OCULAR TRAUMA

Chapter 7

Contributing Authors
Raymond I. Cho, MD, LTC, MC, US Army
Eric Savitsky, MD

All figures and tables included in this chapter have been used with permission from Pelagique, LLC, the UCLA Center for International Medicine, and/or the authors, unless otherwise noted.

Table of Contents

Introduction

Trauma to the eye and its associated structures accounts for a significant number of combat-related injuries. Despite the fact that the eyes cover less than 1 percent of the total body surface area, the proportion of combat injuries involving ocular structures has exceeded 10 percent in recent conflicts, with an increasing trend over the past century of warfare. Ocular injuries accounted for 2 percent of all combat injuries during the First and Second World Wars, compared to 13 percent during Operation Desert Storm (Fig. 1).[1] Although combat-related ocular injuries in the United States (US) military have decreased somewhat over the past several years due to the widespread implementation of combat eye protection, these injuries remain a significant cause of disability and suffering among wounded combat veterans (Fig. 2).

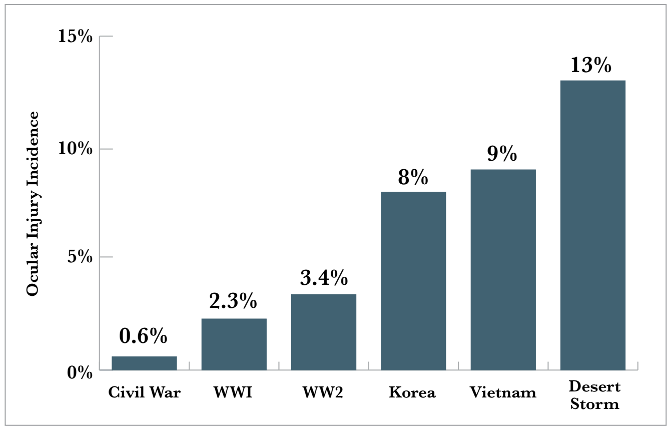


Figure 1. *Ocular injury incidence as a percentage of combat injuries, American Civil War through Operation Desert Storm. Adapted from Wong, 1997.*[1]

Penetrating projectile injuries have had a significant effect on the nature of modern combat ocular trauma, most commonly causing open-globe injuries (55 percent), eyelid injuries (33 percent), orbital fractures (13 percent), orbital foreign bodies (12 percent), corneal/conjunctival foreign bodies (11 percent), and traumatic optic neuropathy/optic nerve avulsion (3 percent).

Many valuable lessons have been learned through the experience of caring for thousands of ocular combat casualties during Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). As has been noted by combat casualty care (CCC) providers throughout the history of warfare, combat injuries tend to be much more severe and extensive than those seen as a result of civilian trauma. These conflicts have also demonstrated that, in counterterrorism and counterinsurgency operations, blast injuries tend to account for a higher proportion (78 percent) of trauma when compared to conventional battlefields of the past.[2] These penetrating projectile injuries have had a significant effect on the nature of modern combat ocular trauma. There has also been a high incidence (62 percent) of concomitant head, face, and neck trauma in ocular trauma patients.[3] This finding in large part has led to the establishment of integrated multispecialty head and neck surgical teams that have been successfully deployed by the US Army in Iraq. Finally, the large number of host national injuries treated by coalition medical personnel has required a rethinking of many

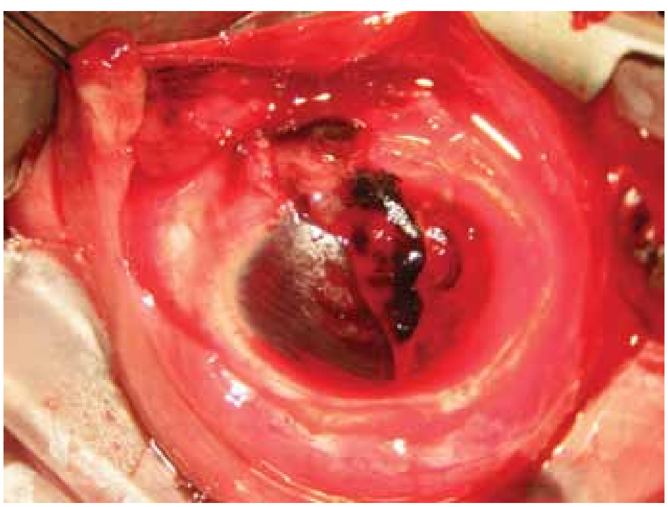


Figure 2. *Open-globe injury with large corneoscleral laceration and uveal prolapse following gunshot wound.*

trauma management patterns that are commonly practiced in the US, but have questionable applicability in resource-limited countries. For example, open-globe repair versus primary enucleation following open-globe injury is addressed later in this chapter.

The most common types of ocular injury requiring specialized ophthalmic care during OIF from 2003 to 2005 were open-globe injuries (55 percent), eyelid injuries (33 percent), orbital fractures (13 percent), orbital foreign bodies (12 percent), corneal/conjunctival foreign bodies (11 percent), and traumatic optic neuropathy/optic nerve avulsion (3 percent) (Table 1).[4] A separate study during OIF from 2005 to 2006 also reported that 20 percent of patients with combat ocular trauma were treated for orbital compartment syndrome.[5] The prevalence of less serious injuries such as corneal abrasion or hyphema has not been recently reported, although during the Vietnam War, hyphemas were seen in 15 percent of ocular combat casualties.[6]

Injury Type	Percent
Open-globe injuries	55
Eyelid injuries	33
Orbital fractures	13
Orbital foreign bodies	12
Corneal / conjunctival foreign bodies	11
Traumatic optic neuropathy/optic nerve avulsion	3

Table 1. *Most common types of ocular injury requiring specialized ophthalmic care during OIF 2003 to 2005. Adapted from Thatch, 2008.*[4]

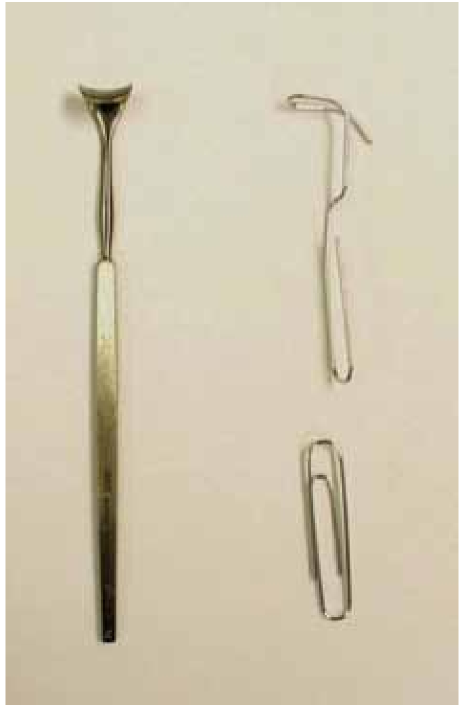
Levels of Ophthalmic Combat Casualty Care (CCC)

Levels I and II

The resources available for treating ocular injuries at Level I and II facilities are limited, but certain actions taken at these levels may prove critical to optimizing ultimate outcomes. It is of utmost importance for providers at this level to recognize when an ocular injury is severe enough to warrant evacuation to the next level of care, and this requires an appropriately thorough ophthalmic examination. It is often difficult to examine an injured eye due to the frequent presence of eyelid edema, hemorrhage, tissue damage, or pain. However, it is possible in most cases to open the eyelids long enough to obtain at the very least a cursory glance at the globe and a gross assessment of visual acuity. If necessary, Desmarres retractors, a lid speculum, or even a bent paper clip can be used to carefully retract the eyelids while avoiding pressure on the globe (Fig. 3). A topical anesthetic (e.g., 0.5 percent proparacaine or tetracaine drops) may be used to decrease the discomfort caused by examination. However, excessive manipulation of the eyelids in the presence of a ruptured globe can increase the risk of intraocular content extrusion. The moment the examiner notes findings suggestive of globe rupture, the examination should be terminated and the injured globe should be protected from further manipulation. The specific exam findings suggestive of an open-globe injury are discussed later in this chapter.

Figure 3. (Right) *Desmarres retractors or a bent paper clip can be used to retract the eyelids during the assessment of the acutely injured eye.*

Figure 4. (Far Right) *Placement of Fox eye shield (right eye) and truncated disposable drinking cup (left eye) for eye protection. The rim of the device rests on the frontal and maxillary bones.*



Patients with ocular injuries should undergo as complete an ophthalmic examination as possible. A detailed description of this exam is provided below, although some aspects, such as the slit-lamp exam, are not feasible at this level. At a minimum, visual acuity, pupils, extraocular motility, and visual fields by confrontation should be assessed. Gross examination of the eyelids, conjunctiva, sclera, cornea, and anterior chamber structures may reveal lacerations, anatomic disruption, hemorrhage, or foreign bodies.

Combat casualty care providers at Level I and II facilities must perform thorough ophthalmic examinations and recognize when an ocular injury is severe enough to warrant evacuation to the next level of care. If globe rupture is suspected, the eye examination should be terminated and the eye protected from further injury. Foreign bodies protruding from the eye or orbit should be left in place unless they are too large to safely immobilize during evacuation. Patients with severe vision loss, pupillary abnormalities, gross proptosis, or limited ocular motility should be evacuated whenever possible.

The most important action medical personnel at Level I or II facilities can perform for a patient with an ocular injury requiring evacuation is to protect the eye from further injury. To this end, Fox eye shields have been recently added as a standard item to the combat medic bag. This eye shield is designed to rest on the bony support of the face and vault over the ocular structures and can be secured with one or more strips of tape spanning the forehead and cheek. In the absence of a Fox eye shield, any item that can effectively perform the same function, such as a specimen cup or truncated disposable drinking cup, can be substituted (Fig. 4). It is important to make the distinction between shielding, as described above, and patching, (i.e., placing a pressure dressing on the eye). Patching of the eye should never be performed by nonophthalmic personnel on a suspected ocular injury. Similarly, the application of solutions or ointments to a suspected open-globe is not recommended. As a rule, foreign bodies protruding from the eye or orbit should be left in place unless they are too large to safely immobilize during evacuation (Figs. 5 and 6).

The decision to evacuate a patient to a Level III facility for ophthalmologic evaluation is not always clear-

Figure 5. *Left orbit impaled with large wooden plank. The plank had been part of a fence, and the portion embedded in the patient's face had to be broken off in order to facilitate transport from the accident scene.*

Figure 6. *Removed wooden fragments adjacent to the primarily enucleated globe.*

cut and must take into account many nonclinical variables such as operational security, the availability of evacuation assets, and the impact of evacuation on the unit's mission. In general terms, patients with severe vision loss, pupillary abnormalities, gross proptosis, or limited ocular motility should be evacuated whenever possible. More specific indications for evacuation include suspected open-globe injuries, corneal infections, large hyphemas, retinal detachments, full-thickness eyelid lacerations, orbital compartment syndromes, and orbital fractures. As discussed below, suspected orbital compartment syndrome must be immediately treated by the first qualified CCC provider prior to evacuating the patient to the next level of care. This list is by no means all-inclusive, and additional guidelines for evacuation are provided later in this chapter. If telephonic or electronic consultation with an ophthalmologist is available in-theater, it should be utilized in cases where doubt exists about the severity of an ocular injury.

Level III

Under current doctrine, specialized ophthalmic care is first available in the combat zone at Level III (Fig. 7). As stated above, ophthalmologists at Level III care facilities are typically deployed as part of multidisciplinary head and neck teams that include neurosurgery, otolaryngology, and oral maxillofacial surgery. Facilities and equipment vary, but the bare minimum should include a slit-lamp biomicroscope, Tono-Pen®, indirect ophthalmoscope, and an operating room with a surgical microscope and complete sets of ophthalmic surgical instruments. Surgical loupes can also be very useful, particularly when treating periocular and orbital injuries. Essential supplies include balanced salt solution (BSS), viscoelastics, microsurgical sponges, orbital implants, and other medications and surgical devices unique to ophthalmic surgery. Individual surgeons should ensure that their preferred sutures are available. Some of the more commonly employed sutures include: 8-0, 9-0, and 10-0 nylon; 4-0, 5-0, and 6-0 polyglactin; 5-0 polydiaxanone; 4-0 and 6-0 silk; 6-0 chromic gut or plain gut; and 6-0 polypropylene.

The mission of the Level III ophthalmologist is to provide treatments that are as definitive as possible within the physical and operational constraints of the care facility. Patients who require more specialized surgery, extensive rehabilitation, or are rendered indefinitely combat ineffective will be evacuated to a Level IV facility and beyond. Conversely, if a soldier can be treated in-theater and returned to duty within

Figure 7. *Ophthalmologic procedure being performed at a Level III facility in Balad AFB, Iraq.*

Figure 8. *Combined ocular and cranial injury caused by gunshot wound. Bullet path is demonstrated by cotton-tipped applicators. The patient underwent decompressive hemicraniectomy, enucleation of the left eye, and left orbital reconstruction.*

a reasonable timeframe, this course of action should be considered. The extent to which host nationals or other noncombatants should be treated is determined by the medical commander.

The Level III facility-based ophthalmologist should provide treatments that are as definitive as possible within the physical and operational constraints of the facility. For patients requiring evacuation, photographic documentation of pertinent clinical findings is helpful to the receiving careproviders.

For patients requiring evacuation out-of-theater, proper medical record keeping is of great importance in optimizing follow-up and appropriate treatment by Level IV and V careproviders. Photographic documentation of pertinent clinical findings, obtainable through the use of a standard point-and-shoot digital camera, can be particularly helpful to careproviders receiving patients evacuated out-of-theater. Photographs can be taken externally or through the lens of the operating microscope or slit-lamp biomicroscope and electronically transmitted to points of contact at the next level of care.

Levels IV and V

Definitive and subspecialized ophthalmic care, such as retinal surgery, intraocular foreign body (IOFB) removal, or traumatic cataract extraction, is available at Level IV and V facilities located outside the theater of operations. Detailed discussion of treatment at this level falls beyond the scope of this chapter.

Evaluation of the Ocular Trauma Patient

History

A detailed ocular history aids in the assessment of injury severity and guides subsequent patient evaluation. In cases of chemical exposure to the eye, treatment should be initiated immediately while history and physical examination are deferred or performed in concert with immediate copious irrigation of the eyes. The ophthalmologic history should establish the premorbid visual acuity. It should also include the patient's use of corrective lenses, ophthalmologic medications, tetanus status, and previous eye surgery.[7,8,9] Patients with a history of prior ocular surgery are at risk for corneal or scleral rupture, even with minor trauma.

In cases of chemical exposure to the eye, treatment should be initiated immediately while history and physical examination are deferred or performed in concert with immediate copious irrigation of the eyes.

In cases of blunt trauma, the mechanism, force, and direction of impact are important in determining the extent of injury. A history of ocular exposure to high-speed projectiles should alert the provider to the possibility of an IOFB.[9] For penetrating injuries, it is important to determine the composition of the potentially retained foreign body. Certain foreign bodies can elicit an intense inflammatory reaction or lead to infection within the globe, while others are well tolerated.[7]

As stated in the introduction to this chapter, combat ocular injuries are often found in conjunction with head, face, and neck injuries (Fig. 8). For example, during OIF from 2005 to 2006, 33 percent of patients with cranial trauma had a concomitant open-globe injury.[5] It is therefore important for CCC providers to maintain a high level of suspicion for the presence of ocular injuries when trauma to the head, face, or neck is recognized. This is particularly true for unconscious patients in whom it is not possible to ascertain the presence of ocular pain, decreased vision, or limited motility.

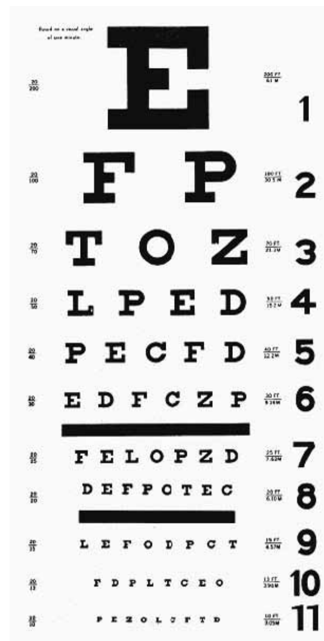


Figure 9. *A Snellen eye chart read at 20 feet, or a near card viewed at 14 inches, should be used to assess visual acuity.*

Visual Acuity

Visual acuity is the vital sign of the eye and its measurement is the first step in all ophthalmologic exams. Visual acuity must be measured in all responsive patients with ocular trauma, as it is a critical factor in establishing diagnosis, guiding treatment, and predicting visual outcome in these patients.[10]

Visual acuity should be determined independently in each eye using a Snellen eye chart at 20 feet or a near card viewed at 14 inches (Fig. 9). The best-corrected visual acuity should be obtained using the patient's spectacle correction or a pinhole test. Binocular acuity testing is not useful in the trauma setting. Topical anesthetics may facilitate visual acuity testing in patients with acute eye pain and blepharospasm.

Visual acuity is the vital sign of the eye, and its measurement is the first step in all ophthalmologic exams.

If an eye chart is unavailable, any form of typed print such as a magazine or packaging from medical supplies may be used. If a patient is unable to visualize typed print, visual acuity should be recorded as counting fingers at a specified distance, hand motion, light perception, or no light perception.

Figure 10. *Teardrop-shaped pupil with the apex of the teardrop pointing to rupture site. Image courtesy of Swaminatha V. Mahadevan, MD, Stanford University.*

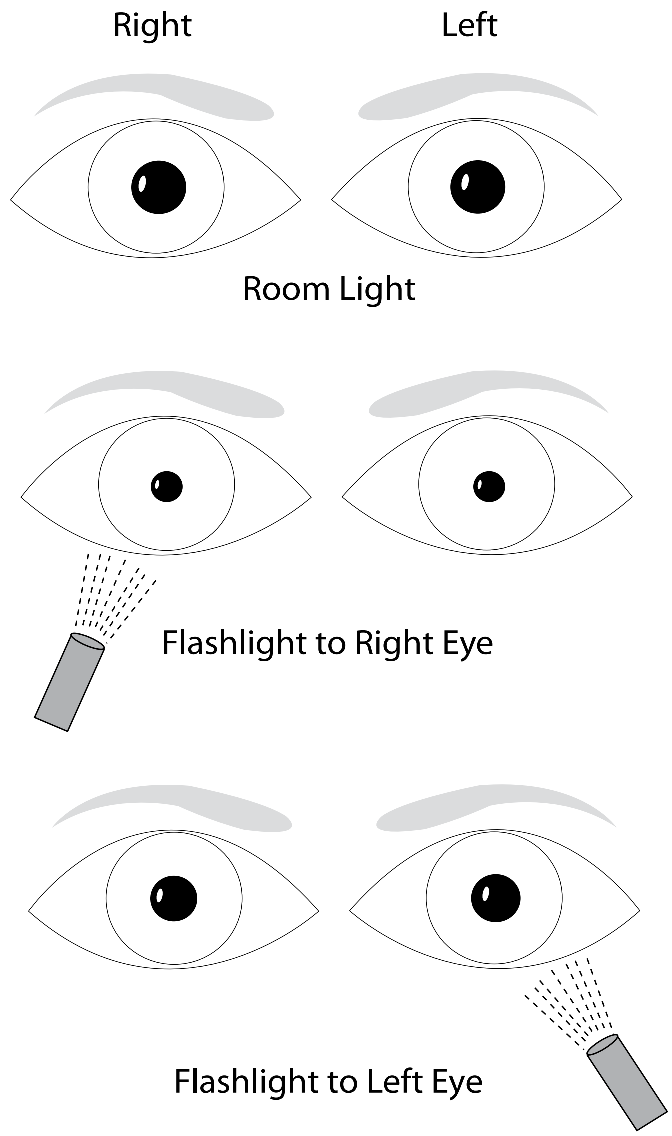


Figure 11. *Afferent pupillary defect. The swinging flashlight test reveals an afferent pupillary defect in the left eye.*

Pupil Examination

The pupil should be examined, noting size, shape, symmetry, and reaction to light. Pupil size is recorded in millimeters (mm). Blunt trauma may cause pupillary irregularities or traumatic mydriasis (i.e., dilated pupil). A teardrop-shaped pupil is suggestive of globe rupture, with the apex of the teardrop pointing to the rupture site (Fig. 10). Each pupil should be assessed for direct and consensual response to light stimulation (i.e., pupillary light reflex). Patients should be screened for the presence of an afferent pupillary defect (APD), also known as the Marcus-Gunn pupil, using the swinging flashlight test (Fig. 11). This test is based upon the assumption that fellow eyes with normal optic nerve function have equal consensual constriction to light. When optic nerve function (the afferent visual pathway) is compromised on one side, the pupil on the involved side will still constrict when light is shined into the fellow normal eye. However, when the light is swung to the abnormal eye, the pupil will be observed to dilate from its once-constricted state, due to the decreased input to the Edinger-Westphal nucleus.

> An afferent pupillary defect should alert the examiner to the presence of optic nerve pathology or severe retinal injury.

Ocular Motility

The corneal light reflex should be at the same relative position on each cornea and the patient should be able to move his or her eyes in all directions of gaze (supraduction, infraduction, adduction, and abduction). Limited extraocular motility may indicate orbital fractures, cranial nerve injury, extraocular muscle injury or entrapment, or restriction of globe motility from intraorbital edema or blood.

It is important to distinguish whether patients complaining of diplopia are experiencing monocular versus binocular diplopia. Diplopia that persists when the uninjured eye is covered (i.e., monocular diplopia) suggests an abnormality in the ocular media, such as corneal irregularity, lens abnormality, or iridodialysis. Diplopia that resolves with occluding either eye (i.e., binocular diplopia) is indicative of a defect in coordinated eye movement.

It is important to distinguish whether patients complaining of diplopia are experiencing monocular versus binocular diplopia.

Visual Field Testing

Visual field testing can detect disorders affecting the retina, optic nerve, anterior and posterior visual pathways, and visual cortex. Patients with visual complaints irrespective of visual acuity should always be screened for visual field defects. Confrontational visual fields are measured one eye at a time and can be assessed by comparing the patient's responses to the examiner's own field with the opposite eye closed (assuming that the examiner has normal visual fields). At a normal conversational distance, any target (e.g., fingers or cotton-tipped applicators) can be presented at the periphery of the visual field equidistant between the examiner and patient. Care must be taken to ensure that the unexamined eye of the patient is completely covered.

Intraocular Pressure Measurement

Intraocular pressure (IOP) may be measured using an applanation tonometer, Tono-Pen®, or Schiotz tonometer (Fig. 12). However, these devices are not usually available at Level I or II facilities. Topical anesthesia (e.g., 0.5 percent proparacaine or tetracaine) is necessary to enable their use in conscious patients. Normal IOP ranges between 10 and 21 mm Hg. Elevated IOP can result from numerous traumatic conditions, including hyphema, angle closure, retrobulbar hemorrhage, or carotid-cavernous fistula. Decreased IOP can result from open-globe injury, uveitis, cyclodialysis (separation of the ciliary body from the sclera), or retinal detachment.[11]

Figure 12. *The Tono-Pen® is a portable device that can be used by ophthalmic and nonophthalmic personnel to accurately measure intraocular pressure.*

If an open-globe injury is suspected, IOP measurements should be deferred to prevent further eye injury.

External Ocular Examination

The eyelids and periocular region should be inspected, taking note of asymmetry, edema, ecchymosis, lacerations, foreign bodies, or abnormal eyelid position. Ptosis (drooping of the upper eyelid) is common

Figure 13. (Above) *Frontal view of a patient with right proptosis due to a large right orbital tumor.* (Top Right) *Worm's-eye view of the same patient, showing the degree of proptosis more clearly.* (Bottom Right) *Bird's-eye view of a different patient demonstrating proptosis of the left eye.*

in trauma settings and is typically the result of edema, but other potential causes include third nerve palsy, levator muscle injury, or a traumatic Horner's syndrome (miosis, ptosis, anhidrosis). Medial eyelid lacerations should raise the suspicion of canalicular injury. The presence of fatty tissue within a lid laceration indicates violation of the orbital septum, raising the suspicion for orbital injury or foreign body. The presence of proptosis (protruding eyeball) should be noted, and may be indicative of a retrobulbar hemorrhage or other pathology such as infection, inflammation, or tumor. Looking at the orbits from above (bird's-eye view) or below (worm's-eye view) can assist in determining the degree of proptosis (Fig. 13). The orbital rims should be palpated and bony step-offs or tenderness noted. Periorbital subcutaneous emphysema is highly suggestive of a fracture involving the orbital floor or medial orbital wall (Figs. 14 and 15). A detailed discussion of examination for the presence of orbital fractures is presented in the Maxillofacial and Neck Trauma chapter.

Anterior Segment Examination

Gross inspection and slit-lamp examination can detect injuries of the anterior segment including the conjunctiva, sclera, cornea, iris, and lens. The conjunctiva and the sclera should be examined for injection, bleeding, lacerations, chemosis (i.e., conjunctival edema), exposed tissues (e.g., darkly pigmented uveal tissues), and foreign bodies. The presence of hemorrhagic chemosis is suggestive of open-globe injury

Figure 14. *Axial computed tomography image of a patient with subcutaneous emphysema in the left upper eyelid resulting from an orbital floor fracture.*

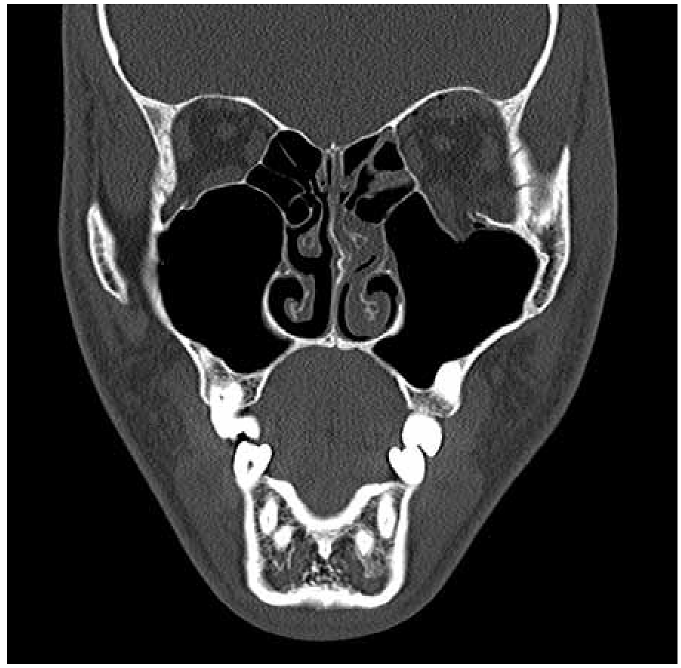


Figure 15. *Coronal computed tomography image of the same patient demonstrating the orbital floor fracture.*

Figure 16. *Presence of hemorrhagic chemosis suggesting open-globe injury.*

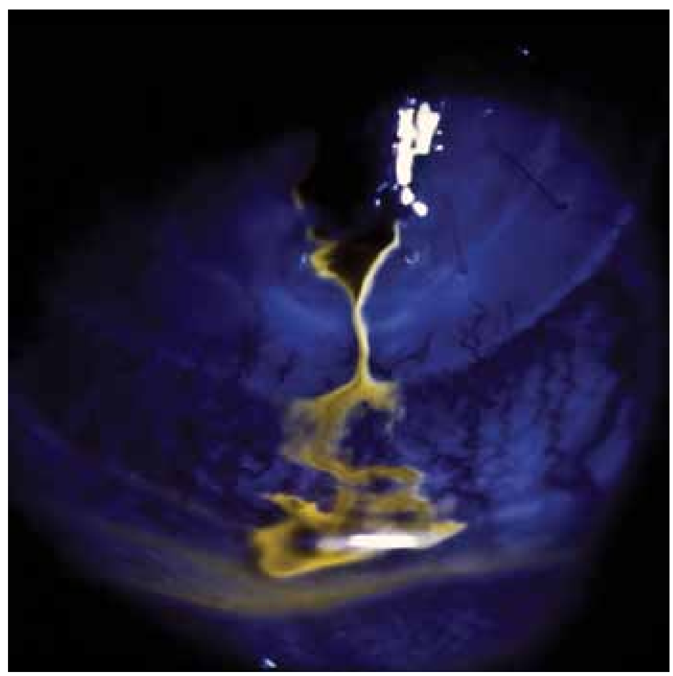


Figure 17. *Positive Seidel's sign identifying aqueous humor leakage. Image courtesy of the University of Michigan Kellogg Eye Center.*

(Fig. 16). The cornea should be examined for lack of clarity, surface irregularities, and foreign bodies. Fluorescein staining of the cornea may assist with the diagnosis of corneal epithelial defects. Removal of contact lenses prior to the application of fluorescein will prevent permanent staining of the contact lens.

(Note: in accordance with DA PAM 40-506, chapter 4-13.c, the US Army prohibits the wearing of contact lenses in field and combat environments.)

The presence of hemorrhagic chemosis is suggestive of open-globe injury.

In cases of suspected corneal perforation, a Seidel test can identify aqueous humor leakage (Fig. 17). A Seidel test is performed by applying a moistened fluorescein strip directly to the area in question, creating a puddle of dark orange concentrated fluorescein. Leaking aqueous humor will dilute the fluorescein and create a stream that fluoresces bright yellow-green under cobalt blue light. While a positive Seidel test is pathognomonic for corneal perforation, a negative test does not necessarily rule it out, as some corneal wounds can be self-sealing.

In cases of suspected corneal perforation, a Seidel test can identify aqueous humor leakage. While a positive Seidel test is pathognomonic for corneal perforation, a negative test does not necessarily rule it out, as some corneal wounds can be self-sealing.

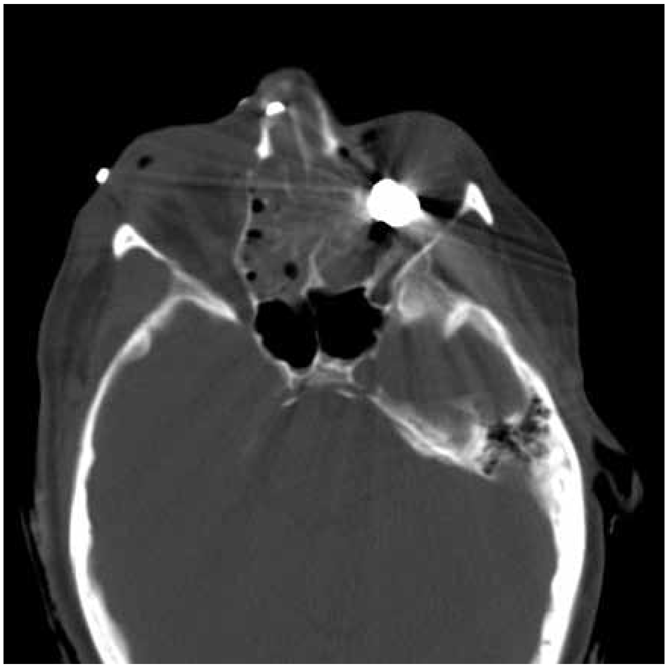
The irides are inspected for color, defects, and irregularities in shape. The crystalline lens is not normally visible on gross inspection, and is best examined with a slit-lamp. Traumatic subluxation of the lens often manifests as a dark crescent moon in the center of the pupil. Gross examination of the anterior chamber may reveal an excessively shallow or deep anterior chamber (in comparison with the opposite eye), suggestive of open-globe injury or lens dislocation. Normally, the anterior chamber is optically clear, but gross inspection may reveal red blood cells (i.e., hyphema) or purulent exudate (i.e., hypopyon). Cell and flare, which are signs of anterior chamber inflammation, can usually only be seen through a slit-lamp biomicroscope. The magnified view of the oblique slit beam reveals individual white blood cells or proteinaceous debris, which resemble dust particles or smoke within a movie projector beam.[8]

Posterior Segment Examination

The vitreous, retina, and optic disc can be visualized through a careful fundoscopic exam. The fundoscopic exam should begin by documenting the status of the red reflex. An abnormal red reflex suggests corneal edema, cataract, vitreous hemorrhage, or a large retinal detachment. Any opacity that disturbs the transmission of light (e.g., foreign body, corneal laceration, or lens injury) will show up as a dark shadow against the red reflex.

An abnormal red reflex suggests corneal edema, cataract, vitreous hemorrhage, or a large retinal detachment.

A complete fundoscopic examination may be facilitated by pharmacologic dilation of the pupils with topical mydriatics (e.g., phenylephrine) and cycloplegics (e.g., tropicamide). Prior to inducing pharmacologic dilation, patients should have a complete pupillary exam and be screened for contraindications to dilation such as significant head trauma or a history of angle-closure glaucoma. All patients with possible posterior segment injuries should be referred to an ophthalmologist for a complete 360-degree retinal examination.



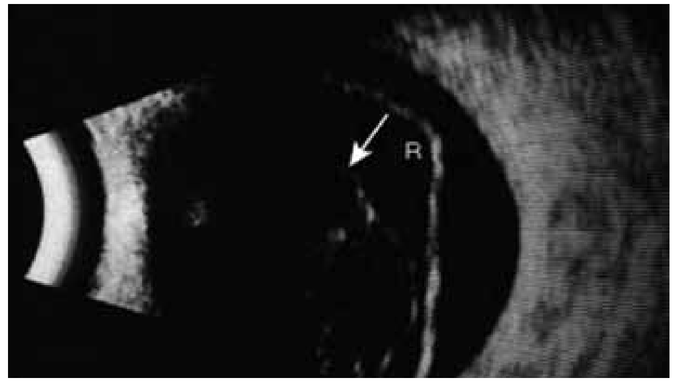


Figure 18. (Left) *Axial computed tomography image of a patient with a left intraorbital foreign body resulting from an improvised explosive device (IED) blast. The metallic foreign body traveled through the right orbit and both ethmoid and nasal sinuses before coming to rest in the medial left orbit adjacent to the optic nerve. It was successfully removed through a transcaruncular medial orbitotomy.*

Figure 19. (Top Right) *B-scan ultrasound image showing retinal detachment (R). The vitreous cavity is black and the curved surface of the posterior sclera (white) is seen on the right side of the image. Image courtesy of Mitchell Goff, MD.*

Ocular Imaging Techniques

Plain film radiography, computed tomography (CT), ultrasound, and magnetic resonance imaging (MRI) have all been used in the evaluation of ocular trauma. Computed tomography has largely replaced conventional plain film radiography for the evaluation of ocular trauma. It is particularly useful in the evaluation of orbital fractures, intraocular and orbital foreign bodies, globe rupture, and retrobulbar hemorrhage.[12,13] However, radiolucent foreign bodies such as glass, plastic, or wood may be difficult to detect on CT or plain film.[14] Standard CT examination should include both axial and direct coronal imaging, although direct coronals are often not obtainable in trauma patients who are unconscious or under cervical spine precautions. Contrast administration is not necessary. Thin cuts (e.g., 1 mm) can be obtained for specific indications, such as localizing foreign bodies, viewing the optic canal, or for coronal reconstruction when direct coronals cannot be obtained (Fig. 18). If CT is unavailable, conventional plain films may be used to screen for metallic foreign bodies or evaluate for orbital fractures and sinus injury.

Within the first 24 to 72 hours following injury, the most valuable imaging modality for the evaluation of ocular trauma is CT scanning, which is widely available at Level III facilities.

When ocular examination is obscured by opaque media (e.g., intraocular hemorrhage), B-scan ultrasound may provide detailed intraocular anatomic information.[15] Ultrasound may detect the presence of an IOFB, retinal detachment, choroidal hemorrhage, vitreous hemorrhage, and orbital hemorrhage (Fig. 19).[13,16] Because the transducer applies pressure to the globe, ultrasound testing should be avoided in cases of suspected globe violation.

Within the first 24 to 72 hours following injury, the most valuable imaging modality for the evaluation of ocular trauma is CT imaging, which is widely available at Level III facilities. B-scan ultrasound can be useful in select cases, but its availability at Level III is variable. Magnetic resonance imaging is not particularly useful in the setting of acute ocular trauma, and is not generally available prior to Level IV.

Closed Globe Injuries

Corneal Abrasion

In most cases, corneal abrasions (traumatic corneal epithelial defects) can be safely managed by nonophthalmic providers. The cause of the abrasion is usually traumatic and the onset of symptoms (pain, foreign body sensation, photophobia, and blurred vision) is immediate. The defect can be visualized with the aid of fluorescein, which stains exposed epithelial basement membrane and fluoresces bright yellow-green when viewed under a Wood's lamp or cobalt blue light (Fig. 20). In most cases, the recommended treatment is a prophylactic topical antibiotic (erythromycin, bacitracin ophthalmic ointment, or polymyxin B sulfate and trimethoprim [Polytrim®] ophthalmic solution) instilled four times a day. Patching is generally discouraged, but sunglasses can provide symptomatic relief. The dispensing of topical anesthetics to any patient for any reason is contraindicated, as they can lead to neurotrophic keratopathy and persistent epithelial defects.[17] Depending on the size of the defect, most corneal abrasions heal spontaneously within a few days. Special care must be taken in contact lens wearers or when the presence of an embedded corneal foreign body or corneal infection (e.g., corneal ulcer) is suspected. Since slit-lamp biomicroscopy, which is not available at Level I or II facilities, is necessary to evaluate and treat these conditions, such cases should be referred to an eye care professional (optometrist or ophthalmologist) when operationally feasible.

> In most cases, non-ophthalmic providers can safely manage corneal abrasions using a prophylactic topical antibiotic. If a superficial foreign body is embedded within or on the surface of the cornea, care must be taken to rule out corneal perforation.

Corneal Foreign Bodies

Combat casualties will often present with superficial foreign bodies embedded within or on the surface

Figure 20. *Corneal ulcer. Note the opaque white inflammatory infiltrate and overlying epithelial defect. Image courtesy of the University of Michigan Kellogg Eye Center.*

Figure 21. *This hyphema demonstrates extensive blood in the anterior chamber.*

of the cornea. Without the aid of a slit-lamp, it may be difficult to determine whether the foreign body has perforated the cornea, which is only 0.5 to 0.9 mm in thickness.[18] In cases where the foreign body is thought to be superficial, the first-line treatment should be irrigation of the eye with sterile saline or eye wash solution. If irrigation is unsuccessful, instrument removal of the foreign body should be performed by an eye care professional. However, if circumstances prevent this from occurring, only experienced nonopthalmic personnel should attempt removal of corneal foreign bodies, using slit-lamp or loupe magnification, and exercising extreme caution. Seidel testing should be performed following foreign body removal and topical antibiotics should be administered until the epitheleal defect has healed. Metallic foreign bodies can leave a rust ring in the cornea, which should be removed by an ophthalmologist, ideally within several days of the injury.

Hyphema

Hyphema is defined as the presence of blood in the anterior chamber, and is usually caused by blunt trauma, unless it is associated with an open-globe injury. The source of bleeding is usually from tears in the iris or ciliary body, and irregular mydriasis or iridodialysis (separation of the iris root) is often an associated finding. In sufficient quantity, the blood is grossly visible as it layers across the bottom of the anterior chamber (Fig. 21). Visual acuity can be affected, depending on the size of the hyphema, and pain and photophobia are often present as the result of coexisting injuries, such as traumatic iritis.

Most hyphemas resolve spontaneously and their treatment is usually nonoperative, consisting of observation, eye protection, and bed rest with head elevation. However, complications sometimes arise that require medical or surgical intervention. The greatest risk of vision loss from isolated hyphemas occurs with rebleeding, which usually occurs two to five days after injury. Permanent vision loss can result from hyphema-related complications, which include glaucoma, corneal bloodstaining, and ischemic optic neuropathy. Patients with sickle trait or disease are at particular risk for these complications, and all hyphema patients of African descent should undergo sickle screening if their status is unknown.

> Most hyphemas resolve spontaneously and their treatment is usually nonoperative, consisting of observation, eye protection, and bed rest with head elevation. Small hyphemas (occupying less than one-third of the anterior chamber) with normal vision and IOP can potentially be monitored for resolution at Level I or II facilities. Patients experiencing vision loss, increased IOP, or larger hyphemas (involving one-third or more of the anterior chamber) should be evacuated to a Level III facility for ophthalmologic management.

Small hyphemas (occupying less than one-third of the anterior chamber) with normal vision and IOP can potentially be monitored for resolution at Level I or II facilities, but eventual evaluation by an ophthalmologist is advisable. Patients with vision loss, increased IOP, or larger hyphemas (involving one-third or more of the anterior chamber) should be evacuated to a Level III facility for ophthalmologic management. Medical treatment includes topical steroids, cycloplegics, and IOP-lowering agents when necessary. Aminocaproic acid has been used to prevent rebleeding in select cases, but its marginal benefits must be weighed against the potential risks of clotting and stroke. Anterior chamber paracentesis with washout is indicated in cases with persistent IOP elevation despite maximal medical therapy, and a lower threshold for surgery is maintained for patients with sickle disease.

Traumatic Iritis

Blunt eye trauma can lead to irritation of the iris and ciliary body, inciting an inflammatory reaction within the anterior chamber known as traumatic iritis or iridocyclitis. Symptoms include deep eye pain, photophobia, and blurred vision. These symptoms may be delayed for 24 to 48 hours following the injury. Evaluation of these patients should include a complete slit-lamp exam, fundoscopic exam, and documentation of IOP. The key physical exam finding is a mild to severe anterior chamber reaction (cells and flare), which, as mentioned previously, can be best appreciated with an oblique slit beam through the slit-lamp biomicroscope. Additional findings include perilimbal injection (i.e., ciliary flush), photophobia, consensual photophobia (i.e., pain in the affected eye when light is shone in the opposite eye), and occasionally decreased vision. Other clues to the diagnosis include pain that does not improve with topical anesthetics and pain with accommodation.[19,20] Treatment regimens can include cycloplegic drops, topical steroids, or topical nonsteroidal antiinflammatory agents (NSAIDs). Isolated traumatic iritis is self-limited and carries a good prognosis, and in the absence of findings suggesting coexisting ocular injuries may be managed at Level I or II facilities. If symptoms worsen or fail to resolve within one week, ophthalmologic evaluation is indicated.

> In the absence of findings suggesting coexisting ocular injuries, isolated traumatic iritis is self-limited, carries a good prognosis, and may be managed at Level I or II facilities.

Lens Subluxation / Dislocation

Patients with lens subluxation or dislocation can present with a history of ocular trauma, distorted vision, monocular diplopia, and pain. Critical findings include a displaced lens on direct ophthalmoscopy, phacodonesis (i.e., quivering of the lens), and iridodonesis (i.e., quivering of the iris). Additional findings include cataract, acute pupillary block glaucoma, and acquired myopia. Partial disruption of the zonular fibers that support the lens will result in subluxation. A subluxed lens can still remain partially visible within the pupillary aperture. Complete disruption of the zonular fibers results in lens dislocation, where the lens may no longer be visible through the pupillary aperture.

> All patients with lens subluxations or dislocations warrant immediate ophthalmologic consultation.

A potential vision-threatening complication of lens dislocation is acute pupillary-block glaucoma.[21] This results from the dislocated lens preventing the aqueous from flowing from the posterior chamber through the pupil into the anterior chamber, which pushes the iris forward and closes the anterior chamber angle where the aqueous exits the eye. Traumatic cataract, another complication, may follow even the most trivial injury to the lens, and can be removed electively at Level IV or V facilities.[21]

Vitreous Hemorrhage

Vitreous hemorrhage may occur from a variety of mechanisms including iris injuries, ciliary body trauma, vitreous detachment, retinal vessel injury, and choroidal rupture.[22] Patients with vitreous hemorrhage can present with varying degrees of vision loss, ranging from hazy vision with cobwebs or floaters to bare light perception vision.

Visualizing blood within the vitreous cavity with direct or indirect ophthalmoscopy confirms the diagnosis of vitreous hemorrhage. It is important to document IOP measurements in these patients, as they are at risk for acute glaucoma. The treatment of vitreous hemorrhage involves bed rest (with head of bed elevation), a protective eye shield, and analgesics (avoiding aspirin and nonsteroidal antiinflammatory drugs). All vitreous hemorrhages, traumatic or otherwise, should be assumed to be secondary to retinal injury and referred for immediate ophthalmologic evaluation.

Retinal / Choroidal Injuries

Ocular trauma may result in a variety of retinal injuries including retinal breaks, retinal detachments, choroidal hemorrhage, and choroidal rupture.[23] Patients with retinal injuries may present with a recent or remote history of ocular trauma. Symptoms include floaters, photopsias (flashes of light), a curtain or shadow over the visual field, and varying degrees of vision loss. Peripheral retinal breaks may initially be asymptomatic only to later lead to retinal detachment. Detailed dilated fundoscopic examination by an ophthalmologist is necessary to diagnose most retinal injuries.

Commotio retinae (Berlin's edema) is a retinal injury resulting from a contrecoup mechanism of injury.[24] The injury is characterized by a transient whitening of the deep sensory retina following ocular trauma, which is visible on direct or indirect ophthalmoscopy. Patients present with variable degrees of vision loss, which is more severe with macular involvement. While there is no specific treatment for commotio retinae, most cases are self-limited and they rarely result in permanent vision loss.

> Patients with retinal injuries may present with a recent or remote history of ocular trauma. Symptoms include floaters, photopsias (flashes of light), a curtain or shadow over the visual field, and varying degrees of vision loss. Careproviders should be able to identify patients with signs or symptoms consistent with retinal injury and refer them for appropriate ophthalmologic consultation.

Combat casualty careproviders must maintain a high suspicion for retinal injuries in all patients with significant ocular trauma. The visual morbidity from delayed treatment of these injuries is high. Definitive diagnosis of these injuries is well beyond the scope of most physicians. Thus, providers should be able to identify patients with signs or symptoms consistent with retinal injury and refer them for appropriate ophthalmologic consultation. In some cases, specialized treatment must be performed within 24 to 72 hours of injury to optimize visual outcomes.[25]

Open-Globe Injuries

Overview

An open-globe injury is defined as any full-thickness violation of the cornea or sclera. While the distinction is largely semantic, a laceration generally implies direct violation by a sharp object, while rupture is usually used to describe the forceful splitting of the eye wall induced by blunt trauma. Foreign body penetration denotes the entry of an object without exiting the involved structure, while perforation indicates the complete through-and-through passage of the object.

Signs and symptoms of open-globe injury include loss of vision, hemorrhagic chemosis, anterior chamber asymmetry, intraocular hemorrhage (hyphema or vitreous hemorrhage), uveal prolapse, hypotony (IOP less than 5 mm Hg), positive Seidel test, and visible protrusion of a foreign body from the globe (Figs.

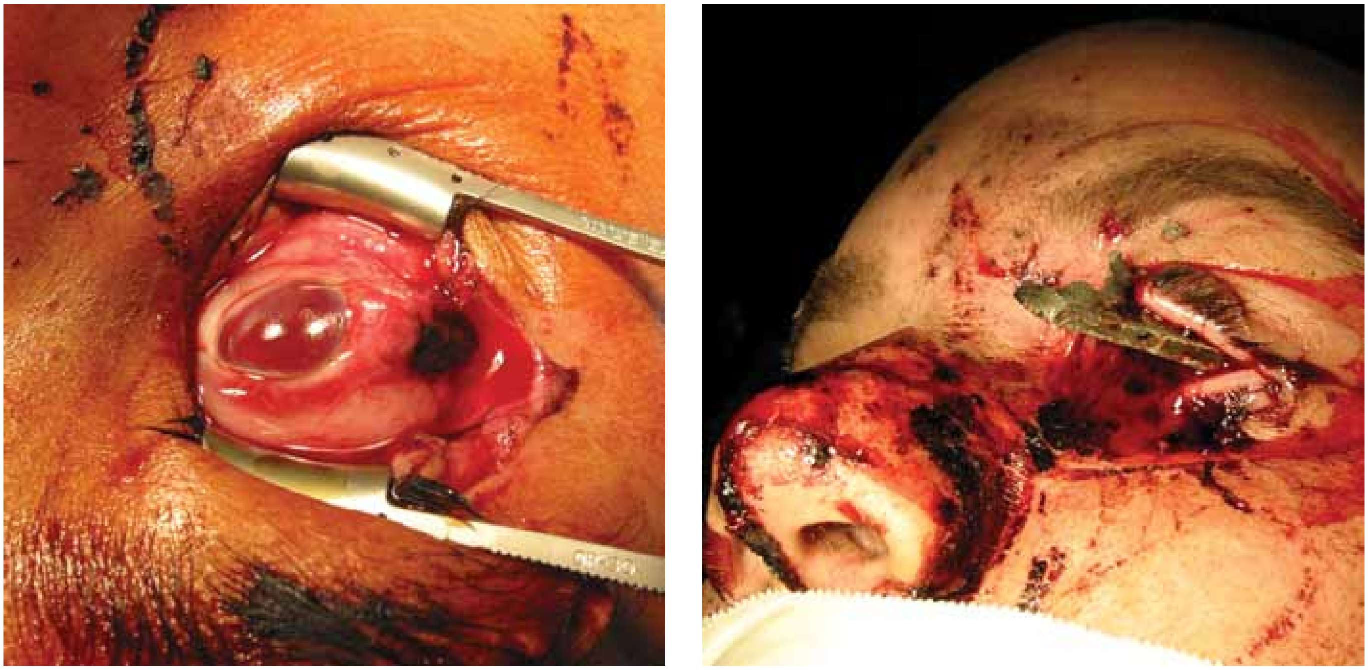


Figure 22. *Signs of open-globe injury:* (Left) *Uveal prolapse and misshapened globe.* (Right) *Protruding intraocular foreign body.*

16, 17, and 22). On CT scan, IOFB or air are diagnostic of open-globe injury, and globe deformation, intraocular hemorrhage, and lens disruption are highly suggestive (Fig. 23).

The prognosis for open-globe injury is highly variable and dependent on the severity of the injury. According to the Ocular Trauma Score, out of all the prognostic indicators for visual outcome, poor initial visual acuity (light perception or worse) is the most important negative predictor.[26] This is followed by globe rupture, endophthalmitis, perforating injury, retinal detachment, and afferent pupillary defect. The prognostic applicability of the Ocular Trauma Score to combat injuries was nicely validated by a study from OEF and OIF.[27] Corneoscleral laceration length and posterior extension more than five mm past the limbus are also negative predictors for globe survival. Barr reported an enucleation rate of 68 percent for globes with corneoscleral lacerations over 13 mm in length in contrast to only 4 percent with lacerations less than nine mm.[28]

An open-globe is defined as any full-thickness violation of the cornea or sclera. Signs and symptoms of open-globe injury include loss of vision, hemorrhagic chemosis, anterior chamber asymmetry, intraocular hemorrhage (hyphema or vitreous hemorrhage), uveal prolapse, hypotony (IOP less than five mm Hg), positive Seidel test, and visible protrusion of a foreign body from the globe. Casualties with open-globe injuries should undergo eye shielding and be evacuated to a Level III facility.

Initial Management of Open-Globe Injuries

Patients with signs and symptoms consistent with open-globe injury require emergent evacuation to a Level III facility for ophthalmologic evaluation. As described above, the eye should be protected with a Fox shield and the patient's tetanus status updated as needed. In anticipation of possible surgery, the patient's last meal should be recorded and they should receive nothing by mouth until they have been evaluated by an ophthalmologist. Pain, nausea, and anxiety should be treated if present, as excessive blepharospasm or valsalva can increase IOP and exacerbate open-globe injuries.

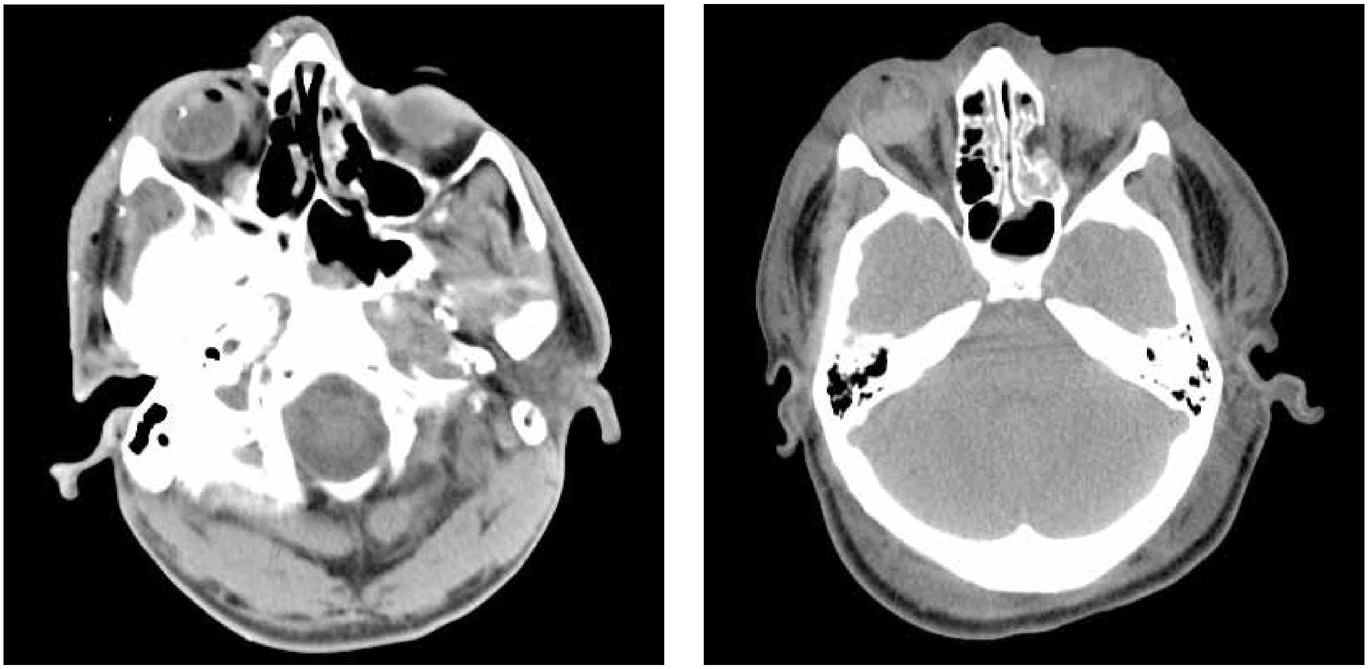


Figure 23. *CT scan findings in open-globe injury:* (Left) *Intraocular foreign body and air.* (Right) *Vitreous hemorrhage and lens disruption, right eye. Deformed and poorly defined globe, left eye.*

Open-Globe Injury Repair

The Level III ophthalmologist is responsible for the definitive treatment of open-globe injuries in the vast majority of cases. Even for the most experienced ophthalmologist, the diagnosis of open-globe injury is not always clear-cut, and the decision to take the patient to the operating room can be difficult. However, if any doubt exists, a low threshold for surgical exploration should be maintained. General anesthesia is required, as retrobulbar injection is clearly contraindicated. It has been suggested that the use of depolarizing paralytic agents is contraindicated in open-globe injuries due to the risk of increased IOP, but this has never been clearly demonstrated to be a problem.[29] Intraoperative findings dictate the extent of the exploration, but one can never be faulted for performing a 360-degree peritomy in order to directly visualize the entire scleral surface. Conjunctival traction sutures (e.g., 4-0 silk) placed at the oblique quadrants can improve surgical exposure dramatically (Fig. 24). Scleral lacerations often originate at or extend beneath the extraocular muscle insertions, and in these instances it is helpful to detach the muscle at its insertion in order to fully visualize and repair the defect. Double-armed 6-0 polyglactin sutures preplaced through the tendon can facilitate retraction and exposure of the field, as well as reattachment of the muscle to the globe at the end of the case.

The overarching principle in the treatment of open-globe injury is to restore the physical integrity of the globe wall. Every attempt should be made to reposit prolapsed intraocular structures prior to wound approximation. The exception to this rule is the crystalline lens, which should be removed if it is prolapsed into the anterior segment or out of the globe. Viscoelastics are quite useful in preventing incarceration of intraocular tissue in the wound during repair. Typically, 10-0 nylon suture is used in the cornea, 9-0 nylon at the limbus, and 8-0 nylon in the sclera. If the limbus is involved, it is generally the first structure to be sutured, being the most critical and easily recognizable anatomic landmark. Basic wound closure principles must be strictly observed, particularly in the cornea. These include: (1) vertical entry and exit

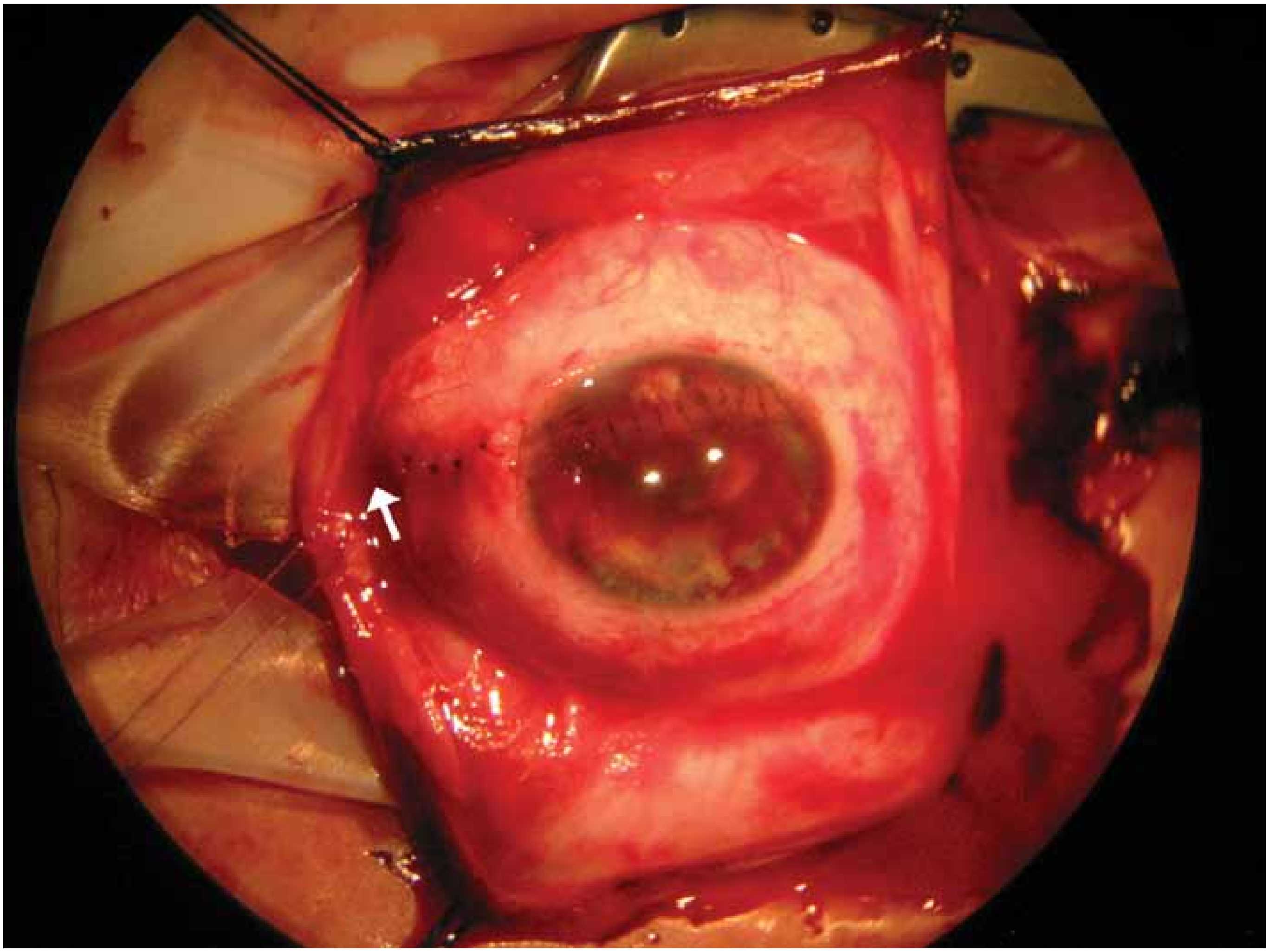


Figure 24. *Corneoscleral laceration repair, right eye. The scleral portion of the laceration extends posteriorly beneath the insertion of the medial rectus muscle, which has been tagged with a double-armed 6-0 polyglactin suture and detached. Note conjunctival traction sutures.*

of the needle point with respect to the corneal surface; (2) 90 percent-stromal-thickness suture passes; (3) exact matching of suture depth and width on each side of the wound; (4) orientation of each suture orthogonal to the wound axis; (5) proper and even spacing of interrupted sutures (space between each suture slightly less than the suture length); and (6) tying of sutures under proper tension (approximation, not strangulation). The use of the adjustable slipknot can greatly aid in achieving the last goal. All corneal suture knots should be buried and directed away from the visual axis if possible.

Occasionally, a watertight closure cannot be achieved with sutures alone, such as in corneal lacerations with a stellate pattern or tissue maceration. In these cases, cyanoacrylate glue can be very useful. Prior to applying the glue, any residual corneal epithelium should be removed from the surface to which the glue will be applied. Nylon 10-0 sutures can then be placed in a criss-crossing or grid pattern to create a scaffold across the defect. The glue is drawn up from the ampule in a tuberculin syringe and sparingly applied to the defect through a small-gauge needle. A completely dry wound surface is necessary for adherence of the glue, but this may be difficult to maintain in the presence of an aqueous leak. Viscoelastic, preferably a cohesive type, can be injected directly beneath the laceration to prevent the egress of fluid. A bandage contact lens should be placed after the glue is applied, and can subsequently be removed once the plug

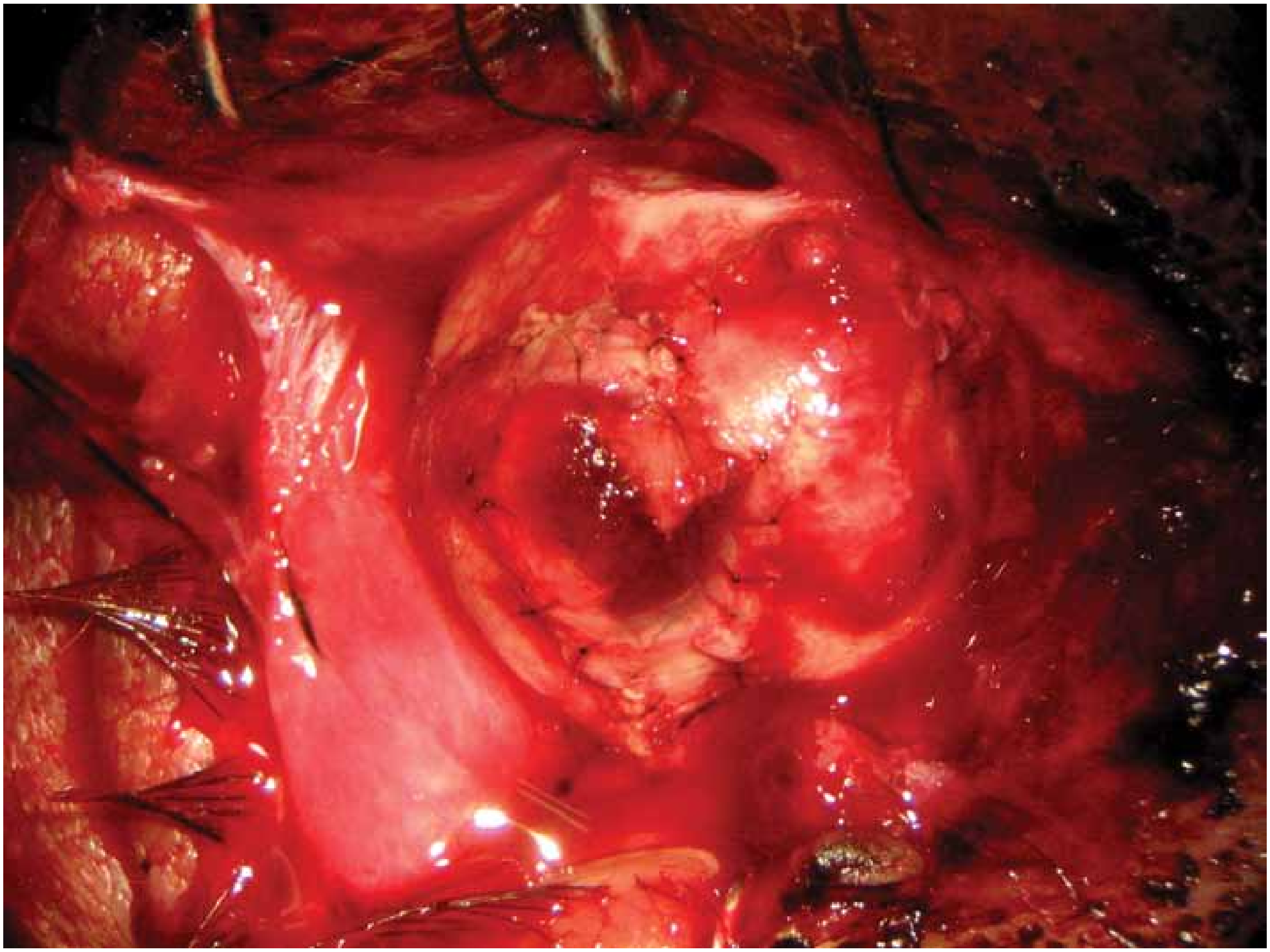


Figure 25. *Severe corneoscleral rupture with corneal tissue loss repaired with Tutoplast® patch graft.*

spontaneously detaches, usually within two to four weeks. Another option for the closure of wounds with damaged or missing tissue is the use of allografts or xenografts, such as acellular dermis or processed pericardium, which can be cut to the size and shape of the defect and sewn into place as a patch graft (Fig. 25).

The overarching principle in the treatment of open-globe injury is to restore the physical integrity of the globe wall. Every attempt should be made to reposit prolapsed intraocular structures prior to wound approximation.

In some cases, intraocular pathology may be addressed during primary globe repair if technically feasible. Foreign bodies in the anterior chamber or within easy reach of the anterior segment can often be safely removed. Disrupted lens material or prolapsed vitreous may also be removed at the discretion of the surgeon. However, as stated above, the primary goal of open-globe repair is to simply close the defect and allow the eye an opportunity for further rehabilitation in the future. Procedures that add surgical time or increase risk to the globe, such as posterior segment foreign body removal, retinal detachment repair, or intraocular lens implantation are not advisable under these circumstances.

Intraocular air may be found either clinically or radiographically in some penetrating globe injuries. While not a major treatment concern, the presence of air may potentially impact the patient's ability to safely undergo aeromedical evacuation, due to the expansion of gas within the globe at high altitude. However, this concern is mitigated by several factors: (1) the rise in IOP at altitude is dependent on the volume of air present within the globe, and studies indicate that eyes with less than 10 percent gas fill (0.6 milliliters) may safely undergo air travel; (2) the half-life of air in the human eye is only 1.3 days; and (3) most open globes, including those that have just undergone repair, are hypotonus and can accommodate moderate increases in IOP. [30,31,32] With these considerations in mind, it is advisable for the ophthalmologist to remove any air that is easily accessible during the course of open-globe injury repair. However, based upon the information provided above, volumes of retained intraocular air less than 0.6 milliliters (approximately 10 mm in diameter on CT scan) should not prevent aeromedical evacuation of a combat casualty.

Intraocular air may be found either clinically or radiographically following penetrating globe injuries. The presence of air may potentially impact the patient's ability to safely undergo aeromedical evacuation due to the expansion of gas within the globe at high altitude. Volumes of retained intraocular air less than 0.6 milliliters (approximately 10 mm in diameter on CT scan) should not prevent aeromedical evacuation of a combat casualty.

While definitive evidence proving benefit is lacking, prophylactic administration of systemic antibiotics is widely recommended for open-globe injuries.[33,34] A variety of single- or multiple-agent regimens have been used, including fluoroquinolones, cephalosporins, or beta-lactams. Topical antibiotics are also advisable. However, the use of intravitreal antibiotics on a prophylactic basis in this setting is of questionable value.[34] A study from OEF and OIF reported no cases of endophthalmitis in 79 eyes with retained IOFBs, despite the fact that only three of them received intravitreal antibiotics at the time of primary globe repair.[35]

Sympathetic Ophthalmia

An uncommon but potentially devastating complication of open-globe injury that can lead to blindness in the fellow eye is sympathetic ophthalmia. Defined as a diffuse bilateral granulomatous uveitis following penetrating globe injury, sympathetic ophthalmia is believed to represent an autoimmune response to the exposure of uveal or retinal antigens previously sequestered within the blood-aqueous or blood-retinal barrier. Incidence reports of sympathetic ophthalmia after wartime open-globe injuries vary widely from 0.02 to 56 percent.[36]

It is widely believed that sympathetic ophthalmia can be prevented by enucleating a severely damaged eye within two weeks of injury, although this time frame is largely based on anectodal data. Evisceration (i.e., removal of the contents of the globe) is generally discouraged in the setting of trauma, due to the potential presence of uveal proteins within the emissary canals of the retained scleral shell. The true risk of developing sympathetic ophthalmia if enucleation is not performed is unknown. Modern estimates of the overall incidence of sympathetic ophthalmia after open-globe injury (including patients who underwent enucleation) range from 0.3 to 1.9 percent.[36]

Globe Repair versus Enucleation

Repair of severe open-globe injuries should be attempted whenever technically feasible, unless proper follow-up care is doubtful. Deciding between primary globe repair and primary enucleation can sometimes be extremely difficult. In smaller globe lacerations where preoperative vision is at least light perception, the decision to repair is clear. On the opposite end of the spectrum, when a globe is so severely damaged that repair is not technically possible, enucleation must be performed to prevent sympathetic ophthalmia and socket contracture.[37,38] In the middle of the spectrum, however, the ophthalmologist will encounter cases in which repair is possible, but the ultimate prognosis for vision or globe survival is slim to nonexistent. In such cases, it is generally felt that repair should be attempted whenever technically feasible. The benefits to the patient are multiple: (1) the patient is assured that a reasonable effort was made to try to save the eye; (2) the lack of visual function despite repair is demonstrated to the patient; (3) the patient is included in the decision-making process leading to removal of the eye; and (4) the patient has time to come to terms with the loss of a major sensory organ before enucleation is performed. This guidance is appropriate in cases where the availability of proper follow-up and ophthalmic surgery can be reasonably assured, such as is the case for service members being evacuated to higher levels of care (Level IV and V facilities). However, if a patient in the same clinical situation may not be able to obtain proper follow-up care (e.g., host national in a country with no reliable health care system), primary enucleation may be more advisable for the patient's long-term welfare.

Repair of severe open-globe injuries should be attempted whenever technically feasible, unless proper follow-up care is doubtful.

Enucleation

Enucleation, defined as surgical removal of the entire globe, is typically performed under general anesthesia, although a retrobulbar block may be utilized if necessary. A 360-degree peritomy is performed, sparing as much conjunctiva as possible. Tenon's capsule is bluntly dissected from the sclera in the oblique quadrants with curved blunt scissors. The rectus muscles are isolated with muscle hooks, and double armed 5-0 or 6-0 polyglactin sutures can be preplaced before detaching them from the globe at their insertions. The oblique muscles are usually cut and not preserved, although some surgeons advocate attaching one or both of them to the orbital implant or to the rectus muscles (e.g., the superior oblique to the superior rectus and the inferior oblique to the lateral rectus). The globe is then retracted by the muscle stumps, with traction sutures (e.g., 4-0 silk passed through the limbus), or with an enucleation spoon, and the optic nerve is strummed and cut with curved scissors (Fig. 26). The length of the optic nerve segment is not critical, as long as the nerve is severed distal to its entrance into the globe. Clamping or cauterizing the optic nerve prior to cutting it may assist in hemostasis. Once adequate hemostasis is achieved by packing with cold-soaked gauze or other hemostatic materials, orbital implant sizers can be used to determine the appropriate implant size. The implant should provide adequate volume replacement while at the same time rest easily within Tenon's capsule without placing undue tension on the Tenon's closure. For ideal orbital volume replacement, the optimal implant

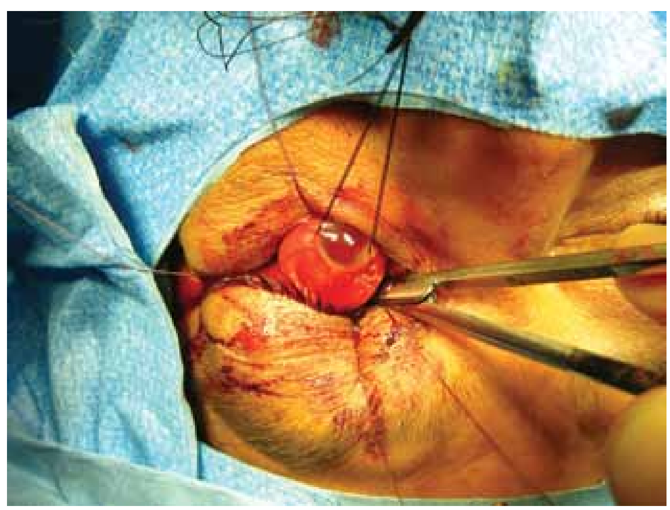


Figure 26. *Enucleation of globe. The four rectus muscles are tagged with 5-0 polyglactin sutures. The globe is retracted with 4-0 silk sutures passed through the limbus as the optic nerve is cut.*

diameter should be approximately two mm less than the axial length of the globe.[39] Given that the average axial length of the adult globe is approximately 24 mm, most orbital implants should be between 20 and 22 mm in diameter, although a smaller size may be used if there is tissue loss or a specific concern for implant extrusion. Care should be taken in the presence of large orbital fractures, which may need to be repaired in order to prevent implant migration into the maxillary or ethmoid sinus. Much debate remains regarding the ideal orbital implant material, and there is insufficient data in the literature to definitively recommend one type over another. Once the implant is placed within Tenon's capsule, the extraocular muscles can be attached to the anterior surface of the implant in order to maximize postoperative motility. Tenon's capsule and conjunctiva are then closed over the implant with absorbable sutures. Separate layered closure of posterior Tenon's capsule (with 4-0 polyglactin) and anterior Tenon's (with 5-0 or 6-0 polyglactin) may decrease the risk of postoperative implant extrusion. A conformer is placed into the socket with antibiotic ointment, and some surgeons perform a temporary suture tarsorrhaphy, which can be left in place for up to three weeks. A pressure patch may also be applied for two to three days to limit postoperative edema. Six to eight weeks of postoperative healing should be allowed before ocular prosthesis fitting is attempted.

Intraocular Foreign Body (IOFB)

By definition, IOFBs are open-globe injuries, and the signs and symptoms are the same as those described at the beginning of this chapter segment. However, the severity of IOFB injuries varies widely, and as one would expect is largely dependent on the size of the offending object. Intraocular foreign bodies should be suspected with blast injury mechanisms, sanding, drilling, grinding, or hammering metal-on-metal. High-velocity metal or glass splinters may enter the eye painlessly. The initial ocular examination may appear deceptively benign, revealing only slight injection or local discomfort (Fig. 27). Visual acuity is typically decreased, but can be normal. Some corneal or scleral perforations can be difficult to detect. Additional findings suggestive of an IOFB include conjunctival chemosis, hyphema, localized cataract, iris injury, pupillary asymmetry, vitreous hemorrhage, decreased IOP, or an aqueous humor leak (as evidenced by a positive Seidel test). CT scanning is helpful in identifying IOFBs in eyes with opaque media. Although small pieces of wood, glass, or plastic may not be seen on CT, the majority of IOFBs can be visualized. The utility of ultrasonography for detecting IOFBs in the setting of open-globe injury is limited by the need to avoid direct pressure to the injured globe.

Figure 27. *Penetrating globe injury caused by a rocket-propelled grenade blast fragment.* (Left) *Anterior segment exam appears relatively benign with mild focal corneal edema seen in the inferior cornea.* (Right) *Posterior segment IOFB is visible on CT scan.*

Intraocular foreign bodies are open-globe injuries and should be suspected with blast injury mechanisms, sanding, drilling, grinding, or hammering metal-on-metal. Level III facility-based ophthalmologists should only remove IOFBs that are easily accessible within the anterior segment. Posterior segment foreign bodies should be left for potential future removal by a vitreoretinal specialist at Level IV or V facilities.

Management of IOFBs depends on the foreign body size, composition, and location within the eye.[40,41] The reactivity of IOFBs is highly variable. Wood, vegetable matter, and metals such as iron, copper, and steel typically incite an intense inflammatory reaction when left in the eye, and surgical removal is indicated.[42] On the other hand, inert foreign bodies such as glass, lead, plaster, rubber, silver, and stone, are often left in the eye if they are minimally symptomatic.[43] As stated above, Level III facility-based ophthalmologists should only remove IOFBs that are easily accessible from the anterior segment. Posterior segment foreign bodies should be left for potential future removal by a vitreoretinal specialist at Level IV or V facilities.

Ocular Adnexal Trauma

Eyelid Lacerations

Lacerations of the eyelid and periocular region are common in combat injuries, and can be seen in isolation or concomitantly with other ocular injuries (Fig. 28). Proper eyelid function is critical to preserving vision and maintaining the health of the ocular surface and cornea. The most important discriminating factor in the management of eyelid lacerations is involvement of the lid margin.[44] This will be manifested as notching or gaping along the lid contour due to violation of the tarsal plate, the dense connective tissue that provides structural support to the eyelid. Orbital fat prolapsing thru an eyelid laceration is indicative of violation of the orbital septum.

Partial-thickness eyelid lacerations that do not involve the lid margin or violate orbital septum can be repaired by careproviders at Level I or II facilities. Absorbable 6-0 or nonabsorbable sutures are generally used, and layered closure is recommended for absorbable sutures. Full-thickness lid lacerations should be repaired at the earliest opportunity by an ophthalmic surgeon at a Level III facility, preferably within 24 to 48 hours of injury. If ocular surface exposure is evident prior to evacuation, a lubricating eye ointment should be instilled until repair of the laceration can be performed.

The principles of lid laceration repair are simple: (1) reapproximation of vital anatomic landmarks, especially the lid margin; (2) preservation of tissues; and (3) avoidance of vertical tension on the lids. While in many other body sites, debridement of devitalized or necrotic-appearing tissue is advocated, such is not the case with the eyelids. Due to their excellent vascular supply, eyelid tissues that appear to be unsalvageable may end up surviving after being anatomically restored. It is also common for lacerated eyelid tissues to roll up or retract, giving the false impression of tissue loss. Careful wound exploration often reveals the presence of tissue previously thought to be missing, making repair or reconstruction much more achievable (Fig. 29).

Partial-thickness eyelid lacerations that do not involve the lid margin or violate orbital septum can be repaired by careproviders at Level I or II facilities. Full-thickness lid lacerations should be repaired by an ophthalmologist or facial plastic surgeon. Canalicular involvement must be ruled out in medial eyelid lacerations.

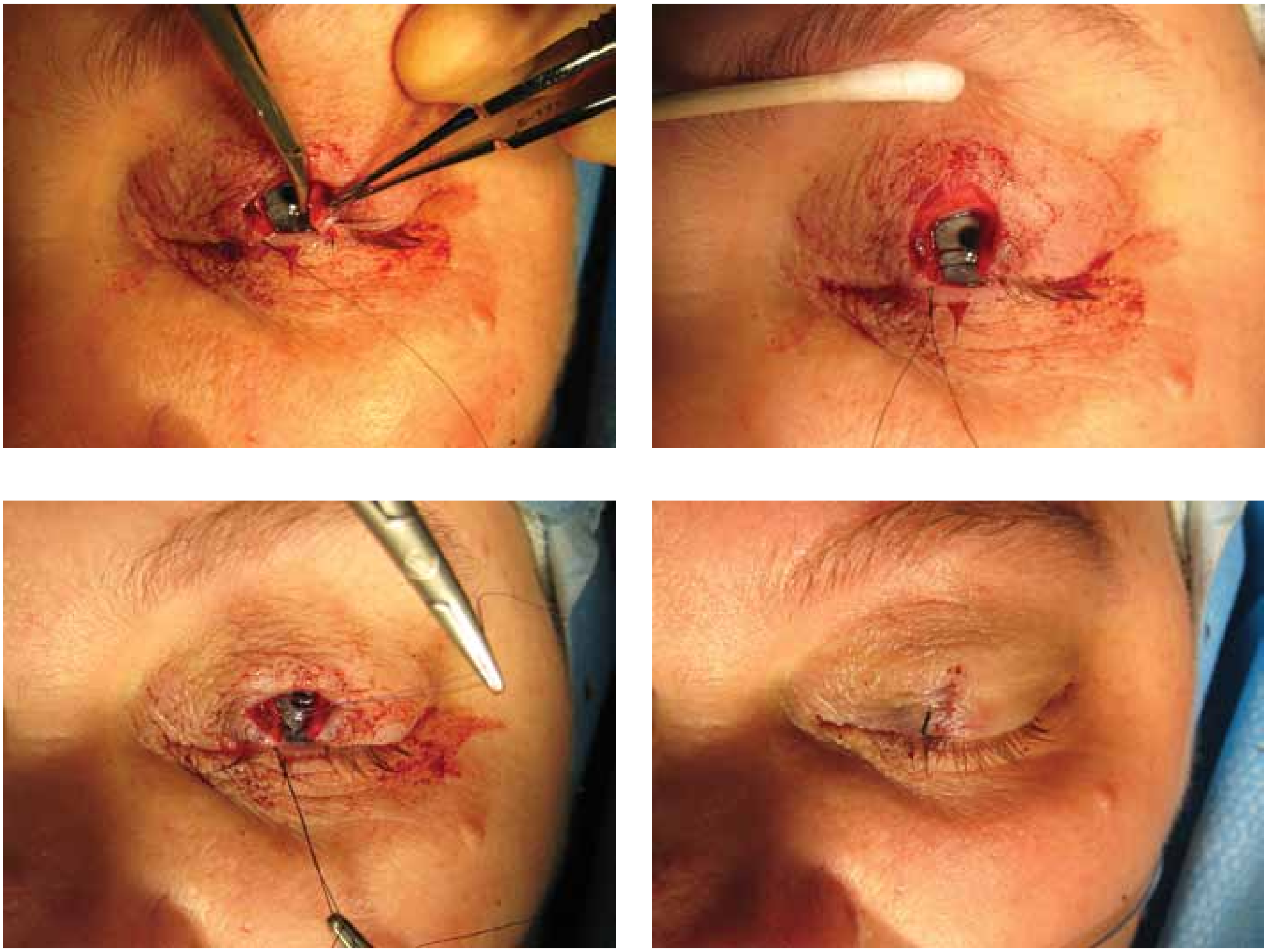


Figure 28. *Stepwise repair of a full-thickness eyelid laceration (demonstrated following a full-thickness wedge resection of the upper lid):* (Top Left) *A 6-0 silk suture is passed through the gray line on both sides of the defect, taking healthy bites of the tarsal plate.* (Top Right) *The same suture is passed in a vertical mattress fashion.* (Bottom Left) *The remainder of the tarsus is repaired with partial thickness passes of 6-0 polyglactin.* (Bottom Right) *The skin is closed with 6-0 fast-absorbing gut sutures. The tails of the margin sutures can be secured with the skin sutures to prevent them from contacting the cornea.*

Repair of full-thickness lid lacerations should begin with approximation of the wound at the lid margin. This is typically performed at the gray line in a vertical mattress fashion with 5-0 or 6-0 silk or polyglactin suture. Additional margin sutures can be placed in similar fashion at the posterior and/or anterior lash lines. To avoid contact with the ocular surface, the suture tails can be cut long and tied down with the tails of the more anterior sutures. Deep absorbable sutures (e.g., 6-0 polyglactin) should also be used to repair the tarsus. The orbicularis and skin can be closed with any of a number of braided or monofilament sutures.

With lacerations involving the medial eyelid, damage to the lacrimal drainage system should be suspected. This can be confirmed by canalicular probing with or without irrigation. Canalicular lacerations should be repaired over a silicone stent (e.g., Crawford tubes), which can either be placed through the entire nasolacrimal duct system, through the upper and lower canaliculi with a pigtail probe, or through the involved canaliculus alone with a monocanalicular stent. The latter option should only be used in proximal

Figure 29. (Left) *Preoperative photograph of a patient who sustained a chainsaw injury to the left globe and orbit. At first glance, a significant amount of tissue appears to be missing, but careful wound exploration revealed minimal tissue loss, and primary repair was successfully accomplished. The globe was repaired prior to eyelid reconstruction.* (Right) *Postoperative photograph.*

canalicular lacerations with a normal punctum. Once the canaliculus is intubated, the pericanalicular tissues are approximated with 7-0 or 8-0 polyglactin suture. It should be remembered that damage to the medial canthal tendon is often seen with canalicular lacerations. Repair of both the posterior and anterior cruri of the medial canthal tendon should be performed as necessary.

Occasionally, lid lacerations will be encountered in association with an open-globe injury or proptotic eye. In these cases, it may be advisable to perform a lateral canthotomy and cantholysis to relieve the pressure on the globe and decrease the tension on the lid repair. If a significant amount of eyelid tissue is lost, reconstruction may be attempted depending on the expertise and comfort level of the ophthalmologist. However, it is acceptable to perform a temporary suture tarsorrhaphy and evacuate the patient to Level IV or V facility, where ophthalmic plastic and reconstructive surgery services are available.

Conjunctival Lacerations

Patients with conjunctival lacerations following ocular trauma may present with eye pain, foreign body sensation, and conjunctival injection or hemorrhage. Physical exam often reveals a conjunctival laceration upon white light examination. The damaged conjunctiva typically folds over on itself at the site of the laceration providing an unobstructed view of exposed white sclera. The damaged region of conjunctiva may fluoresce bright yellow-green following fluorescein staining and cobalt blue light illumination. The presence of a conjunctival laceration should raise the suspicion of potential open-globe injury and/or IOFB, and merits evaluation by an ophthalmologist.

> Patients with small conjunctival defects, less than one centimeter (cm), will typically heal without surgical intervention. Patients with conjunctival defects larger than one cm will often need surgical repair, which should be performed by an ophthalmologist.[45] Aftercare involves topical antibiotic administration for up to one week until the affected area has healed.

Orbital Trauma

Retrobulbar Hemorrhage

Retrobulbar hemorrhage is typically caused by blunt trauma to the orbit, and frequently results in an acute orbital compartment syndrome, a true ocular emergency.[46,47] Another potential cause of orbital compartment syndrome in the setting of trauma is third-spacing of fluid into the orbit following massive fluid resuscitation for burn patients. Signs and symptoms of orbital compartment syndrome include acute vision loss, eye pain, headache, proptosis, resistance to retropulsion, increased IOP (typically over 40 mm Hg), afferent pupillary defect, ophthalmoplegia (loss of extraocular motility), and hemorrhagic chemosis. When orbital compartment syndrome is suspected clinically, lateral canthotomy and inferior cantholysis should be performed immediately. Timing is critical, as experimental studies suggest that permanent vision loss occurs with orbital ischemia lasting greater than 100 minutes.[48] While imaging studies can help to confirm the presence of retrobulbar hemorrhage, the diagnosis of orbital compartment syndrome is clinical, and treatment should not be delayed to obtain a CT scan (Fig. 30).

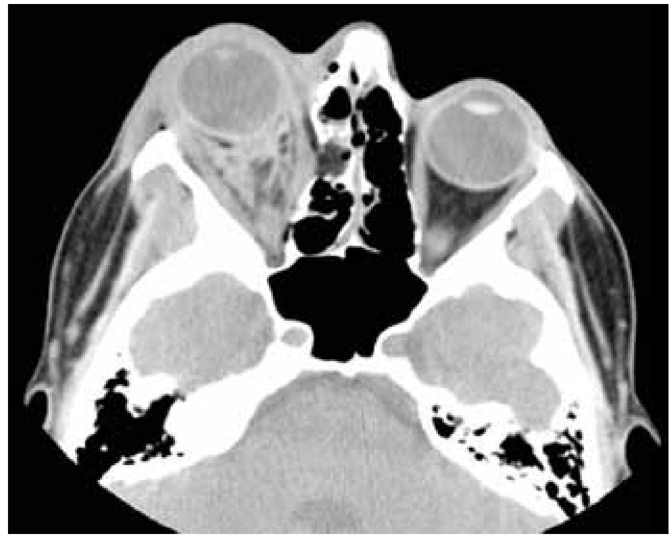


Figure 30. *CT scan appearance of right retrobulbar hemorrhage. Note the loculated pattern of blood within the orbital fat, posterior tenting of the globe from optic nerve traction, and severe proptosis.*

The goal of lateral canthotomy and inferior cantholysis is to convert the orbit from a closed to an open compartment by releasing the attachment of the lower lid to the lateral orbital rim (Fig. 31). Scissors are used to make a horizontal cut from the lateral commissure to the orbital rim, effectively separating the lateral canthal tendon into its superior and inferior portions (lateral canthotomy). The lower lid is then grasped with forceps and pulled away from the rim to place the lateral canthal tendon under tension, and the tendon is "strummed" and cut with scissors (inferior cantholysis). The hand grasping the lid during this maneuver should feel an immediate release when the tendon is cut. Significant drainage of blood from the orbit is not necessary for the procedure to be effective, nor is it expected. However, if the decompressive effect from the inferior cantholysis is insufficient, a superior cantholysis can be performed by releasing the upper lid in the same manner as the lower. The efficacy of the treatment can be assessed soon after the procedure through repeat IOP measurements and visual acuity assessment.

> Retrobulbar hemorrhage is typically caused by blunt trauma to the orbit, and frequently results in an acute orbital compartment syndrome, a true ocular emergency. When orbital compartment syndrome is suspected clinically, lateral canthotomy and inferior cantholysis should be performed immediately. There is no other procedure in all of ophthalmology that can more simply, quickly, and dramatically treat and prevent such devastating vision loss and so profoundly impact a patient's final visual outcome.

If orbital ischemia persists despite complete inferior and superior cantholysis, additional maneuvers may be attempted. Blunt scissors can be placed through the canthotomy incision and used to spread the orbital fat in

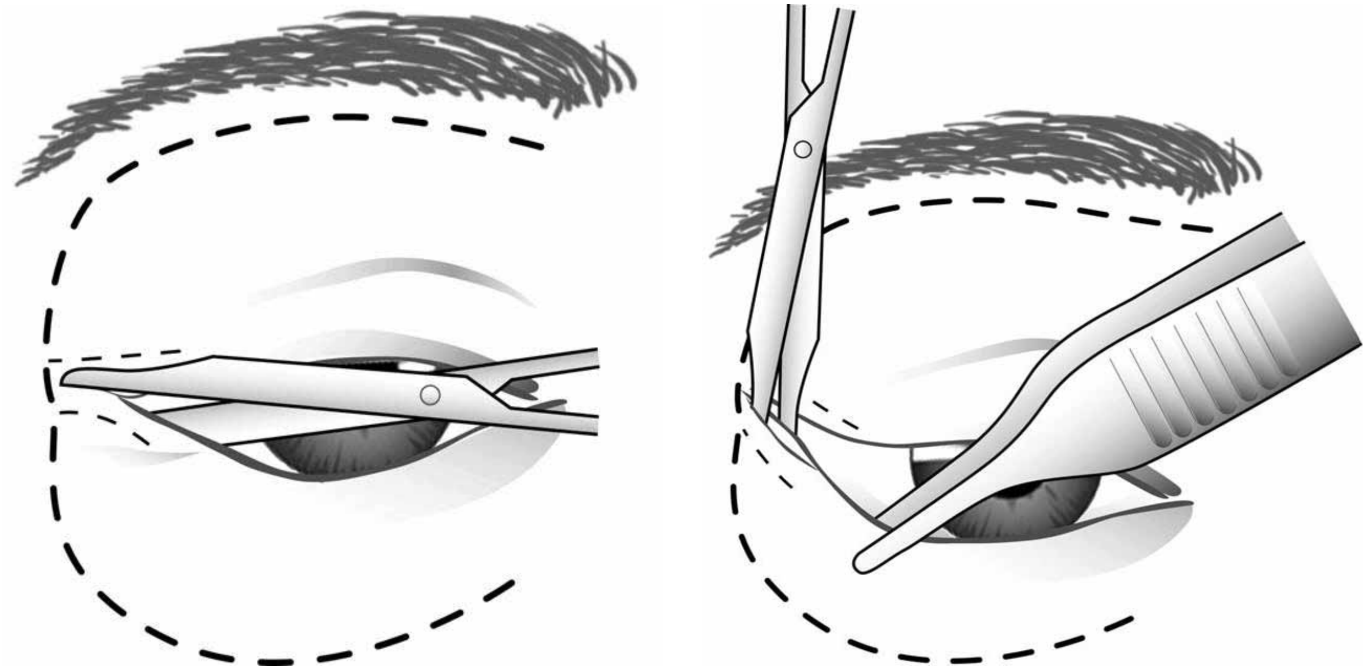


Figure 31. *Lateral canthotomy and inferior cantholysis. Heavy dotted line represents the orbital rim, lighter dotted lines represent the superior and inferior cruri of the lateral canthal tendon.* (Left) *The lateral canthotomy is created by cutting horizontally from the lateral commissure to the lateral orbital rim.* (Right) *The lower lid is distracted away from the lateral orbital rim and the inferior crus of the lateral canthal tendon is cut, separating the lower lid from the lateral orbital rim. Image courtesy of Juan D. Nava, Medical Illustrator, Brooke Army Medical Center.*

the inferotemporal quadrant, releasing any pockets of loculated blood within the orbit.[49] If this maneuver fails, the patient may be taken to the operating room for formal orbitotomy and decompression by whatever means necessary. Medical therapy with intraocular-pressure-lowering agents such as osmotics or aqueous suppressants may also be considered.

The value of canthotomy and cantholysis in the setting of orbital compartment syndrome cannot be overstated. There is no other procedure in all of ophthalmology that can more simply, quickly, and dramatically treat and prevent such devastating vision loss and so profoundly impact a patient's final visual outcome. Performed promptly enough, it can literally make the difference between no-light-perception and 20/20 vision. Given the time-critical nature of this condition, ophthalmologists are strongly encouraged to train fellow CCC providers on the indications for and use of this simple technique.

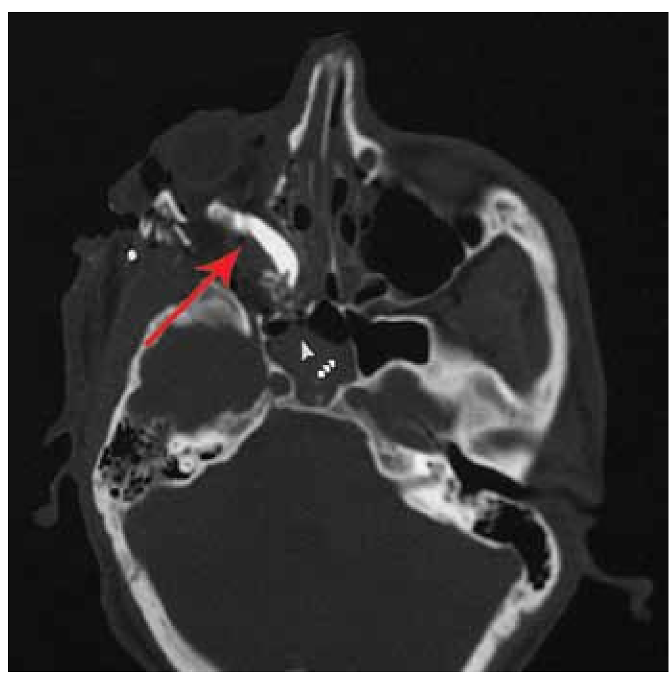


Figure 32. *Orbital foreign body sustained from a blast injury.*

Orbital Foreign Bodies

Penetrating orbital injury from projectiles or stab injuries can result in retained orbital foreign bodies (Fig. 32). Patients typically present with varying degrees of periocular edema/ecchymosis, proptosis, impaired ocular motility, decreased vision, and pain. Orbital compartment syndrome can also result, and must be managed in the manner described above. As is the case with IOFBs, the composition of the object is important in predicting its long-term tolerability within the orbit and determining the need for removal. Removal of organic foreign bodies is generally recommended, while inorganic foreign bodies can in many cases be observed.[50] Complications of orbital foreign bodies include vision loss, proptosis, diplopia, cellulitis, or a chronic draining fistula. Foreign body removal can be attempted in such cases, although the unique anatomy of the orbit can make this procedure technically difficult, and it should only be performed by an experienced orbital surgeon. The use of intraoperative fluoroscopy has been described as an adjunct to increase the ease of orbital foreign body removal.[51]

Orbital Fractures

Diagnosis and management of orbital fractures are covered in detail in the Maxillofacial and Neck Trauma chapter.

Miscellaneous Ocular Injuries

Chemical Eye Injuries

Chemical exposure of the eye is a true ophthalmologic emergency and may occur with acid or alkali agents. The resulting damage to the eyelids, conjunctiva, cornea, and anterior segment structures may produce permanent visual impairment. In general, alkali burns are more severe than acid burns.[52] Alkali burns cause a liquefactive necrosis, saponifying corneal proteins and initiating corneal collagen destruction. Acid burns cause injury through coagulation necrosis and tend to precipitate corneal proteins, which serve to limit penetration of the acid. Alkali agents are found in more commercially available products than acids, making alkali exposure a relatively more frequent occurrence. Exposure of the eyes to chemical warfare agents is also an ocular emergency. Blistering agents such as mustard gas are particularly toxic to the ocular surface, and the acute management of exposure to these agents mirrors that for standard chemical exposures.

A patient who presents with chemical exposure should undergo immediate copious irrigation of the eye before any time is wasted on additional history and physical examination.[53] In terms of efficacy, no therapeutic difference exists between normal saline, normal saline with bicarbonate, lactated Ringer's solution, or balanced salt solution.[54] Irrigation with a minimum of one liter of irrigating solution is recommended. During irrigation, the lids should be retracted and the stream of irrigating fluid should be directed onto the globe and conjunctival fornices. The fornices should be carefully swabbed to remove any chemical particulate matter. Topical anesthesia will facilitate these maneuvers. Irrigation should continue until the pH of the tear film obtained at the inferior conjunctival fornix is neutral, as measured with litmus paper or the pH indicator of a urine dipstick.[55] Waiting several minutes after completion of irrigation will allow for pH equilibration. No attempt should be made to neutralize chemicals with either acids or alkalis. The immediate irrigation of metallic sodium, metallic potassium, or yellow or white phosphorous has the theoretic potential to initiate further chemical injury. Despite this concern, authorities still recommend copious irrigation of eyes exposed to these chemicals.[53]

Chemical injury to the eye is a true ophthalmologic emergency and may occur with acid or alkali agents. A patient who presents following chemical exposure should undergo immediate copious irrigation of the eye before any time is wasted on additional history and physical examination.

The severity of a chemical eye injury is related to the type of chemical, surface area of contact, duration of chemical contact, and depth of chemical penetration. If an epithelial defect is highly suspected but none is found on initial staining with fluorescein, the procedure should be repeated, as sloughing of the corneal basement membrane may result in delayed fluorescein uptake. The ultimate prognosis depends on the loss of corneal clarity and degree of limbal ischemia, graded on a scale of I to IV. Patients with mild injuries (grade I) may be treated with a cycloplegic (avoiding mydriatics such as phenylephrine due to their vasoconstrictor effects), a topical antibiotic (e.g., erythromycin), and oral pain medication. These patients should be seen by an ophthalmologist daily until healing is documented, after which they may return to duty in the absence of visually significant complications. Patients with moderate to severe injuries (grades II to IV) warrant emergent ophthalmologic assessment and evacuation out-of-theater. Subsequent treatment will focus on lysis of adhesions, minimizing infection potential, and treatment of iritis and elevated IOP. Long-term complications of chemical injuries include corneal scarring and neovascularization, adhesions of the lids to the globe (symblepharon), glaucoma, cataracts, and retinal necrosis.

Traumatic Optic Neuropathy

Traumatic optic neuropathy (i.e., injury to the optic nerve) may occur with blunt or penetrating ocular trauma. It is often associated with a blow to the eyebrow or forehead, the force of which can be transmitted through the orbital roof to the optic canal. Patients with traumatic optic neuropathy typically note an immediate and profound loss of vision and present with an afferent papillary defect.[56] The optic disc usually appears normal upon initial fundoscopic examination, as optic disc pallor can take several weeks to develop following the injury. The underlying etiology of nerve injury may be nerve compression, transection, or ischemic injury.[57] The diagnosis of traumatic optic neuropathy is typically made only after other causes of vision loss are excluded by an ophthalmologist. Computed tomography imaging often shows associated orbital fractures, but radiographically evident optic canal fractures are much less common.[58] Therapeutic options for traumatic optic neuropathy include high-dose corticosteroids or surgical decompression of the optic nerve if impingement is suspected. However, controversy remains over the efficacy of these treatments. The International Optic Nerve Trauma Study, the most extensive prospective study of traumatic optic neuropathy to date, showed no definitive benefit from either steroids or surgery, and both of these modalities can pose significant potential risks to the multisystem trauma patient.[59] The decision to treat should be individualized for each patient, taking into account their ocular status, mechanism of injury, presence of fracture on CT scan, and comorbid conditions.

Traumatic optic neuropathy may occur following blunt or penetrating ocular trauma. Patients with traumatic optic neuropathy typically note an immediate and profound loss of vision and present with an afferent papillary defect.

Summary

The basic principles of ocular trauma management in combat do not differ significantly from those followed in the civilian sector. Recent developments during OEF and OIF in casualty evacuation and combat trauma systems have facilitated the delivery of ocular trauma care which replicates the standards of care maintained in civilian trauma system. However, the overall severity and complexity of these injuries are generally much greater in combat, calling for the utmost skill and dedication from military ophthalmologists and other combat health support personnel. Combat casualty care providers at Level I and II facilities must be able to recognize ocular injuries that require further evacuation and take appropriate steps to protect the eye during transport. Ophthalmologists at Level III facilities must be prepared to make difficult clinical decisions and perform technically challenging surgery within the physical and operational constraints of the theater level hospital. Every attempt should be made to repair open-globe injuries, except for severely ruptured globes in patients for whom proper access to further ophthalmologic care is doubtful. Given the frequent association of ocular injuries with head, face, and neck injuries, ophthalmologists should expect to work in close conjunction with surgeons in other specialties, particularly neurosurgery, otolaryngology, oral maxillofacial surgery, and facial plastic surgery.

Case Studies

Case 1

A 26-year-old male enlisted soldier arrived intubated at a Level III hospital after sustaining a blast injury to his head and face from an IED. Examination of his right eye revealed a large perilimbal scleral laceration with uveal prolapse and a large complex laceration to his right upper eyelid and brow (Fig. 33). His left eye was markedly proptotic and resistant to retropulsion, with marked upper eyelid edema and ecchymosis, a mid-dilated non-reactive pupil, and inferior hemorrhagic chemosis (Fig. 34). Based

Figure 33. *Preoperative photograph of a combat casualty following blast injury to the head and face from an IED.*

Figure 34. *Left eye proptosis, lid ecchymosis, hemorrhagic chemosis, and mid-dilated pupil indicative of retrobulbar hemorrhage. Lateral canthotomy and inferior cantholysis have been performed.*

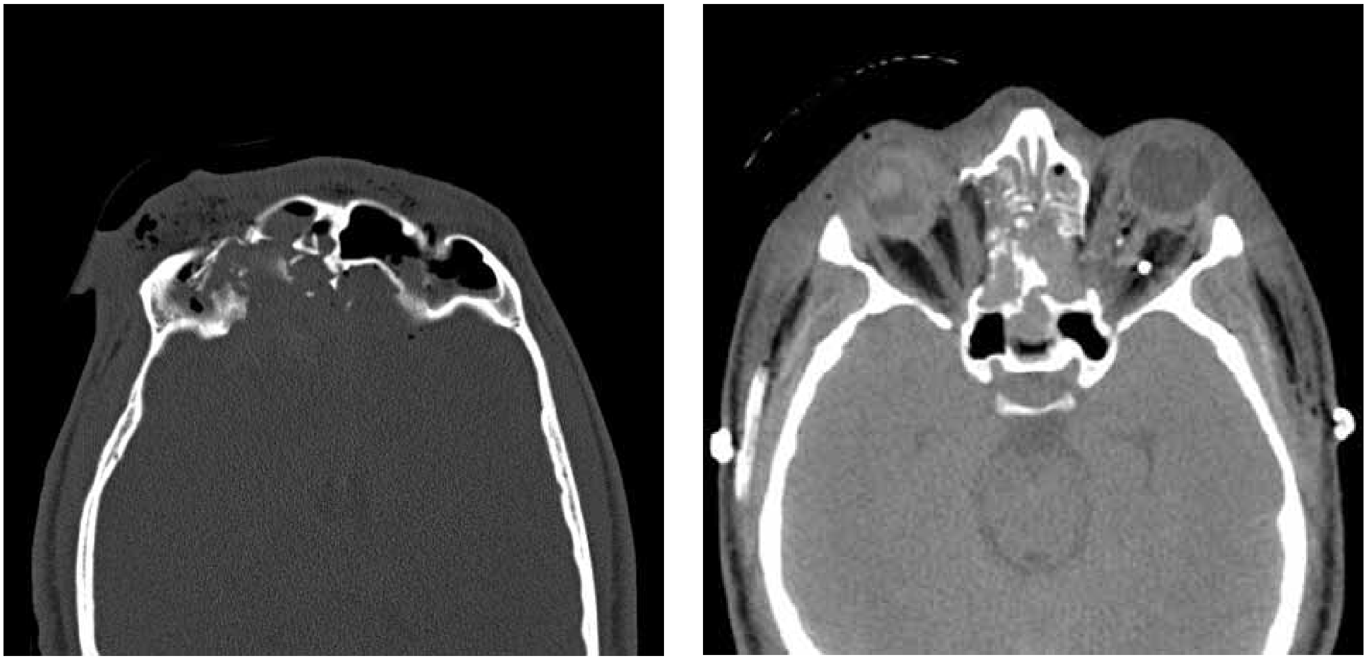


Figure 35. *Computed tomography image showing:* (Left) *Severe bilateral frontal sinus fractures and frontal lobe injury.* (Right) *Deformed right globe with intraocular hemorrhage, bilateral ethmoid fractures, and left retrobulbar hemorrhage with intraorbital foreign body. The foreign body has passed through the right orbit and both ethmoid sinuses and entered the left orbit.*

on these clinical findings, a left orbital compartment syndrome was suspected and a lateral canthotomy and inferior cantholysis were immediately performed in the emergency room. Subsequent CT scan revealed a misshapened right globe with lens disruption and vitreous hemorrhage, fractures of both ethmoid sinuses with a metallic foreign body and retrobulbar hemorrhage in the left orbit, fractures of both frontal sinuses, and a penetrating injury of the right frontal lobe (Fig. 35).

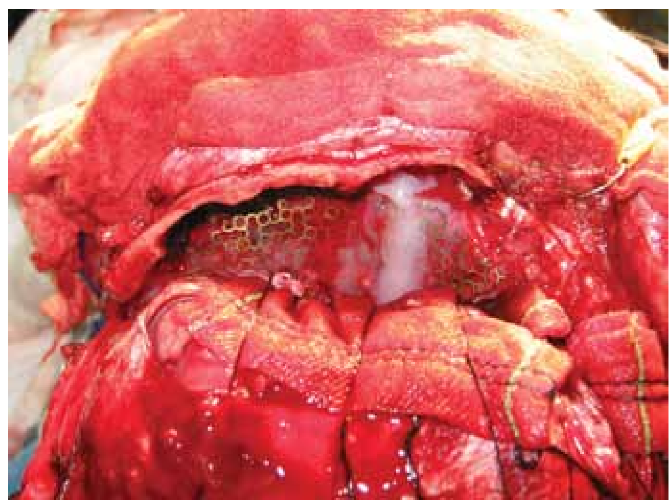


Figure 36. *Intraoperative view of frontal craniotomy showing bilateral frontal sinus cranialization and repair of floor of anterior cranial fossa.*

The patient was emergently taken to the operating room, where a craniotomy was performed with a partial right frontal lobectomy, cranialization of the frontal sinuses, and reconstruction of the floor of the anterior cranial fossa with titanium mesh, fibrin tissue sealant, and a pericranial graft (Fig. 36). Attention was then turned to the right eye, where a 25 mm scleral laceration was repaired with 8-0 nylon sutures after repositing the prolapsed ciliary body back into the globe (Fig. 37). The right upper lid and brow laceration were then addressed (Fig. 38). A lateral canthotomy and superior cantholysis were first performed in order to reduce the tension on the eyelid reconstruction and prevent undue pressure on the freshly repaired globe. The tarsus was then repaired with interrupted 6-0 polyglactin sutures, taking 90 percent-thickness bites of the tarsus and tying the knots on the anterior side. The lid margin was approximated at the gray line and lash line with 6-0 silk sutures. The remainder of the upper lid and brow laceration was repaired in layers with deep 5-0 polydiaxanone sutures

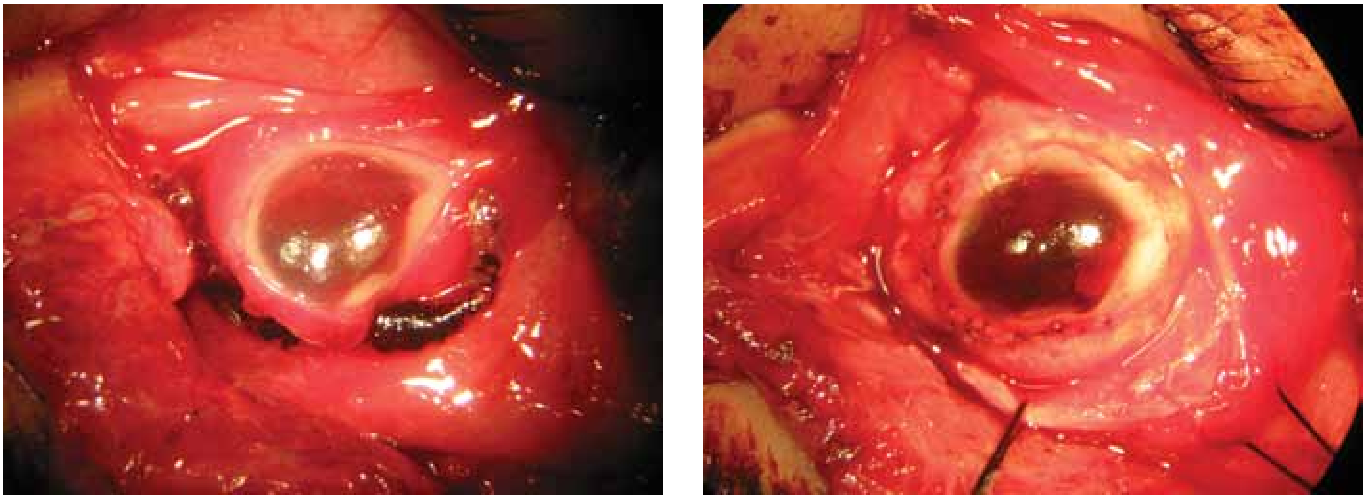


Figure 37. *Intraoperative photograph of right globe before* (Left) *and after* (Right) *scleral laceration repair. Note the prolapsed ciliary body.*

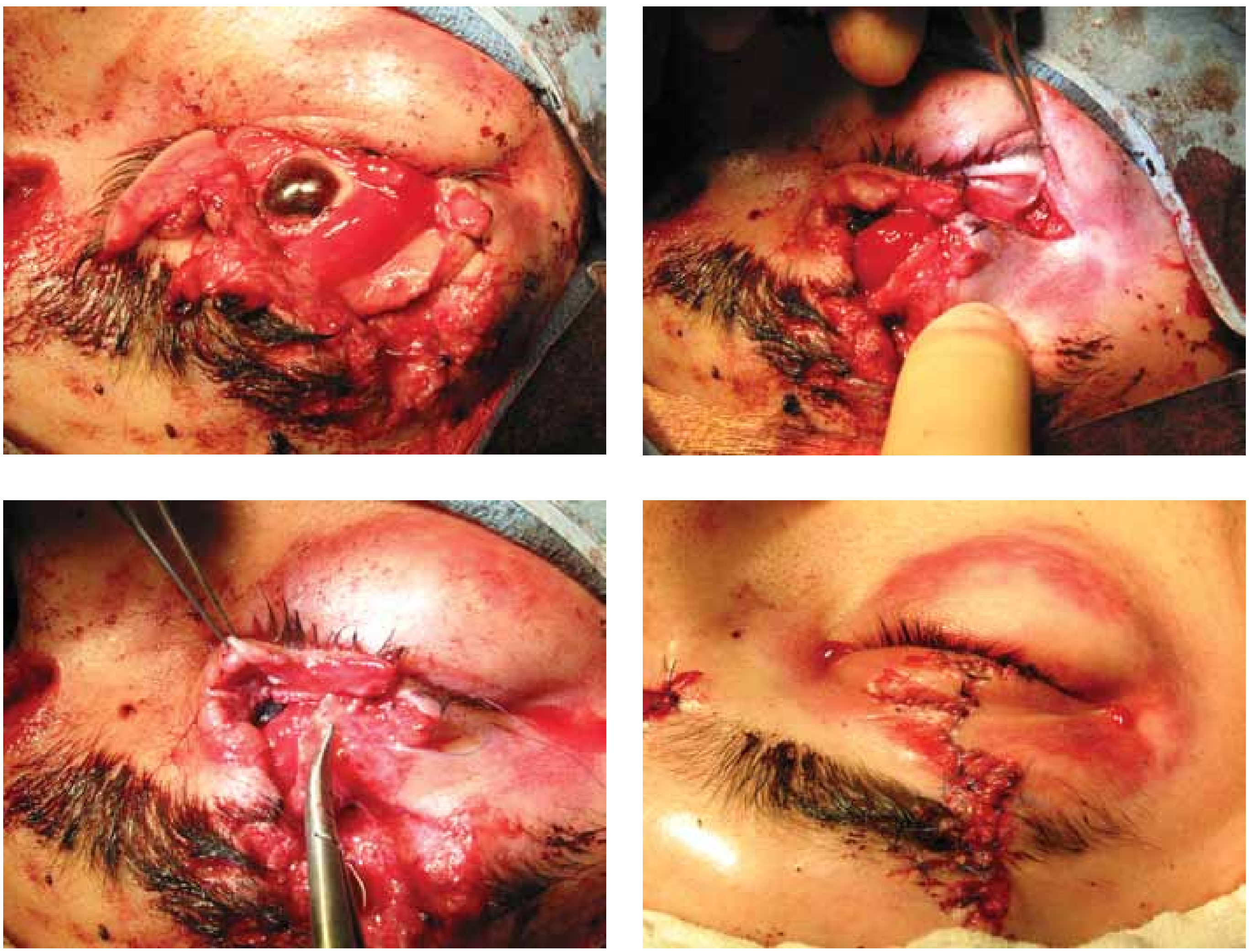


Figure 38. *Repair of complex right upper lid and brow laceration:* (Middle Left) *View of defect.* (Middle Right) *Right lateral canthotomy and superior cantholysis.* (Bottom Left) *Repair of upper tarsus.* (Bottom Right) *Completed repair of right upper lid and eyebrow.*

and interrupted 5-0 Prolene® skin sutures, taking care to properly align the brow hairs. Following surgery, the patient was promptly evacuated out-of-theater and subsequently received follow-up care at a Level V facility. His blind painful right eye was enucleated within two weeks of the injury.

Figure 39. *Photograph showing multiple punctate facial lacerations caused by glass foreign bodies.*

This case demonstrates the complexity of the head and facial injuries that are often seen concomitantly with ocular combat injuries. The vision-threatening orbital compartment syndrome of the left eye was quickly diagnosed based on clinical findings in the absence of radiographic confirmation and appropriately treated with canthotomy and cantholysis. Surgical intervention proceeded in an orderly fashion, dealing with the intracranial injury first, followed by the ruptured globe repair, and finally the eyelid and brow laceration repair. Removal of the left orbital metallic foreign body was not attempted, as it posed no immediate risk to the globe and very little risk of long-term complication.

Case 2

This 24-year-old male enlisted soldier was injured when a rocket-propelled grenade struck the windshield of his vehicle. Upon evaluation at the Level III hospital, it was apparent that he had sustained multiple glass foreign bodies to his face (Fig. 39). On CT scan, two IOFBs were present in the left eye, along with multiple

Figure 40. *Preoperative CT scan showing glass foreign bodies in the anterior segment* (Left) *and posterior segment* (Right) *of the left eye. Note multiple additional soft-tissue and subconjunctival foreign bodies.*

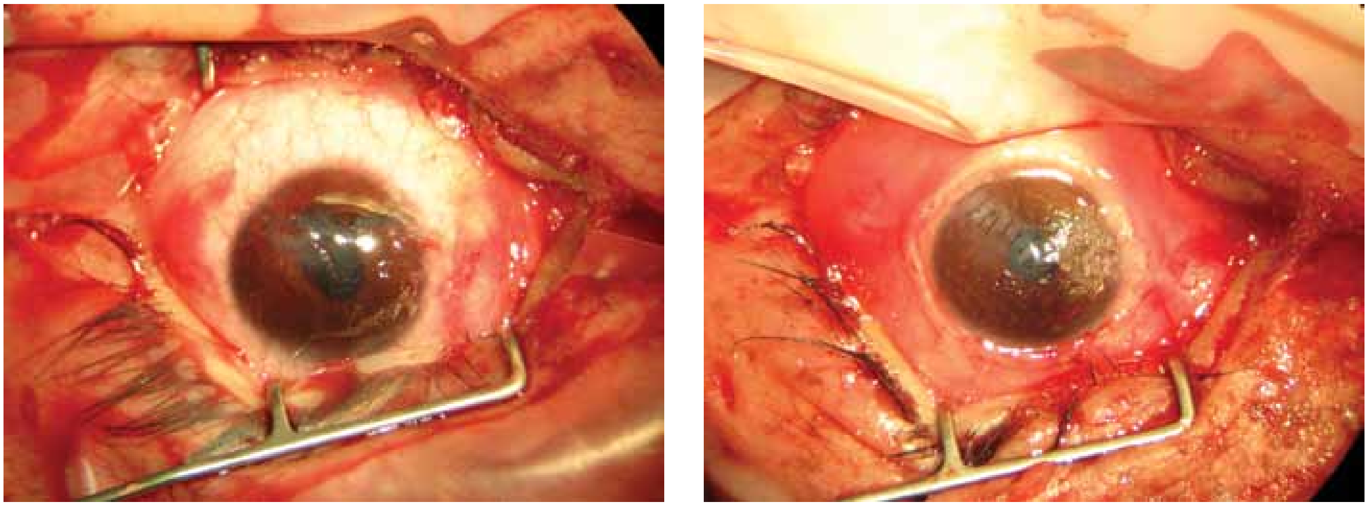


Figure 41. *Intraoperative photos before* (Left) *and after* (Right) *repair of two separate corneal lacerations, left eye. Note the cyanoacrylate glue plug over the inferonasal laceration, which obscures the underlying 10-0 nylon sutures.*

bilateral subconjunctival foreign bodies (Fig. 40). One of the foreign bodies was located in the anterior segment, and the other was in the posterior segment near the posterior pole. The patient was taken to the operating room, where the anterior chamber foreign body was easily removed through the corneal laceration it had created. The curvilinear inferotemporal laceration was repaired with multiple 10-0 nylon sutures. The second foreign body had entered the eye through the inferonasal cornea, perforated the iris and crystalline lens, and come to rest in the vitreous cavity just over the macula. The resulting stellate corneal laceration, although smaller than the first laceration, proved much more difficult to repair. A watertight closure could not be achieved with multiple 10-0 nylon sutures placed at all angles across the wound. Thus, a plug of cyanoacrylate glue was placed over the suture scaffold, with the aid of viscoelastic in the anterior chamber to prevent aqueous leakage (Figs. 41 and 42). Once a watertight seal was obtained, a bandage contact lens was placed. No attempt was made to retrieve the posterior segment foreign body. Prophylactic topical and intravenous fluoroquinolones were administered. No intravitreal antibiotics were used. The patient was evacuated to a Level V hospital, where his traumatic cataract was extracted and the retained foreign body was successfully removed by a retina specialist (Fig. 43). Visual acuity at last known follow-up was 20/25 with an aphakic rigid gas-permeable contact lens.

This case illustrates the management of corneal lacerations and IOFBs. The size of the corneal laceration does not always correlate with the difficulty of wound repair, and cyanoacrylate glue can be a valuable tool when sutures alone are inadequate in achieving a watertight closure. Foreign bodies in the anterior segment can often be safely removed, but removal of posterior segment foreign bodies should be deferred to a vitreoretinal specialist at Level IV or V facilities.

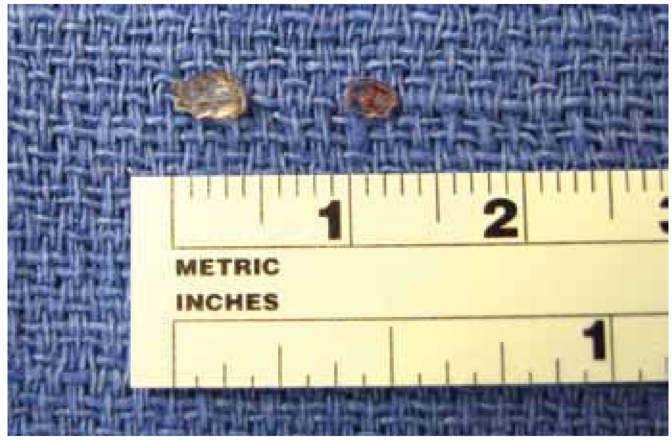


Figure 42. (Top Right) *Anterior segment and subconjunctival foreign bodies after removal.*

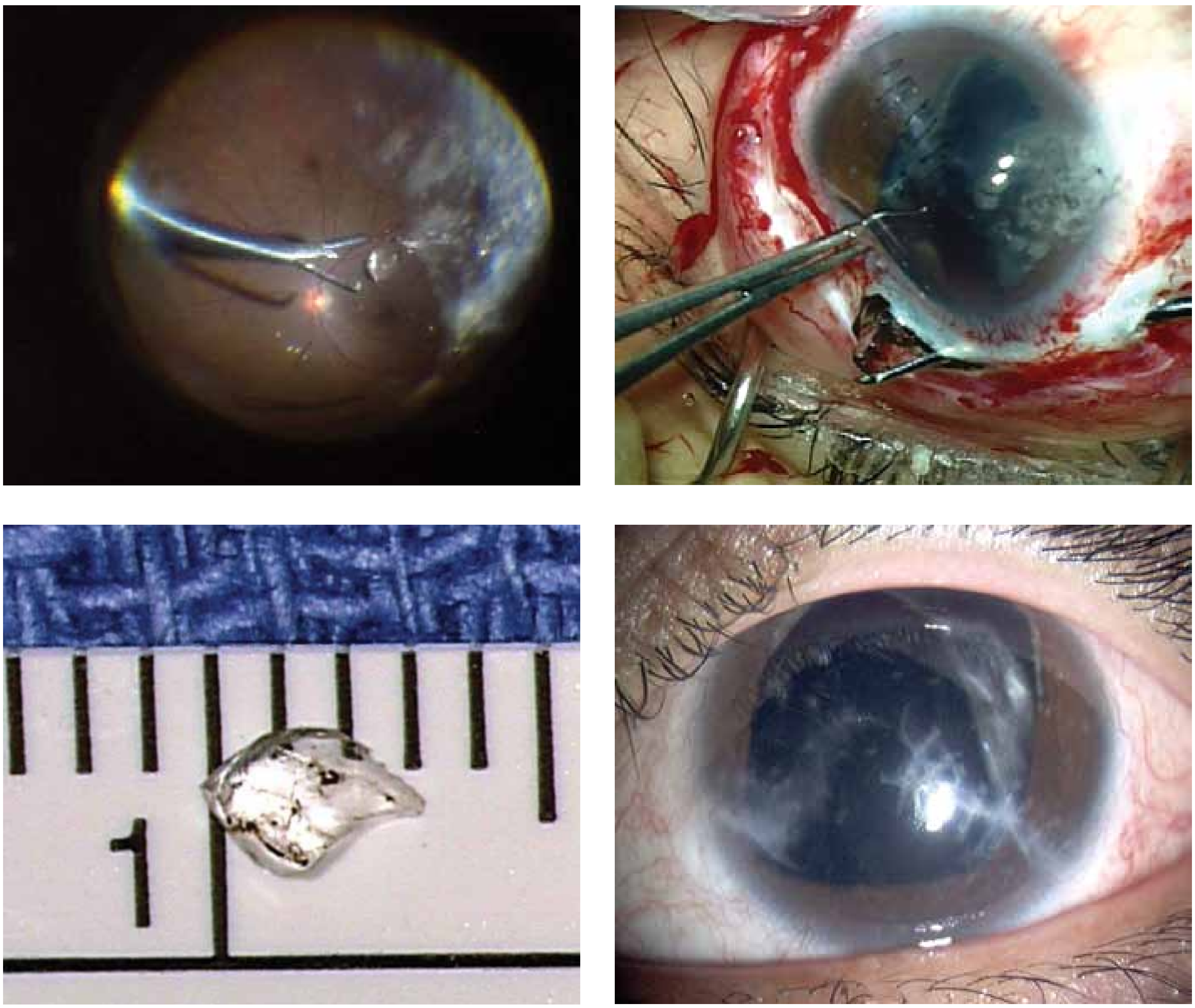


Figure 43. *Intraoperative photographs showing removal of posterior segment foreign body at Level V hospital:* (Middle Left) *IOFB being grasped with basket forceps and* (Middle Right) *removed through a scleral tunnel incision.* (Bottom Left) *IOFB after removal.* (Bottom Right) *Slit-lamp photograph at four-month postoperative visit. Images courtesy of Eric D. Weichel, M.D.*

References

1. Wong TY, Seet MB, Ang CL. Eye injuries in twentieth century warfare: a historical perspective. Surv Ophthalmol 1997;41(6):433-459.

2. Owens BD, Kragh JF Jr, Wenke JC, et al. Combat wounds in Operation Iraqi Freedom and Operation Enduring Freedom. J Trauma 2008;64(2):295-299.

3. Mader TH, Carroll RD, Slade CS, et al. Ocular war injuries of the Iraqi insurgency, January-September 2004. Ophthalmology 2006;113(1):97-104.

4. Thach AB, Johnson AJ, Carroll RB, et al. Severe eye injuries in the war in Iraq, 2003-2005. Ophthalmology 2008;155(2):377-382.

5. Cho RI, Bakken HE, Reynolds ME, et al. Concomitant cranial and ocular combat injuries during Operation Iraqi Freedom. J Trauma 2009;67(3):516-520.

6. Hornblass A. Eye injuries in the military. Int Ophthalmol Clin 1981;21(4):121-138.

7. Handler JA, Ghezzi KT. General ophthalmologic examination. Emerg Med Clin North Am 1995;13(2):521-538.

8. Juang PS, Rosen P. Ocular examination techniques for the emergency department. J Emerg Med 1997;15(6):793-810.

9. Linden JA, Renner GS. Trauma to the globe. Emerg Med Clin North Am 1995;13(3):581-605.

10. Hutton WL, Fuller DG. Factors influencing final visual results in the severely injured eyes. Am J Ophthalmol 1994;97(6):715-722.

11. Kylstra JA, Lamkin JC, Runyan DK. Clinical predictors of scleral rupture after blunt ocular trauma. Am J Ophthalmol 1993;115(4):530-535.

12. Sheldrick JH, Vernon SA, Wilson A. Study of diagnostic accord between general practitioners and an ophthalmologist. BMJ 1992;304(6834):1096-1098.

13. Lustrin ES, Brown JH, Novelline R, et al. Radiologic assessment of trauma and foreign bodies of the eye and orbit. Neuroimaging Clin North Am 1996;6(1):219-237.

14. Otto PM, Otto RA, Virapongese C, et al. Screening test for the detection of metallic foreign bodies in the orbit before magnetic resonance imaging. Invest Radiol 1992;27(4):308-311.

15. McNicholas MM, Brophy DP, Power WJ, et al. Ocular trauma: evaluation with US. Radiology 1995;195(2):423-427.

16. Zuravleff JJ, Johnson MH. An ophthalmic surgeon's view of orbital imaging techniques. Semin Ultrasound CT MR 1997;18(6):395-402.

17. Rocha G, Brunette I, Le Francois M. Severe toxic keratopathy secondary to topical anesthetic abuse. Can J Ophthalmol 1995;30(4):198-202.

18. Kitsos G, Gartzios C, Asproudis I, et al. Central corneal thickness in subjects with glaucoma and in normal individuals (with or without pseudoexfoliation syndrome). Clin Ophthalmol 2009;3:537-542.

19. Sklar DP, Lauth JE, Johnson DR. Topical anesthesia of the eye as a diagnostic test. Ann Emerg Med 1989;18(11):1209-1211.

20. Talbot EM. A simple test to diagnose iritis. Br J Med 1987;295(6602):812-813.

21. Netland KE, Martinez J, LaCour OJ III, et al. Traumatic anterior lens dislocation: a case report. J Emerg Med 1999;17(4):637-639.

22. Spraul CW, Grossniklaus HE. Vitreous hemorrhage. Surv Ophthalmol 1997;42(1):3-39.

23. Olsen TW, Chang TS, Sternberg P Jr. Retinal detachments associated with blunt trauma. Semin Ophthalmol 1995;10(1):17-27.

24. Berlin R. Zur sogenannten commotio retinae. Klin Monatsbl Augenheilkd 1873;11:42-78.

25. Reppucci VS, Movshovich A. Current concepts in the treatment of traumatic injury to the anterior segment. Ophthalmol Clin North Am 1999;12(3):465-474.

26. Kuhn F, Maisiak R, Mann L, et al. The Ocular Trauma Score (OTS). Ophthalmol Clin North Am 2002;15(2):163-165.

27. Weichel ED, Colyer MH, Ludlow SE, et al. Combat ocular trauma visual outcomes during operations Iraqi and enduring freedom. Ophthalmology 2008; 115(12):2235-2245.

28. Barr CC. Prognostic factors in corneoscleral lacerations. Arch Ophthalmol 1983;101(6):919-924.

29. Chidiac EJ, Raiskin AO. Succinylcholine and the open eye. Ophthalmol Clin North Am 2006;19(2):279-285.

30. Mills MD, Devenyi RG, Lam WC, et al. An assessment of intraocular pressure rise in patients with gas-filled eyes during simulated air flight. Ophthalmology 2001;108(1):40-44.

31. Lincoff H, Weinberger D, Stergiu P. Air travel with intraocular gas. II. Clinical considerations. Arch Ophthalmol 1989;107(6):907-910.

32. Thompson JT. The absorption of mixtures of air and perfluoropropane after pars plana vitrectomy.

Arch Ophthalmol 1992;110(11):1594-1597.

33. Duch-Samper AM, Chaqués-Alepuz V, Menezo JL, et al. Endophthalmitis following open-globe injuries. Curr Opin Ophthalmol 1998;9(3):III:59-65.

34. Mittra RA, Mieler WF. Controversies in the management of open-globe injuries involving the posterior segment. Surv Ophthalmol 1999;44(3):215-225.

35. Colyer MH, Weber ED, Weichel ED, et al. Delayed intraocular foreign body removal without endophthalmitis during Operations Iraqi Freedom and Enduring Freedom. Ophthalmology 2007;114(8):1439-1447.

36. Albert DM, Diaz-Rohena R. A historical review of sympathetic ophthalmia and its epidemiology. Surv Ophthalmol 1989;34(1):1-14.

37. Ward TP. Sympathetic ophthalmia. In Thach AB, ed. Ophthalmic Care of the Combat Casualty. Washington, DC: Borden Institute, Walter Reed Army Medical Center; 2003. p. 265-279.

38. DeBacker CM, Holck DEE. Enucleation in orbital trauma. In: Holck DEE, Ng JD, editors. Evaluation and treatment of orbital fractures: a multidisciplinary approach. 2nd ed. Philadelphia: Elsevier Saunders; 2006. p. 365-368.

39. Kaltreider SA, Lucarelli MJ. A simple algorithm for selection of implant size for enucleation and evisceration: a prospective study. Ophthal Plast Reconstr Surg 2002;18(5):336-341.

40. Nasr AM, Haik BG, Fleming JC, et al. Penetrating orbital injury with organic foreign bodies. Ophthalmology 1999;106(3):523-532.

41. Finklestein M, Legmann A, Rubin PA. Projectile metallic foreign bodies in the orbit: a retrospective study of epidemiologic factors, management, and outcomes. Ophthalmology 1997;104(1):96-103.

42. Khani SC, Mukai S. Posterior segment intraocular foreign bodies. Int Ophthalmol Clin 1995;35(1):151-161.

43. Punnonen E, Laatikainen L. Prognosis of perforating eye injuries with intraocular foreign bodies. Acta Ophthalmol (Copenh) 1989;67(5):483-491.

44. Packer AJ. Ocular trauma. Primary Care 1982;9(4):777-792.

45. Cohen EJ, Rapuano CL. Trauma. In: Cullom RD, Chang B, editors. The Wills eye manual: office and emergency room diagnosis and treatment of eye disease. 2nd ed. Philadelphia, PA: JB Lippincott; 1994. p. 27.

46. Fry HJ. Orbital decompression after facial fractures. Med J Aust 1967;1(6):264-266.

47. Hislop WS, Dutton GN, Douglas PS. Treatment of retrobulbar haemorrhage in accident and emergency departments. Br J Oral Maxillofac Surg 1996;34(4):289-292.

48. Hayreh SS, Kolder HE, Weingeist TA. Central retinal artery occlusion and retinal tolerance time. Ophthalmology 1980;87(1):75-78.

49. Burkat CN, Lemke BN. Retrobulbar hemorrhage: inferolateral anterior orbitotomy for emergent management. Arch Ophthalmol 2005;123(9):1260-1262.

50. Ho VH, Wilson MW, Fleming JC, et al. Retained intraorbital foreign bodies. Ophthal Plas Reconstr Surg 2004;20(3):232-236.

51. Cho RI, Kahana A, Patel B, et al. Intraoperative fluoroscopy-guided removal of orbital foreign bodies. Ophthal Plast Reconstr Surg 2009;25(3):215-218.

52. Pfister RR. Chemical injuries of the eye. Ophthalmology 1983;90(10):1246-1253.

53. Grant WM. Toxicology of the eye. 3rd ed. Springfield, MA: Charles C Thomas; 1986.

54. Herr RO, White GL Jr, Bernhisel K, et al. Clinical comparison of ocular irrigation fluids following chemical injury. Am J Emerg Med 1991;9(3):228-231.

55. Wagoner MD. Chemical injuries of the eye: current concepts of pathophysiology and therapy. Survey Ophthalmol 1997;41(4):275-313.

56. Shoff WH, Sheperd SM. Ocular trauma. In: Ferrera PC, Colucciello SA, Marx JA, et al, editors. Trauma management: an emergency medicine approach. 1st ed. St Louis, MO: Mosby; 2001. p. 197-217.

57. Villarreal PM. Traumatic optic neuropathy. A case report. Int J Oral Maxillofac Surg 2000;29(1):29-31.

58. Wang BH, Robertson BC, Girotto JA, et al. Traumatic optic neuropathy: a review of 61 patients. Plast Reconstr Surg 2001;107(7):1655-1664.

59. Levin LA, Beck RW, Joseph MP, et al. The treatment of traumatic optic neuropathy: The International Optic Nerve Trauma Study. Ophthalmology 1999;106(7):1268-1277.