal), in the retina (intraretinal), under the retina (subretinal), or within the vitreous cavity. Preretinal fibrosis and retinal striae may present weeks to months after severe laser retinal injuries.[7]

The RPE in acute retinal injuries appears cream colored or white (Figure 25-7). Within a few weeks, these areas manifest varying degrees of pigment hyperplasia and atrophy.

TREATMENT

Laser injuries involving the external adnexa should be treated similarly to thermal burns from other sources. Topical antibiotics should be applied to the exposed area. Ophthalmic antibiotic ointment preparations are used to prevent toxic damage to the eye that may result from the use of nonophthalmic preparations.

Anterior Segment

Nonpenetrating injuries involving the cornea are treated similarly to corneal abrasions. Topical ophthalmic antibiotic preparations should be applied directly to the globe. If the individual has severe discomfort from corneal injury, a pressure patch can be placed over the affected eye to prevent eyelid movement. This patch is similar to that applied for a corneal abrasion. Patching is contraindicated in wearers of soft contact lenses. If both eyes are affected, the more severely affected eye should be patched. Corneal injuries should be seen daily until the epithelium has healed. Perforating laser injuries involving the cornea are treated similarly to perforating injuries from other sources. A Fox shield is placed over the eye, and systemic antibiotics are instituted to cover Gram-negative and Gram-positive organisms. Analgesics and antiemetics are used as needed. *No drops or ointment of any kind are placed on an eye with a suspected perforating injury.*

Posterior Segment

Treatments for laser injuries to the posterior segment of the eye are limited. In the absence of a retinal detachment, vitreous hemorrhages are initially treated with bed rest and at least 30° elevation of the head. Dense vitreous hemorrhages may require ultrasound evaluation to rule out a retinal detachment. The fundus should be examined frequently as the hemorrhage clears, to rule out underlying retinal holes or retinal detachment. If these are found, the patient should be immediately referred to an ophthalmologist for further treatment. Bilateral vitreous hemorrhages that obscure the visual axis require evaluation by an ophthalmologist for consideration of pars plana vitrectomy.

Retinal tears and retinal detachments resulting from laser injuries require urgent evacuation to an ophthalmologist for further care. Patients with retinal detachments should refrain from reading and remain sedentary to prevent extension of the retinal detachment. Individuals with macular holes from laser exposure should be referred to an ophthalmologist for evaluation. Some of these patients may benefit from pars plana vitrectomy with air–fluid exchange to close the edges of the macular hole and possibly improve vision.[8]

Individuals with subretinal hemorrhage under the fovea should be evaluated by an ophthalmologist as soon as possible. Early evacuation of subretinal hemorrhage with pars plana vitrectomy may limit subsequent damage to retinal photoreceptors and, in some cases, may improve visual prognosis.[9] Research is ongoing in this area.

To date, there are no proven medical interventions for the treatment of laser injuries involving the retina. The use of intravenous steroids in the acute setting to limit subsequent epiretinal and subretinal fibrosis is controversial and unproven to date. Intravitreal injection of tissue thromboplastin activator (TPA) has been successful in removing subfoveal blood.[10]

PREVENTION

Because treatment options are limited for individuals with laser injuries, prevention is extremely important. In an environment where laser use is suspected, individuals should be instructed to refrain from looking directly at bright lights. The use of optical sighting devices such as binoculars and rangefinders should be limited, as these devices increase any laser energy delivered to the eye. If available, all personnel should wear laser eye protection at all times (Figure 25-8). The laser eye protection must correspond to the threat wavelength to be effective. In many cases, simple measures such as taking cover or setting up a smoke screen can prevent harmful laser exposure.[2] The use of indirect viewing methods for target acquisition and surveillance can prevent laser injuries, as well.

It is also important to avoid laser injury from friendly laser sources. Rangefinders and target designators should not be pointed directly at personnel, and individuals using these lasers should avoid looking at the output end.

Fig. 25-8. Examples of ballistic laser eye protection currently in US Army inventory.

SUMMARY

Increasing military applications of lasers will lead to a concomitant increase in ocular laser exposure and ocular laser injuries. Laser exposure of the unprotected eye may result in injury to the eyelids, cornea, lens, retina, and choroid. Hemorrhage into the vitreous cavity may also be encountered if adjacent ocular structures bleed. Patients with prolonged visual loss or intraocular hemorrhage after possible laser exposure should be referred to an ophthalmologist for further care. Conversely, personnel exposed to laser emissions with mild or no ocular injury should be returned to duty as soon as possible to minimize secondary gain and limit the potential psychological impact on fellow personnel. Proper identification and treatment of laser injuries by medical personnel will allow friendly forces to sustain the fighting strength.

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