

## Wounds and Injuries of the Eye

Under battlefield conditions, the casualty with an injured eye is usually seen first by nonspecialized personnel at a facility that has little or no specialized equipment. If his injury is minor, the soldier is treated and sent back to his unit. If it is not, he should be promptly evacuated. The distinction between minor and serious ocular injuries is not always easy to make. The most trivial-appearing injury may prove to be very serious indeed. If an injury of the eye is properly managed, a good result (or at least some salvage of vision) is often secured even in serious injuries. If improperly managed, a trivial penetrating ocular wound may be converted into a serious one; a large majority of these may result in blindness. All care providers must know how to detect, assess, and initially manage patients with eye injuries. The mandatory principles of initial management are presented in this chapter. In ophthalmic surgery, the first opportunity to repair an injury is usually the only opportunity. There is an inordinately high rate of ocular injury relative to the amount of surface area exposed to injury. Although comprising as little as 0.10 % of total body surface and only 0.27% of the erect frontal silhouette, the eye is injured in nearly 10% of nonfatal casualties. The likelihood of ocular injury is further increased by various postures assumed in warfare. For example, although 25% of the projected body surface is exposed in the prone position, the eye comprises a considerable proportion of the prone silhouette. The recent introduction of laser technology to the battlefield will lead to a new class of ocular injury. These injuries are most likely to fall into two categories. The first category is that of thermal burns of the eyelids and cornea. The second category constitutes injury to the retina and vitreous body, leading to intraocular hemorrhage. Laser injuries of the eye are covered separately.

## EXAMINATION AND DIAGNOSIS

As in any echeloned system of care, if the patient can communicate and combat conditions permit, an ocular examination should always begin by recording the circumstances of injury and the type of wounding agent. A penetrating ocular injury should be suspected in every wound of the eye and of the upper portion of the face until it is proved not to exist. The preliminary examination, should be conducted with the lids retracted, after loose foreign matter has been flushed out of the conjunctival sac with copious irrigations of plain water or physiologic salt solution or wiped out with a wet cotton-tipped applicator. Foreign bodies in contact with the eyeball should be removed from the lids. Since voluntary opening of the eyelids is often impossible, topical anesthesia (proparacaine hydrochloride 0.5%) and gentle lid separation with Desmarres retractors may be required for both vision testing and inspection. In the absence of available lid retractors, a pair of paperclips can be opened and bent into a curved blade configuration to serve as retractors, and any force required should be applied to the orbital bones, not the globe itself. The slightest pressure on the globe which has been lacerated or perforated may cause irretrievable loss of the vital contents.

Visual acuity, the most important parameter in evaluating the seriousness of the eye injury, should be recorded as follows: no light perception, light perception, perceives hand motions, counts fingers, or reads. In evaluating light perception, it is important to pass a very bright light alternately in front of and away from the eye. At the same time, the other eye must be completely shielded, and the patient must be questioned carefully to detect inaccurate responses. Spurious perception of light may result simply from the patient's natural desire to see, from an awareness of heat from the light, from a sensation of air movement on the skin produced by motion of the light source, or from incomplete shielding of the other eye. The other tests of visual acuity should be utilized with as much precision as circumstances permit.

It is imperative to inspect the anterior chamber of the eye with a bright light placed near the cornea and directed from the temporal to nasal side. A magnified view can be obtained by employing either a + 18D refracting lens, or the high plus (black numbered) lenses on the ophthalmoscope. A marked deepening of the anterior chamber compared to the normal side, coupled

with loss of the normal red reflex when the eye is illuminated and viewed in the axial direction, indicates the presence of a posterior segment penetrating injury which may be hidden and seemingly associated with only minor lid lacerations. These wounds may have actually perforated the lids and penetrated the globe. Additional findings on this inspection may include pupillary irregularities, blood within the anterior chamber (hyphema), shallowing or even collapse of the anterior chamber, where loss of aqueous humor causes the iris to impinge directly against the posterior surface of the cornea. Lacerations of the eyelids, cornea, or sclera; foreign bodies within the eye or orbit; or disruption of the globe may be present. Gross contamination by dirt or other particulate matter frequently accompanies these injuries.

**Corneal** lacerations are usually evident by loss of the anterior chamber and distortion of the pupil. Iris incarceration or prolapse through the wound is common. Scleral lacerations often exhibit extruding, darkly pigmented choroid. However, small perforating wounds and even large scleral lacerations may be obscured by **sub-conjunctival** hemorrhage. More extensive prolapse of intraocular contents (vitreous humor, uvea, even lens and retina) may present within the lips of any laceration of the globe.

If the general appearance of the eye is undistorted and careful inspection reveals no site of ocular penetration, gross differences in intraocular tension may be estimated by *very gentle digital palpation*. The tips of the index fingers are used in ballottement of the globes through the upper, closed eyelids. First, test the tone of the unaffected eye, and then compare with that of the injured eye. Asymmetric tension is indicative of serious ocular injury to the softer eye.

Unless total disruption is evident, the possibility of salvaging the eye should be considered. This possibility exists even in the face of questionable light perception since vitreous hemorrhage alone may mask the perception of light. Since the advent of vitreous surgery, many eyes previously considered hopelessly damaged may now be salvaged. For this reason, the decision to **enucleate** any eye must be made by the most skilled specialist available. The principle goal of all others who manage the patient is to protect the eye from further damage.

## MANAGEMENT

## Minor Injuries

Minor ocular injuries which may be handled safely in the division area include laceration of the eyelids, subconjunctival hemorrhage, superficial foreign bodies, and corneal abrasions. Irrigation of the eyes and removal of superficial corneal foreign bodies may be performed under 0.5% Opthaine or Ophthetic (Proparacaine hydrochloride 0.5%) or 0.5% Pontocaine (Tetracaine hydrochloride) anesthesia. A sharp-pointed instrument, such as a large needle or eye spud, should be used. The superficial abrasion left after the object is removed is treated by instillation of an antibiotic ointment and patching. If the particles are found to be multiple and more deeply imbedded than has been anticipated, the patient should be evacuated. Foreign bodies should be managed as previously described in the section on examination and diagnosis.

Subconjunctival hemorrhages associated with neither decrease of visual acuity nor blood in the anterior chamber (hyphema) or in the vitreous humor require no treatment. However, thorough ophthalmoscopy through a well-dilated pupil is necessary before returning the patient to duty. If blood is found in the anterior chamber or the vitreous humor, the patient should be placed on bedrest, with elevation of the head, monocular patches applied, and prepared for immediate evacuation.

Contusions of the eyelids and eyeball should likewise be examined carefully. If there is only subcutaneous and subconjunctival hemorrhage, without intraocular hemorrhage or disturbance of vision, the patient can be returned to duty.

Foreign body sensation, aggravated by blinking, and pain referred to the upper lid are characteristically found with corneal abrasion, which is usually a minor, but always painful lesion. Documentation by the use of a fluorescein strip, placed momentarily in the conjunctival fovea, may be diagnostically helpful. The abrasion can often be seen merely by focusing on the anterior corneal surface with + 8D and + 12D lenses (black numbers) using the conventional direct ophthalmoscope. The inner surface of the upper lid should be carefully examined for the presence of foreign bodies. This may necessitate careful eversion of the upper lid.

The treatment of ordinary corneal abrasions consists of: (1) cycloplegia, using two drops of either scopolamine hydrochloride 0.25-0.5%, cyclopentolate hydrochloride 1-2%, or homatropine hydrobromide 5%; (2) instillation of ophthalmic antibiotic solution or ointment; and (3) application of a tight patch to insure immobility of the eyelid. The patch can usually be discontinued in 24-36 hours, but **repatching** for another 24-36 hours may be necessary for larger abrasions. Lack of progressive improvement necessitates referral to an ophthalmologist. The use of topical anesthesia for other than facilitating vision testing, examination, or instrumentation is contraindicated. Repeated installation inhibits healing. Topical steroids or steroid antibiotic combinations are likewise contraindicated. Steroids are unnecessary and will cause rapid progression of a dendritic ulcer, including corneal perforation, should this lesion exist or supervene. **Fungal superinfection** and glaucoma may also result from injudicious use of topical steroids.

## MAJOR INJURIES

**Division Area**-The management of ophthalmic injury begins as far forward as possible. Only first aid, including foreign body removal as previously discussed, is administered in these forward areas, and all significant casualties are evacuated to facilities where a physician is assigned. Early identification of ocular injury is an urgent matter. Serious eye injuries are **second** in priority of evacuation only to life-threatening wounds. In severe injury to the globe, inadvertent delay in ophthalmologic care can mean the difference between salvage and loss of the eye.

Any abnormality in the appearance of the eye injured by blast or fragmentation weapons, or by severe blunt trauma, demands the following course of action preparatory to evacuation:

1. Instruct the patient not to squeeze his eyelids.
  2. Do not remove any penetrating foreign body protruding from the globe or the conjunctival fomices, as ocular contents may be extruded.
  3. Occlude both eyes, but avoid any pressure directly on the eyes. The battle dressing tied around the head suffices.
  4. Give systemic **analgesics** for moderate to severe pain.
  5. Evacuate immediately as a supine litter patient to a forward
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hospital, preferably with ophthalmology capability.

Where penetrating injury to the globe is suspected, the patient's eye can be protected from his own reflex lid squeezing by administration of a Nadbath block as follows: 1.0 cc of 2% xylocaine is injected using a 23 to 27 gauge needle no longer than **10mm**. The area immediately behind the ear is palpated, and the needle is placed perpendicular to the anterior surface of the mastoid in the triangular space formed by the ear anteriorly, the mandible inferiorly, and the mastoid process posteriorly. The needle is advanced to the hub, delivering the anesthetic to the facial nerve as it exits the region of the stylomastoid **foramen**.

Ocular burns are usually first seen in the division area. Ultraviolet, thermal, and non-alkali chemical burns are treated as for **corneal** abrasions. However, non-alkali chemical burns require initial irrigation with tap water or saline solution for **10-15** minutes under topical anesthesia.

With white phosphorous burns of the eye, instillation of 0.5% copper sulfate solution identifies particles, which are otherwise presumptively located by foci of smoke or by darkening the particles. Larger particles may require removal with a needle or spud. The particles should be continuously irrigated to retard their further oxidation (**reignition**) and resultant tissue damage. These patients urgently require treatment by an ophthalmologist, in whose hands continuous irrigation with ophthalmic antibiotics in Ringer's solution may be performed by a percutaneous, indwelling, superior **fornix** angiocatheter, since severe edema of the lids often prevents the conventional administration of topical medication. Alkali burns may result from exposure to sodium hydroxide, lye, quick lime, ammonia, and agents often found in degreasing solvents. These burns represent an ocular emergency! Chemical penetration is so rapid that irrigation with copious volumes of water or sterile saline must be initiated within seconds. This irrigation must be continuous for at least 60 minutes. Irrigation should be continued until the **pH** remains below 8.0 for at least five minutes after irrigation ceases. An alkali burn is potentially devastating and prognosis may be poor, especially if the cornea appears cloudy or the conjunctive blanched. Atropine sulfate 1% and chloramphenicol ointments should be applied 3-4 times a day. Phenylephrine, which will further constrict blood vessels and worsen **limbal** ischemia, should not be used. Steroid ointment should be used only in the most severe burns and only during

the first three days, as its use later may promote **stromal** melting. In an effort to reduce erosion of the corneal **stroma** when evacuation must be delayed beyond three days, N-acetyl-L-cysteine (MUCOMYST) may be applied by dropper in a 20% solution as frequently as each hour. Prompt evacuation is necessary,

**Forward Hospital**-In the absence of an ophthalmologist, treatment of major ocular injuries in forward hospitals normally is managed by the general surgeon and ideally is limited to interim measures aimed at prevention of infection within the eye. Systemic antibiotics and tetanus prophylaxis should be instituted at the earliest opportunity in the preoperative period.

Lid and conjunctival debris should be carefully irrigated away. Any sterile irrigating solution, including water, is acceptable. This should be followed by generous topical application of fresh solutions of an ophthalmic antibiotic (gentamycin sulfate, **chloramphenicol** or neomycin sulfate-polymixin B sulfate) and atropine sulfate 1%. A sterile, four-by-four-inch gauze strip is applied to keep the area clean, and additional protection is afforded by taping a Fox (or similar type) shield over the injured eye. A pressure dressing should be avoided as it may cause serious damage by expressing intraocular contents through a penetrating wound. Since patching also helps provide an excellent culture medium for bacteria, particularly *Pseudomonas*, topical antibiotic solution is carefully reinstilled every four hours, and a fresh, sterile gauze patch reapplied twice daily. Sterile irrigation of mucopurulent secretions from the lid margins and **conjunctiva** should be carried out when the **gauze** dressing is changed. The uninjured eye should be patched to reduce unwanted ocular motion.

No ocular surgery should be performed. **Particularly, no** attempt should be made to remove protruding or penetrating foreign bodies or to repair corneal or scleral lacerations. Preferably, no repair should be undertaken for lacerations involving the lid margin or the nasolacrimal apparatus. Even an eye which appears grossly irreparable may have surgery deferred, utilizing the same regimen of sterile gauze dressings and antibiotics.

Until recently, the selection of systemic antibiotics has been beset with two problems: (1) many drugs do not pass the **blood-aqueous** and **blood-retina** barriers to give adequate intraocular tissue concentrations, and (2) earlier drugs have had limited

bactericidal spectra, especially for strains of *Pseudomonas aeruginosa*. When ophthalmologic care must be delayed, the following initial antibiotic regimen may be used if infection is suspected and the wound is of such size and location that extrusion of intraocular contents is not a risk:

Subconjunctival: Gentamycin 40mg  
Cephaloridine 100 mg

or

Gentamycin 40mg  
Methicillin 100 mg

Topical: Gentamycin **9mg/cc**  
Bacitracin **5,000u/cc**

Systemic: Cephaloridine, 1gm stat, **IV.** then 500mg q 6 hr.  
or

Methicillin **2gm, IV.,** q 8 hr.

Subconjunctival injection is best accomplished using topical proparacaine (05%) anesthesia, a small-volume syringe (**2.5cc**) and a short (5/16") 27 gauge needle. The bulbar conjunctiva is **engag**ed near the upper or lower **fornix** with the bevel facing the globe, and the needle is advanced toward the **fornix**, the injection being given while the needle tip is visible through the conjunctiva. Subconjunctival injections are contraindicated if the wound is of such size and location as to risk extrusion of intraocular contents. In such cases, only the topical and systemic routes should be used, as noted above.

While ideally handled by an ophthalmologist, many of the following ocular injuries can be managed well by surgeons or general medical officers:

1. Eyelid laceration, with and without margin involvement.
2. Deeply embedded corneal foreign bodies.
3. Ocular burns.
4. Ocular contusion injuries.

If evacuation or ophthalmologic care is delayed, repair of lid lacerations by a non-ophthalmologic surgeon may be necessary. Evaluation of any lid injury must include an evaluation for coexisting injury to the eyeball and penetrating injury to the intracranial contents. Lacerations and avulsions near the medial **canthal** tendon necessitate a careful examination for interruption of the canaliculus. In the repair of any lid injury, it is necessary to respect the complex anatomy of the lid, exact anatomical

realignment being necessary (Figure 31). It is especially important that the levator muscle, the tarsal plate, and the medial **canthal** tendon be precisely reapproximated, or severe functional and cosmetic disabilities may ensue. Adequate coverage of the cornea is of critical importance. The repair of lid injuries requires a knowledge of the anatomy of the lid, fine ophthalmic instruments and sutures, and magnification provided by either loupes or an operating microscope. Lid tissue should be preserved wherever possible. Only tissue that is clearly necrotic should be debrided. Totally avulsed lid segments should be reattached after cleansing. Lacerated lids should be extensively irrigated and all foreign bodies removed.

Lid lacerations should be repaired in the following manner. Lacerations through the skin horizontal to the lid margin can be repaired with 6-0 black silk sutures. Lacerations that involve the lid margin itself must be repaired precisely: 4-0 black silk suture should be used to approximate the tarsal plates elsewhere and 6-0 black silk should be used to approximate the anterior and posterior borders of the lid margin and the skin of the lid elsewhere. Lid margin sutures should stay in for ten days. The lid should be placed on stretch using the long arms of the 4-0 black silk sutures for at least three days after the repair of the injury. A light pressure dressing should be placed over the eye after the instillation of an antibiotic ointment. The cornea must be checked each day. No elaborate reconstruction of the lids should be performed in a combat zone, though every effort should be made to preserve and reapproximate lid tissues at the time of the primary repair.

Lacrimal Secretory System. It is necessary to recognize a **prolapsed** orbital lobe of the lacrimal gland, distinguishing it from normal orbital fat. The orbital lobe of the lacrimal gland is pinkish-gray in contrast to the creamy-yellow color of orbital fat. The prolapsed orbital lobe should be irrigated and repositioned in its **fossa** by means of a 4-0 chromic suture passed through the lobe and the periosteum lining the **fossa**.

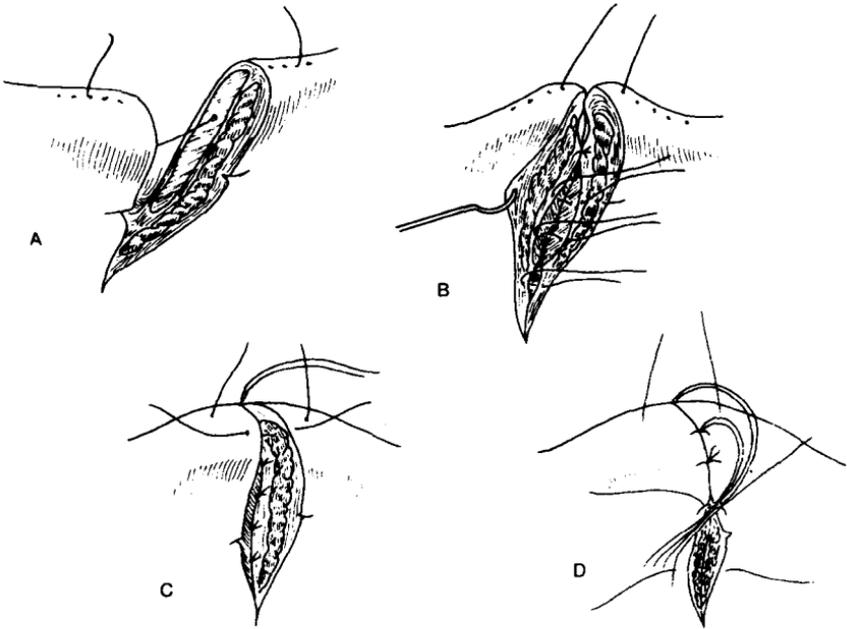


FIGURE 31.—Closure by layers of lid lacerations.

**Lacrimal Excretory System.** It is critically important to identify lacerations of the canaliculi so that they may be repaired properly at the time of wound repair. The canaliculi must be stented, preferably with silicone tubing. If silicone is not available, fine silver wire (e.g. 3-O or 4-O Bowman probe) can be bent in the form of a Johnson lacrimal rod and used as a stent. In cases of **mid**-face trauma where the nasolacrimal duct may have been interrupted, the entire lacrimal excretory system should be stented with silicone tubing.

**Orbit.** A careful examination of the globe is mandatory in all cases of injury to the orbit. The globe is significantly injured in 25% of orbital fractures. Retrobulbar hemorrhage must be detected and treated if it is producing marked elevation of intraocular pressure and/or decreased visual acuity. If so, a lateral canthotomy and cantholysis of the inferior **crus** of the lateral **canthal** tendon should be performed. If these maneuvers do not produce an improvement in intraocular pressure (i.e., decreasing it)

and vision, the hemorrhage must be released by an incision through the conjunctiva and Tenon's capsule between the lateral rectus and the inferior rectus muscle into the muscle cone. The incision should be made with sharp scissors, and blunt tip scissors should be used to gently spread the orbital fat within the muscle cone to permit the escape of blood. Pressure on the globe and optic nerve during any surgery upon the orbit and its contents must be avoided. Blindness can result from prolonged retraction pressure on the globe and nerve. Intraorbital extraocular foreign bodies are best left undisturbed unless they are large (greater than 1 cm in largest diameter) or are producing globe or optic nerve dysfunction. Radiographic evaluation of orbital fractures should include a stereo Waters' view and computerized tomography with coronal and sagittal reformatting. The latter is especially important in the evaluation of fractures of the optic canal. Blowout fractures of the orbital floor in general do not require immediate repair. Forced duction testing should always be performed before resorting to surgical repair. If surgery is performed, ductions of the globe should be tested intraoperatively to help prevent incarceration of tissues incident to surgical manipulation.

**Enucleation.** Under no circumstances should an eye be excised by a general surgeon in a forward unit unless the globe is completely disorganized.

In the unlikely circumstance that a patient with a severe ocular injury cannot be evacuated within several days to a facility that has an ophthalmologist and the ophthalmologist cannot be brought to the forward facility, primary enucleation should be considered if the patient has no light perception using the brightest available light source. Such a severe injury would most likely be an extensive corneoscleral laceration with either prolapse or loss of intraocular contents. However, even in the face of a severely damaged eye with no light perception, cosmetic function may remain; therefore, consultation with an ophthalmologist should be sought before such a definitive procedure is undertaken.

Be assured that this policy of delay is perfectly safe as it relates to sympathetic ophthalmia. Sympathetic ophthalmia (involvement of the uninjured eye) never develops until at least ten days after trauma, and only very exceptionally develops before 21 days. There is sufficient time for the patient to reach an ophthalmologist.

If the decision is made to remove the eye, the conjunctiva is incised at the **limbus** to separate it from the globe. Using a combination of blunt and sharp dissection, the four rectus muscles are exposed from their insertions as far posteriorly as possible (usually 10-15mm). Tenon's capsule (the connective tissue surrounding the globe) is separated from the globe in the four quadrants between the rectus muscles. The extraocular muscles are then cauterized and severed 2mm from their insertions on the globe.

Traction should be exerted on the globe in the anterior direction as a curved Halsted clamp is placed behind the globe as deeply into the orbit as possible. By blunt dissection, the optic nerve is isolated, clamped to crush the central retinal vessels, and cut distal to the clamp. The globe is removed from the orbit. Before the Halsted clamp is removed, hemostasis should be achieved by direct cautery of the nerve stump. If available, it is most important to place a silicone sphere no larger than 16mm in diameter in the position occupied previously by the globe. The sphere should be placed within the muscle cone, posterior to the posterior layer of Tenon's capsule, and a careful closure of posterior Tenon's and anterior Tenon's, using interrupted 4-0 chromic catgut sutures, is completed. The conjunctiva is closed horizontally with interrupted 5-0 plain catgut sutures. If available, a ring conformer should be placed between the bulbar and palpebral conjunctiva to prevent obliteration of the conjunctival cul-de-sacs which impairs the patient's subsequent wearing of a prosthesis. A scleral ring, rather than a scleral shell type of conformer, is preferred because the ring eliminates direct pressure on the conjunctival suture line.

In the event that the patient still retains light perception or even better vision in the face of a corneal or scleral laceration, primary closure of the wound should be performed by the **non-ophthalmologist** physician if the patient cannot be treated by an ophthalmologist within a few days. The guiding principle is meticulous wound closure without debridement, except for the excision of prolapsed intraocular tissue.

Magnification of any type will be of great assistance. Instruments should not be introduced through the wound into the eye. If the laceration involves both the cornea and sclera, the cornea should be repaired first. The smallest (7-0) silk suture material available and the finest available instruments should be used. The first suture should not be placed until the edges of the wound

are carefully aligned. Close attention to the **limbal** landmarks will assist in proper alignment. The curved needle is introduced almost perpendicularly into the tissue about 2mm from the wound edge, and is taken to midstromal depth (the cornea is less than 1mm thick in most areas) from where it is directed horizontally to the edge of the wound. The needle should penetrate the other edge of the wound at midstromal depth, and exit the cornea 2mm from the wound edge. The interrupted sutures should be placed every 2mm.

Scleral wounds should be closed similarly, using meticulous technique and midstromal depth placement of sutures. **Non-colored** sutures are usually used on the scleral wound, since these will remain buried after the **conjunctiva** is closed.

As a final note, all individuals rendering care for ophthalmic injuries must be aware of the frequent occurrence of combined neurosurgical and maxillofacial injuries when the eye and orbit are involved. Optimal treatment in these cases depends upon a well-coordinated team effort.

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## CHAPTER XXV

# Laser Injury of the Eye

### INTRODUCTION

Military application of laser devices will most certainly, in the future generate casualties with laser injuries of the eye. The energy output of currently deployed rangefinders, for example, is sufficient to produce significant eye injuries at ranges up to a kilometer. High-energy output laser weapons with considerably greater potential for injury to the eye have not, to date, appeared on a battlefield.

### LASER PRINCIPLES

1. Basics. A laser produces a beam of coherent light which travels at 186,000 miles per second, the speed of light. This beam can vary in wave length throughout the electromagnetic spectrum and can be visible or invisible. The common wavelengths of laser rays correspond approximately to the wavelengths of colors in the spectrum, specifically, the ultraviolet (below 400 nm), the visible (400-700 nm) , and the infrared spectra (above 700 nm). These various wavelengths of energy are absorbed by different layers within the eye.

a. Ultraviolet. Lasers utilizing the ultraviolet spectrum (below 400 nm) are absorbed in the anterior segments of the eye, primarily by the cornea, as well as by the lens.

b. Visible. Laser radiations in the visible spectrum (400-700nm) are absorbed primarily within the retina by the pigment epithelium and the choroid. Penetration depth is greater for the longer wavelengths (red) than with shorter wavelengths (blue).

c. Infrared. Absorbption of lasers in the infrared spectrum (above 700 nm) occurs in two areas of the eye. Lasers at the lower end of the infrared spectrum (1000 nm) damage the retina and

the choroid, whereas the cornea is damaged by lasers at the top end of the infrared spectrum (3000 nm).

**TABLE 14.—*Typical lasers and their wavecmgths***

<b>Krypton</b>	<b>350 nm</b>	<b>ultraviolet</b>
<b>Argon</b>	<b>514 nm</b>	<b>visible</b>
<b>Ruby</b>	<b>694 nm</b>	<b>visible</b>
<b>CO<sub>2</sub></b>	<b>10,600 nm</b>	<b>infrared</b>

2. Continuous versus Pulsed Waves. Continuous wave lasers, as the name implies, are constantly emitted. These continuous wave lasers vary in energy output from fractions of a watt up to the kilowatt range. In contrast, pulsed lasers deliver lower energy levels (10–50 microwatts), but nevertheless exhibit a higher potential for eye injury. The greater destructive power of the pulsed laser lies in the very short time interval (billionth of a second, ns) over which the energy is delivered. On a comparative basis, a 20 mj pulse delivered over a 20 ns time period is comparable in power to one million watts of continuous laser emission.

3. Collimation. To collimate is to make parallel. The beams emitted from a laser, although not perfectly collimated, are very close to being parallel. The converse is true of the beams of light emitted from an ordinary incandescent light bulb, which diverge in all directions. As a result of this small divergence of laser beams, the entire silhouette of a soldier or the entire optical system of a battle tank can be covered by a single laser source six kilometers away.

4. Irradiance. Irradiance refers to the concentration of energy applied per unit area. Irradiance is expressed in watts per square centimeter. The energy output of a particular laser is a constant feature of that laser, whether it be the continuous or pulsed variety. Laser beams can be focused onto a small target or defocused by beam divergence to cover a larger area, the energy per unit area correspondingly increasing or decreasing according to the square of the target size. For example, because of divergence, the area covered by a beam at six kilometers is greater than the area covered by the same beam at one kilometer; however, the energy impacted per unit area (irradiance) is greater at one kilometer. Therefore, the “energy dose” received by the human eye at six km is less than at one km. On the other hand, optical devices such as binoculars,

periscopes, and weapons-sighting devices all gather light and laser waves and magnify by converging the rays onto a smaller surface area within the eye, thereby increasing the potential for damage.

5. **Tissue Effects.** The biological effects produced by lasers are different for continuous and pulsed lasers. Continuous wave lasers produce primarily a thermal effect, photocoagulation. Eye examination may reveal superficial and deep burns of the cornea with opacification and tissue loss, or areas of retinal burns and necrosis. Pulsed lasers, on the other hand, produce injury faster than thermal conductivity principles would predict. Pulsed lasers produce mechanical effects, acoustic shock waves, ultrasonic waves, and high energy fields. The end result is tissue disruption (manifested as retinal tears) hemorrhage of the retina and the vitreous, and subsequent necrosis of the retina and the vitreous.

### SPECIFIC LASERS

1. **Carbon Dioxide Laser.** The  $\text{CO}_2$  laser, with a wavelength of 10.6 microns, is not visible. It is highly absorbed by water, glass, plastics, all biological tissues (cornea and skin), most organic substances, and all fabrics. A high-energy, continuous wave  $\text{CO}_2$  laser will in one second char skin, destroy the cornea, opacify optical lenses, shatter glass, craze windshields, incinerate uniforms, and ignite fuels six kilometers distant from the source of emission. A similar laser operating in a pulsed mode can, in a single nano-second pulse, ablate the corneal epithelial surface. These effects, plus the fact that this laser is not visible, can produce devastating effects on troop morale and combat effectiveness.

2. **Noedymium:YAG (Nd:YAG) Laser.** This laser, with a wavelength of 1064 nm, operates near the infrared wavelength spectrum. This wavelength is not visible. It is employed most commonly in the pulsed mode, producing retinal tears and hemorrhage within the retina and vitreous, and later retinal detachment and necrosis.

3. **Lasers in the Visible Spectrum.** The principal lasers employed in a military setting in this category are the pulsed ruby (red, wavelength 694 nm), the frequency doubled Nd:YAG (green, wavelength 532 nm), and the continuous wave argon (blue-green, wavelength 514 nm). They all produce retinal thermal burns. The presence of flash blindness, retinal burns, and retinal vitreous

hemorrhage may indicate exposure to pulsed laser.

4. **Ultraviolet.** Lasers operating in this region of the spectrum are currently generally encountered in a laboratory setting. Their biological effect is one of inducing a photochemical reaction. However, a pulsed ultraviolet laser may produce tissue burns. The cornea and the skin are the organs most affected.

## MEDICAL CONCERNS

1. **Index of Suspicion.** Reports by combatants of observing bright flashes of light, of experiencing sudden eye discomfort or poor vision, or of feeling focal heat should alert the medical officer to the possibility of laser exposure and injury. Obvious lesions such as corneal burns, retinal tears, and hemorrhage or skin burns confirm one's suspicions. Conceivably, one might confuse the use of invisible lasers with chemical agent exposure which also irritates the eyes and skin. Spontaneous fires and unexplained damage to optical instruments further corroborate laser exposure

2. **Physical Examination.** Surface and deep burns of the cornea and the skin indicate that a high energy CO<sub>2</sub> laser has been used. Retinal hemorrhage probably implicates use of pulsed laser in the visible or near-infrared portion of the spectrum. Isolated retinal burns probably indicate exposure to a visible laser in the continuous wave mode.

3. **Therapy.** At the present time there is no definitive treatment for laser injury of the eye. Corneal burns are treated the same as ocular burns from other traumatic agents, specifically topical antibiotics, patches, and frequent examinations to monitor epithelial healing. It should also be borne in mind that the likelihood of an isolated corneal burn, especially of only one eye, is very small. Generally, there will be burns of both eyes as well as burns about the face and mouth. The general principles of treatment of facial burns and airway maintenance apply.

a. Soldiers who sustain laser injuries of the retina only should not be treated the same as those with corneal burns of the eye. Their injuries may range from small retinal spot burns to complete detachments and vitreous hemorrhages. Eye patches should be used sparingly in these cases, since eye patches only serve to magnify the soldier's visual impairment and increase his dependency for the basic needs of survival on others.

b. Panic and hysteria may **be the** major difficulty encountered. The fear of blindness and the witnessing of blinding injuries in comrades can cause a major disruption of combat effectiveness. Although the long-term disability for these casualties is great, their near-term medical requirements are small. They do not require a large expenditure of resources and should not be allowed to overburden the medical evacuation system if other more critically wounded require those resources. The tactical situation and the availability of surface or aeromedical evacuation assets will determine when these patients are moved to the rear. Retinal burns and vitreous hemorrhage cases can be delayed. Corneal or other **sur-**face burns receive standard first aid measures and are evacuated. For those with lesser injuries, an assessment of visual function and the presence of pain will determine how useful a soldier- can be to his unit and whether or not he should be evacuated.

4. Prevention. For **CO<sub>2</sub>** lasers, ordinary spectacle lenses will protect the eyes and ordinary visors will protect the face. When struck by the laser beam, one's spectacles and visors may become opaque or burned, thereby impeding vision. For visible laser protection, narrow-band filters for the elimination of lasers of specific or multiple wavelengths are currently undergoing development. The ideal protector will filter out only the deleterious wavelengths while allowing the remaining visible light to pass. Use of these wavelength filters may cause some tinting of one's vision. The use of several different wavelength filters may impair vision, particularly at night and during the hours of dusk and twilight due to their dark color.

## Wounds and Injuries of the Ear

Injuries of the ear are common in combat. Such injuries may be confined to the external ear in the form of contusions, lacerations, or avulsions. Blast injuries of the middle or inner ear may cause deafness which may be permanent. These wounds often are overlooked or relegated, to a low priority of treatment in a busy aid station or field hospital. However, such injuries, if not **ap**propriately treated, may result in prolonged morbidity or permanent disability.

Patients who have sustained injuries to the ear that include **im**pairment of hearing should be protected from additional acoustic trauma until maximum recovery is assured. Temporary or **perma**nent reassignment of duty may be necessary.

### THE EXTERNAL EAR

Trauma to the auricle is usually quite obvious and, unless treated promptly, may result in considerable cosmetic deformity. Among the more common injuries are lacerations, avulsions, contusions, or thermal injury.

In simple lacerations, the auricle should be debrided carefully with minimum excision of only the devitalized tissues. The physician then should close the laceration in layers, being careful to realign cartilage with absorbable suture material and the skin and subcutaneous tissues with a fine, atraumatic suture. All cutaneous sutures should be removed in 3-5 days.

If the auricle is partially avulsed, careful surgical debridement and reapproximation should be accomplished as soon as possible. In those instances when a portion of the auricle is missing, approximation of the anterior and posterior layers of skin over the exposed cartilage should be accomplished. Fragments of the auricle which are still present should not be sutured out of their normal anatomical alignment. In instances of total avulsion, the

cartilage should be debrided of all overlying tissue and buried subcutaneously in the abdominal wall (or other suitable area) so that it may be used for reconstruction at a later date.

When there is a hematoma of the auricle, the hemorrhage is usually subperiochondral in origin. Such hematomas are evacuated surgically and a sterile pressure dressing is applied. The dressing should be removed at least every 48 hours and the wound inspected for recurrence of the hemotoma.

Thermal injury should be treated by careful cleansing and application of topical antibacterial agents such as mafenide (Sulfamylon) on fine mesh gauze. Asepsis is critical. Suppurative chondritis can be prevented by careful attention to the avoidance of further trauma. A mesh dressing can be used to protect the entire head. No pillows are used.

In all of the cited injuries, systemic coverage with broad spectrum antibiotics, tetanus toxoid booster, and aseptic technique are essential.

If a laceration of the external auditory meatus is recognized early, precise initial suture repair is indicated. However, lacerations of the external auditory canal or fractures through its bony portion are less obvious and may be overlooked. Thus, they often do not become apparent until secondary infection has occurred. The external canal should be cleansed as aseptically as possible and a cotton or gauze wick impregnated with broad-spectrum antibiotic ear drops placed in the canal. Such patients should then be referred to the care of an otolaryngologist because of the strong possibility of stenosis as the canal heals.

The problems of external otitis, especially in tropical and subtropical climates, is well known to combat physicians. As innocuous as this entity may seem, it has caused considerable morbidity. In such circumstances, the skin of the external canal becomes macerated, affording an excellent culture medium for secondary infection. The organisms most commonly encountered are various species of *Pseudomonas* and *Proteus* with an occasional *Staphylococcus*. Thus, thorough cleansing plus broad-spectrum topical (and at times systemic) antibiotics are the treatment. A wick placed into the swollen canal allows topical medicines to be more effective. Water precautions are instituted. Such infections are often extremely painful, requiring analgesics.

## THE MIDDLE EAR

Injury of the tympanic membrane, which is common, is often associated with other much more serious injuries of the middle ear. The damage may be caused by direct penetration of a missile, by a fracture of the base of the skull involving the tympanic ring, or by sudden compression of the air in the external auditory **meatus** as the result of blast. A blast injury may cause a small hemorrhage in the substance of the membrane, rupture of the outer fibers, or a linear tear; or it may result in complete disintegration. The great risk is secondary infection, with possible deafness likely to be the end result.

Injury of the middle ear often does not present clear-cut symptoms. When it is suspected, the ear should be examined under aseptic precautions, with good illumination.

If rupture has occurred, instrumentation, drops, and syringing are all contraindicated. Wax is left in situ unless pain, deafness, or both require its removal. This is seldom necessary in a forward hospital. Eighty percent of these perforations will close spontaneously.

Treatment in the forward area consists of simple protection of the ear with a sterile dressing or a loose packing of sterile cotton. If the pinna is also damaged, the **meatus** should be packed with sterile cotton while the outer ear is being cleansed.

Until the ruptured tympanic membrane has healed, every precaution is taken to avoid nasopharyngeal infection. The patient is warned not to blow his nose. If suppuration occurs, it must be vigorously treated by ear drops and other standard measures to prevent chronicity. Delayed cholesteatoma formation is common in blast injuries.

## BAROTRAUMA

Barotrauma is often encountered in flying personnel. Symptoms usually occur on descent, when edema of the eustachian tube mucosa prevents equalization of pressure within the middle ear. This can result in symptoms varying from mild pain and slight hearing loss to severe pain and extreme vertigo. When it occurs, topical and systemic nasal decongestants, coupled with frequent Valsalva maneuvers, often will reverse the process. On occasion,

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a myringotomy may be required. Prompt recognition and treatment will often sharply decrease the associated morbidity. The condition is more prone to occur in those with upper respiratory infections.

### THE INNER EAR

Trauma to the inner ear may occur in combination with the above injuries or as an isolated injury secondary to blunt trauma. Such injury may be accompanied by total hearing loss, severe vertigo, high-pitched tinnitus, or facial nerve palsy. These injuries should be treated symptomatically and evacuated to the care of an otolaryngologist. If a basilar skull fracture is suspected, the use of antibiotics (usually penicillin) is mandatory. In all of these instances the patient should be cautioned against blowing his nose.

## Wounds and Injuries of the Neck

Wounds of the neck, because of the large number of vital structures within a compact area, are frequently complicated injuries which demand prompt surgical care. A single wound may damage multiple systems, involving the larynx, trachea, pharynx, esophagus, major vessels, multiple nerves, the spinal cord, and the cervical spine. Asphyxia and severe hemorrhage commonly occur. Pharyngeal and esophageal wounds that communicate with the mediastinum via the fascial planes of the neck may result in bacterial contamination of the mediastinum and subsequent mediastinitis. Foreign bodies carried through these soft tissues may cause further contamination. Small injuries to the skin and fascia may be associated with more severe injuries of deeper structures. Neck wounds are often associated with oral and intrathoracic injuries. These injuries may initially be occult but will demand attention. The hallmarks of good management of neck wounds are adequate incisions, generous exposure, and careful debridement followed by wide drainage. Antibiotics should be given to all patients with deep neck wounds.

### IMMEDIATE LIFE THREATENING INJURY, MAJOR BLEEDING, AND AIRWAY OBSTRUCTION

Severe and even fatal external hemorrhage can occur from innocuous-appearing wounds of the neck. Probing or blind clamping of an open, bleeding neck wound rarely controls hemorrhage and frequently causes further injury. The hemorrhage in many severe neck injuries is venous in origin and can be controlled by external pressure. Airway compromise may result from direct trauma, from endotracheal blood and blood clots, from laryngotracheal edema, or from nerve injury. Endotracheal intubation in these cases may be impossible, particularly in patients with extensive bleeding from wounds of the mouth or pharynx. When

airway obstruction persists in the patient who cannot be intubated orally, cricothyroidotomy provides rapid and safe airway control. This should be viewed as a temporizing life-saving procedure which will be replaced by a tracheostomy under controlled circumstances if one anticipates the requirement for airway control lasting more than 48 hours.

## WOUNDS OF THE LARYNX AND TRACHEA

Serious wounds of the larynx and trachea may present in the following ways:

1. **Asphyxia.** Asphyxia results from serious laryngotracheal obstruction. The obstruction may be caused by destruction of the larynx, the fragments of which form obstructing flaps; by hemorrhage, which blocks the airway with blood or clots; or by traumatic laryngotracheal edema. Restlessness observed in these patients, if secondary to cerebral hypoxia, heralds impending asphyxia.

2. **Dyspnea.** Dyspnea may result from lesser damage to the larynx or trachea. The cause of asphyxial injuries is usually immediately apparent, whereas injuries causing dyspnea can often be found only by careful examination. The most common symptoms and signs of airway injury, in addition to dyspnea, are dysphonia, laryngeal cough, hemoptysis, dysphagia, and excess mobility of the larynx. Roentgenologic examination of the laryngeal and tracheal cartilages, which are always ossified to some degree in adults, and preoperative laryngoscopy are of diagnostic assistance

3. **Subcutaneous emphysema of the face and neck.** Retropharyngeal swelling, although infrequently detected on physical examination, is readily demonstrable on biplanar soft-tissue X-ray films by narrowing or distortion of the air column.

All injuries of the trachea and larynx are serious. Diagnosis is confirmed by laryngoscopy or bronchoscopy, which should be performed at the slightest suspicion of injury. These examinations are often done at the time of airway control, following which an endotracheal tube may be inserted. The early use of this procedure often precludes the performance of a hasty tracheostomy. On the other hand, emergency tracheostomy may be necessary when the injury crushes or distorts the larynx or hypopharynx such that intubation cannot be accomplished. In such cases,

urgent decompression of the deep subfascial space may also be necessary to relieve pressure on the airway. In the presence of a functioning tracheostomy, laryngeal injuries can go undiagnosed, with subsequent serious loss of function, much of which may have been prevented by early diagnosis and appropriate treatment.

Careful and conservative debridement of laryngotracheal injuries is emphasized. Following debridement, the fragmented larynx or trachea should be reapproximated and an intraluminal stent utilized to maintain the anatomical architecture. Late tracheal and laryngeal stenosis from injudicious and excessive removal of tissue, particularly cartilage and mucosa, must be prevented. Care must be taken to identify associated wounds of adjacent structures, such as esophagus, pharynx, and major vessels.

Airway control via either endotracheal intubation or tracheostomy requires constant aftercare to avoid sudden obstruction with resultant asphyxia. Proper tube size is important. Too small a tube can result in gradual respiratory insufficiency, leading to hypoxia and cardiac arrest. Overinflation of "hard" endotracheal tube balloons must be prevented to avoid damage to tracheal tissue.

## WOUNDS OF THE PHARYNX AND ESOPHAGUS

The pharynx and esophagus are often involved in injuries of the neck, with resultant high likelihood of contamination of the deep fascial planes of the neck and the mediastinum. Small lesions of the posterior pharynx and esophagus are often overlooked in the presence of other neck injuries and can lead to severe morbidity and death. Examination must be thorough and includes endoscopy. Any penetrating injury, however small, must be suspect. Soft-tissue X-ray films may be useful as previously described. Radiopaque contrast media may demonstrate leaks not apparent by other means.

Management is based on surgical exploration, both to identify lesions and to debride and close lacerations of the mucosa and muscularis of the pharynx and esophagus. Double-layer closure of defects is the treatment of choice, followed by adequate external drainage. Wide wounds of the pharynx or esophagus which cannot be closed require either marsupialization or wide drainage. Nasogastric intubation is necessary early on to minimize wound

contamination secondary to regurgitation and later on for feeding purposes.

### VASCULAR INJURIES

Injury of major neck or mediastinal vascular structures is often fatal. Venous injuries have the added risk of air embolism. Serious vascular injuries may be masked by the severe shock state in the patient with multiple injuries. These may become apparent only after resuscitation has begun. The severity of blood loss may be masked when neck wounds communicate with the pleural space (hemothorax). Suspicion of vascular injury requires early exploration. Anterior thoracotomy in the third interspace on the involved side permits immediate intrathoracic access to the great vessels. Bleeding sites can be controlled with direct pressure and packs while developing definitive exposure. Definitive exposure of this region is then provided by median sternotomy. This exposure also can be obtained by extending the neck incision into a full median sternotomy incision.

The following points regarding the management of vascular injuries are emphasized:

1. The mortality from uncontrolled hemorrhage is second only to asphyxiation in wounds to the neck. Airway control and hemostasis are, therefore, the initial steps.

2. Serious vascular injury often presents as a gradually enlarging hematoma, which can encroach upon the airway. Airway encroachment is produced by hematoma which expands within the triple-layered, closed, deep fascial compartments of the neck. The fascial arrangement also prevents outward expansion of extravasating blood, sometimes making the diagnosis of vascular injury difficult.

3. Penetrating wounds of the neck, because of the possibility of vascular injury, require definitive surgical exploration. Exploration should include the carotid and internal jugular systems. Should vascular repair be required, adequate exposure with proximal and distal control is the cardinal technical consideration in vascular surgery.

4. Lateral repair or end-to-end anastomosis after debridement of the injured wall of any artery is preferred. If this is not possible, an autogenous vein graft may be used to bridge an arterial defect.

The use of an internal or external shunt to maintain cerebral circulation during repair is preferred. The importance of adequate oxygenation and maintenance of blood volume cannot be overemphasized.

5. The external carotid system may be ligated without morbidity. Ligation of the internal carotid artery may be the safest procedure for patients with an injury to this vessel when there is an already established neurological deficit.

6. Ligation of the internal jugular system is indicated when lateral repair is not possible.

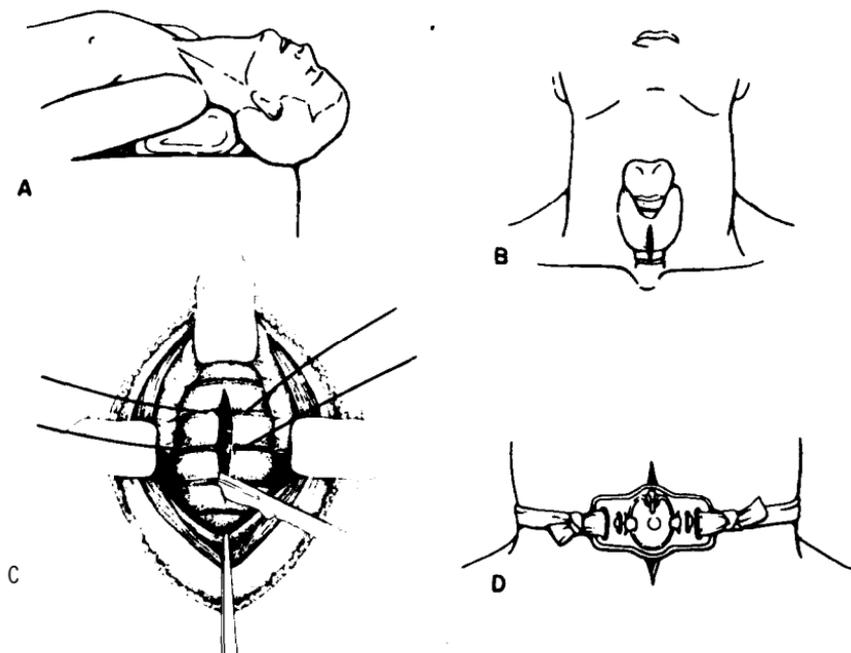
### NERVE INJURIES

Nerve injuries should be identified and recorded for possible later repair. In general, immediate repair of traumatic nerve defects is not recommended, except for isolated injuries of the facial and spinal accessory nerves. Even when ideally treated by delayed neurorrhaphy, the proximal location of the nerve injury in the neck precludes significant success. High-velocity missile wounds of the neck involving the spinal cord are almost always fatal.

### EMERGENCY TRACHEOSTOMY

**Tracheostomy** as a lifesaving procedure has proven its worth many times over (Figure 32); however, tracheostomy requires a thorough knowledge of anatomy and must be performed many times before it can be done both quickly and safely.

Adequate lighting is essential. Positioning is also very important in tracheostomy. The patient lies supine, with the shoulders elevated by sandbags or folded towels, so that the neck is extended. Local anesthesia is usually utilized. The incision may be longitudinal or transverse. The transverse incision will insure a better cosmetic result, but the longitudinal incision is almost bloodless and there is more rapid exposure of the trachea with it. It is made in the midline, through the skin and platysma, from the **cricoid** cartilage to the suprasternal notch. The strap muscles are separated in the midline by blunt dissection. When they are retracted, the trachea is exposed. If the isthmus of the thyroid is encountered, it is displaced upward or downward. Local



**FIGURE 32.-Technique of tracheostomy. A. Position of the patient with neck hyperextended. B. Location of the incision. C. Thyroid isthmus elevated, pretracheal veins separated, vertical incision in trachea. D. Tracheostomy tube in place.**

anesthesia, in the amount of 1-2 cc, is injected into the tracheal lumen to reduce the cough reflex. The pretracheal fascia is incised and stripped laterally as necessary to expose the underlying cartilages.

The ideal level at which to incise the trachea is at the level of the second, third, and fourth tracheal rings. The trachea is retracted with a hook between the cricoid and first ring while a vertical incision is made through three tracheal rings. The incision should be made long enough to accommodate the diameter of the tube to be inserted. A heavy silk suture, passed through each side of the incised trachea, may later be used as a retractor and guide to facilitate early tracheostomy tube changes. The adult male trachea can easily accommodate a size 6-9 tracheostomy tube. Smaller tubes cause airway resistance and can lead to hypoxia. Position and secure the tube. The skin incision does not require closure.

Suction should be available at operation to remove secretions from the trachea. If it is not available, the head should be lowered

as soon as the trachea has been opened.

Complications associated with tracheostomy are more frequent than realized and should be mentioned:

1. Asphyxia from dislodged or occluded tubes.
2. Immediate or delayed severe hemorrhage from innominate, subclavian, and carotid vessels.
3. Subcutaneous emphysema with possible pneumomediastinum or pneumothorax.
4. Tracheoesophageal fistula.
5. Tracheal and laryngeal stenosis.

### TECHNIQUE FOR CRICOTHYROIDOTOMY

As previously mentioned, in extreme airway emergencies or when the medical officer has had no experience with endotracheal intubation or tracheostomy or lacks the appropriate equipment, a cricothyroidotomy should be performed. The inferior border of the large, prominent thyroid cartilage is identified by palpation. The cricoid cartilage, which is the smaller protuberance just below, is similarly identified. The taut membrane which separates the thyroid cartilage from the inferiorly located cricoid cartilage is relatively superficial. After adequate skin incision, the space between these cartilages, which is avascular, is incised transversely and the tracheal lumen is readily entered through the incision. A small endotracheal tube, no. 5 or no. 6, should be rapidly inserted and the balloon inflated. If no tube is available, a clamp may be used temporarily to keep the incision open. The cricothyroidotomy should be relied upon for only 48 hours. If airway management is anticipated for greater than 48 hours a conventional tracheostomy should be accomplished under controlled circumstances as soon as possible.

# Wounds and Injuries of the Chest

About 15% of combat injuries sustained during conventional land warfare will involve the thoracic viscera and/or the chest wall. In two-thirds, the thoracic wound will be the principle injury. The spectrum of injury ranges from casualties with grossly mutilating blast injuries to those with only tiny superficial fragment wounds. The great majority of chest casualties will have penetrating trauma. After excluding the approximately 10% with only soft tissue wounds, the remainder can be categorized into two populations: about two-thirds will have missile wounds of the heart, great vessels, or pulmonary hilum; and the others will have missile wounds of the pulmonary parenchyma. It is unusual for casualties in the former category to present as treatment problems, since the vast majority exsanguinate before reaching a medical treatment facility. By way of contrast, casualties with wounds of the lung usually survive to reach medical treatment, which in most instances involves no more than the insertion of a chest tube. About 5% of the total thoracic casualty population will have sustained blunt trauma, more often than not occurring when an armored fighting vehicle is damaged by a mine. Viewed from the historical perspective, the principal function of thoracic surgery in wartime has not been the performance of emergency life-saving surgery, but rather the management of chronic complications such as clotted hemothorax and empyema. Whether better field resuscitation, more rapid evacuation from the battlefield, and the availability of surgeons trained in the management of thoracic trauma will change the role of thoracic surgery is unclear.

### ANATOMICAL AND PHYSIOLOGICAL PATHOLOGY

Shock and hypoxia, the pathophysiological derangements by which chest trauma kills, result from decreased venous return or

inadequate alveolar gas exchange. Decreased venous return is usually a manifestation of exsanguination, thus the paramount importance of controlling bleeding. Inadequate alveolar gas exchange can result from such factors as loss of the usual negative intrapleural pressure, leading to collapse of the lung, and obstruction of the smaller air passages by secretions or blood. The therapeutic goal is to restore normal physiology and thereby to restore cardiac and pulmonary function. Thus is true not only in the immediate post-injury phase, but also later in the course when the surgeon is faced by such chronic complications as trapped lung or the need to reconstruct the chest wall. Salient aspects of common battlefield thoracic problems are considered below.

### PNEUMOTHORAX

The presence of air in the pleural space results in the loss of the normal negative pressure gradient across the alveoli and the visceral pleura. The lung is no longer coupled to the parietal pleura and is collapsed by the recoil of its elastic tissue. Air no longer enters the collapsed alveoli which, however, remain perfused at least until hypoxia-mediated pulmonary vasoconstriction reduces flow. Perfusion of the nonventilated lung tissue results in a ventilation-perfusion inequality, which is apparent as **desaturation** of the arterial blood. The source of the intrapleural air is usually laceration of the pulmonary parenchyma. In a minority of casualties, the lacerated pulmonary tissue forms a flap valve which allows air to enter the pleural space, but not to exit. **In**-trapleural pressure may become so positive that the mediastinum is displaced to the opposite side and the uninjured lung severely compressed. The dire consequences of a tension pneumothorax are profound alveolar hypoventilation and decreased cardiac output, the latter probably being due to impeded venous return secondary to mechanical kinking of the great veins. Untreated, death may occur within minutes of injury. Pneumothorax may also result from air entering through a hole in the chest wall. Here the problem is not positive intrathoracic pressure, but the fact that, given a sufficiently large hole relative to the area of the airway, there will be less resistance to airflow into the pleural space than into the lung. Profound alveolar hypoventilation results. Open pneumothorax is not commonly seen in living casualties because

the trauma necessary to produce a large defect usually causes a fatal intrathoracic injury.

### HEMOTHORAX

Hemothorax is dangerous not only because it can lead to hypovolemic shock, but also because it may result in compression of the injured lung and thereby cause a reduction in vital capacity. Bleeding may arise from lacerated pulmonary parenchyma, from systemic arteries such as the **intercostals** or the internal **mammaries**, or from the heart and great vessels. Bleeding from the latter may be so massive as to create a rapidly fatal condition best characterized as a tension hemothorax.

### HEMOPNEUMOTHORAX

About one-half of casualties with penetrating wounds of the lung will present with hemopneumothorax, a situation to be expected because of the propensity of a missile to lacerate contiguous structures, such as bronchioles and arterioles. A frequent concomitant injury is pulmonary "contusion." There is increasing evidence that the contusion around the missile tract is actually hematoma in a parenchymal laceration. Contusion remote from the permanent missile tract is due to intraalveolar blood which has entered the bronchial tree and is aspirated into the uninjured lung. A more severe manifestation of combined bronchial and arterial injury is seen in many fatally wounded thoracic casualties who quite literally drown in their own blood.

### PERICARDIAL TAMPONADE

The great majority of missile wounds of the heart create a pericardial defect which allows blood from the lacerated **myocardium** to freely escape. Tamponade cannot occur and death results from exsanguination. Small fragment wounds are compatible with **tamponade**. As blood collects in the pericardial space, the transmural pressure gradient progressively falls, resulting in collapse of the great veins and displacement of the intraventricular septum to the left. As blood continues to collect, venous pressure

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risers and cardiac output and blood pressure fall. Because of the nonlinear pressure-volume characteristics of the pericardium, a point is ultimately reached at which a small additional increment of blood will result in sudden cardiovascular collapse and death.

### BLUNT CHEST TRAUMA

The clinical syndrome associated with multiple rib fractures and a flail chest is the quintessential expression of blunt trauma and does not differ in its manifestations or treatment in combat casualties and civilian trauma victims. The severity of the injury is dependent upon the number and locations of the fractured ribs (which in turn determine the extent to which the chest wall is unstable), the presence of an underlying lung injury, whether a hemo/pneumothorax is present, and the magnitude of associated injuries to other thoracic viscera, such as an aortic disruption or a ruptured diaphragm. The unstable portion of the chest wall moves paradoxically with respiration, being drawn inward during inspiration and blown outward during expiration. The former results in decreased pulmonary ventilation, while the latter results in a weak cough and consequent retention of tracheobronchial secretions. Pulmonary contusion is frequently associated with flail chest and this, rather than the mechanical instability of the chest wall, may dominate the clinical picture

### TRAPPED LUNG/EMPYEMA

These chronic complications of thoracic trauma have the potential to become important sources of morbidity in future wars, unless the lessons learned in the past are remembered. Trapped lung results from incomplete early evacuation of blood from the pleural space with subsequent replacement of the fibrin clot by fibrous tissue, which, as it contracts, squeezes the lung into a non-functioning organ. Vital capacity is reduced and arterial hypoxemia may be apparent. Empyema, a frequent cause of death in World War I thoracic casualties, is another manifestation of inadequate evacuation of a hemothorax.

## RETAINED MISSILE

Retained missiles may cause problems in two different ways. First, they may become the nidus of infection that results in an empyema or wound-tract sepsis. Second, they may on rare occasions enter the circulation by migrating from the lung or by being dislodged from a previously dormant state within a cardiac chamber. Then they may embolize in a quite unpredictable manner to other parts of the arterial tree.

## DIAGNOSIS

Establishing a diagnosis of a thoracic injury in a combat casualty is exceedingly simple: there is a hole (or holes) in the chest, and the casualty usually complains of pain when he breathes. Often the casualty will be obviously dyspneic or be in frank respiratory distress, fighting for every breath. Those less severely injured will cough up bloody sputum, while gurgling breath sounds will be all too obvious in the dying. The casualty may have some of the more obvious clinical signs of shock: rapid and weak peripheral pulse, cold clammy skin, depressed sensorium, etc Inspection may reveal a large hole in the chest wall from which frothy fluid is expelled with each exhalation. Certain clinical syndromes have stigmata which are so obvious that they may even be useful in spite of the chaotic conditions of the battlefield. With a tension pneumothorax, the trachea as felt in the neck is displaced to the side opposite to the injury, and the affected hemithorax may sound like a drum when it is percussed. When blunt injury has occurred, the medical officer will find tenderness to palpation and possibly bony crepitus in the traumatized area. He may notice that a portion of the chest wall, in size usually exceeding the area of the palm, appears to be moving out of sequence with the rest of the chest and abdomen.

Given the paucity of diagnostic imaging capabilities in the lower echelons providing combat casualty care, it is indeed fortunate that so much can be done with inspection and palpation. However, chest X-ray is useful if for no other reason than it allows the surgeon to determine that a chest tube has been placed where it should be placed. Furthermore chest X-ray is helpful in establishing whether a small pneumothorax is present or whether

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a hemothorax has been adequately evacuated. A chest X-ray may also give some idea as to the likelihood of a cardiac injury, since the localization of a missile within the cardiac silhouette, especially when combined with shock, is suggestive of tamponade. Combat experience has shown that the classic physical findings of tamponade (muffled heart sounds, dilated neck veins, narrowed pulse pressure, a "paradoxical" decrease in systolic pressure of more than 10 mm Hg during inspiration, and enlarged heart to percussion), cannot be depended upon to establish this diagnosis.

### TREATMENT

What therapeutic interventions can be undertaken is determined by the echelon of care. What echelons will be used depends in turn upon the pathway of evacuation. Casualties may be evacuated directly from the battlefield to surgical facilities, or they may pass through progressive echelons of increasingly sophisticated care. Regardless of the evacuation pathway, the medical **officer** at any echelon is unlikely to do any harm if he does the following:

REMOVE bloody secretions from the airway

SEAL chest wall holes

REMOVE air from the pleural space

REMOVE blood from the pleural space

RESTORE circulating volume deficits

REMOVE blood from the pericardial sac

REMOVE pus from the pleural space

Surgical and radiographic facilities are not available in battalion aid stations. Therefore, treatment of chest wounds at this echelon must be limited to first aid and lifesaving interventions. These are best addressed in terms of the Advanced Trauma Life Support (ATLS) course's priorities which are, of course, applicable to all echelons of care.

Relief of upper airway obstruction is assigned first priority. The great majority of combat casualties with upper airway obstruction have either massive trauma to the face or a severe brain injury. It is quite clear that both nasal and oral endotracheal intubation in the former population is likely to prove quite **difficult**. Thus, most casualties requiring airway control will need a surgical airway or an oral airway. A description of the technique for performing

either a cricothyroidotomy or **tracheostomy** is found in the chapter on neck injuries. It is necessary at this point to comment about cervical spine control. Penetrating cervical cord wounds in salvageable combat casualties are quite unusual. It is essential that misplaced concern about aggravating a possible cervical cord injury should not interfere with life-saving care for real problems.

Second priority is accorded to correcting respiratory problems. At the unit level, this will mean first and foremost inserting an intercostal drainage tube by means of a closed thoracostomy or, much less commonly, dressing an open chest wound. The casualty with a tension pneumothorax is most expeditiously managed by first venting the hemothorax by inserting a large-bore needle (14 gauge) through the second intercostal space. A chest tube should then be inserted. The technique for inserting a chest tube is described in the chapter on multiple injuries. The essential feature is to make an incision in the chest wall sufficiently large to allow entrance of a finger. By so doing, one assures that the chest tube is in fact placed within the pleural space. The large hole also assures that a chest tube of optimal caliber (40-45 Fr.) can be inserted. Sites for insertion are usually the fifth intercostal space midaxillary line or the second intercostal space midclavicular line. A closed thoracostomy utilizing a trocar is a useful alternative to the above, although the size of the chest tube may be insufficient to allow adequate removal of blood and clot. A chest tube should not be inserted through the missile tract. The chest tube should be secured to the patient and connected to a flutter valve such as the Heimlich.

Third priority is assigned to the management of bleeding and shock. Little can be done for the thoracic casualty in shock at this echelon other than to start an intravenous infusion of crystalloid fluid through two or more large-bore catheters.

Given a tactical situation in which direct aeromedical evacuation from the battlefield to surgical treatment facilities is not possible, the fundamental contribution of the unit level to the medical care of the thoracic combat casualty will be to prepare the casualty for safe evacuation to a definitive care facility. From the practical standpoint, this means that casualties with penetrating missile wounds of the chest that are clearly not superficial should have chest tubes placed. Ancillary interventions must include the administration of a potent **antimicrobial** agent and relief of pain if indicated.

## MANAGEMENT AT THE DIVISION LEVEL

Whatever could have been done at the unit level but was not done should be done by the divisional medical officer. Chest tubes should be connected to underwater seal and suction. X-ray will help determine whether additional tubes are needed. Antibiotic administration should be continued. The ability to infuse blood may make possible the salvage of occasional casualties who are exsanguinating. Perhaps the most important function of this echelon of care is triage. Two categories of casualties need to be recognized: those who need early surgical care and therefore need priority evacuation, and those casualties who stand a good chance of early return to duty. Thoracic casualties with little or no air leak or bleeding are good candidates for prompt return to duty and **should be** removed from the evacuation pathway.

## MANAGEMENT AT THE SURGICAL TREATMENT FACILITY

Emergency life-saving interventions may be necessary in casualties evacuated directly from the battlefield. However, more often than not, the important problem facing the surgeon will be to decide whether an operation beyond simple soft tissue wound care is indicated. The most common reason for performing a thoracotomy is massive or persistent bleeding. Since bleeding from most missile wounds of the lung parenchyma will stop when the lung is expanded, thoracotomy is seldom required. However, with the advent of more potent small arms, the surgeon is likely to encounter casualties with grossly destructive wounds of the lung, wounds which will not stop bleeding without surgical intervention. As a general rule, hemorrhage from chest wall arteries will require surgical ligation. Casualties with wounds of the heart or great vessels are much less common, constituting only **2-3%** of the total thoracic population who survive to be evacuated from the battlefield.

The following are useful indications for performing a formal thoracotomy:

1. An **opacified** hemithorax on X-ray.

2. Initial drainage of 1,500 ml of blood followed by 500 ml or more in the next hour.

3. Drainage of 200-300 ml of blood per hour for more than 4 hours.

4. Massive airleak with continuous bubbling throughout the respiratory cycle

5. X-ray evidence of massive pulmonary contusion or hematoma, with clinical and laboratory evidence of a life threatening shunt or airway compromise secondary to pulmonary bleeding.

6. Physical signs of pericardial tamponade or suspicion of tamponade or shock, and X-ray evidence of a missile in proximity to heart.

Suspected wounds of the lungs are best approached through a formal posterior lateral thoracotomy made through the fifth or sixth interspace. Wounds of the heart are best approached through an anterior thoracotomy made in the fifth intercostal space on the side of the missile wound with extension across the sternum if necessary. A median sternotomy is less often employed if for no other reason than that appropriate instruments to divide the sternum may not be available. A pericardiocentesis should not be used as an alternative to thoracotomy. The need to be constantly vigilant for signs of recurrent tamponade, and the possibility that the operating room will have been preempted by a mass casualty situation just when it is obvious that conservative management has failed, speak against pericardiocentesis in a combat zone hospital.

Although it is usually said that the casualty should have received optimal resuscitation (correction of hypovolemia and acidosis, etc) prior to going to the operating room, from the practical standpoint this is frequently not possible because operation is required for resuscitation. All thoracotomies should be done under general anesthesia with controlled positive pressure ventilation through a secure airway. Intraoperative management will usually involve debridement of partially detached lung, ligation of bleeding vessels, and oversewing of lacerated lung. If airleaks persist, if the parenchyma of one or more lobes has been shattered, or if the anesthetist reports persistence of copious tracheobronchial bleeding a formal resection should be considered. Although unusual, there are case reports of lifesaving lobectomies and pneumonectomies given such circumstances. Chest closure should

follow standard practice. At least two chest tubes should be inserted, one high and anterior and one low and lateral. Antibiotic coverage, starting before the incision is made, is essential.

Wounds of the heart seen at operation are usually small, and hemorrhage can be controlled by digital pressure while bolstered mattress sutures are inserted. Care should be taken not to incarcerate an epicardial coronary artery in the suture; the suture can always be placed deep to the artery. A rare casualty will have a wound of an epicardial artery. Given the nonavailability of cardiopulmonary bypass, there is no alternative but to ligate the vessel and hope for the best.

Large open wounds of the chest wall require debridement and airtight closure of the musculofascial layer. Rib fragments should be removed and rib ends smoothed to prevent subsequent laceration of the lung. It is frequently possible to evaluate the lung and to evacuate the pleural space by extending the wound defect. Thus the casualty is spared a formal thoracotomy. This fact helps explain why fewer 20% of thoracic casualties have formal thoracotomies; many have de facto minithoracotomies as part of their chest wall wound management.

Clotted hemothorax and infected hemothorax are complications which may become apparent prior to evacuation from the combat zone. A clotted hemothorax should be surgically removed if it is less than 7-10 days old. Beyond that time, thoracotomy should be delayed for 4-5 weeks, after which a pleural decortication should be performed. During the decortication, care should be taken when performing the dissection where the parietal pleura reflects onto the lung posteriorly. If this "comer" is not turned properly, the dissection may enter the aorta or esophagus. The same problem exists when the dissection is carried into the diaphragm. If the procedure is delayed for months, the problem will be a trapped lung. Decortication is indicated if more than the equivalent of one lobe is nonfunctional. An infected hemothorax cannot be removed by tube drainage and will require decortication at whatever time it becomes apparent. Retained foreign bodies should be removed electively if they exceed 1.5 cm in size. Notwithstanding the experience of World War II, intracardiac foreign bodies should not be removed unless cardiopulmonary bypass is readily available.

Penetrating combat trauma involving the esophagus or trachea is rare. There is suggestive evidence that small penetrating injuries,

especially of the membranous trachea, may be benign. If **pneumo-**mediastinum is apparent on X-ray, bronchoscopy is indicated. If no wound is apparent, observation is indicated. When an esophageal wound is found at the time of thoracotomy performed for bleeding, more often than not a gross defect is found which can be treated only by defunctionalization. Use of a gastric patch to close a low esophageal war wound has been described. Another rare manifestation of penetrating chest trauma is post-traumatic pneumatocele. Lungs tolerate the temporary cavity produced by a high-energy transfer missile with much less damage than do solid parenchymal organs, such as the brain and liver, but occasional casualties will be seen who develop a cyst around the permanent tract. This should occasion some concern because such **post-**traumatic cysts may become infected or be the site of massive hemorrhage. If they do not promptly regress, they should be excised.

About 20% of the casualties with wounds of the trunk will have penetrating injuries of both the chest and abdomen. In about 50% of these casualties, the same missile is responsible for both components. Experience has shown that the abdominal component usually has the greatest injury severity, and that adequate treatment consists of laparotomy and insertion of a chest tube. The surgeon must not neglect to close the perforation of the diaphragm.

#### POSTOPERATIVE MANAGEMENT AND EVACUATION CONSIDERATIONS

The combat surgeon must not expect to find available the same spectrum of resources as are found in the civilian surgical intensive care ward. Nevertheless, survival of at least 90 % of the chest casualties evacuated from the battlefield is to be expected. In the postoperative period, careful attention should be paid to the maintenance of adequate pulmonary ventilation and the removal of tracheobronchial secretions by coughing and suctioning. These interventions have been instrumental in lessening the incidence of the pulmonary edema-like syndrome known as "wet lung," which was so common in World War II casualties. Analgesia, preferably given by intercostal block, may lessen the need for suction. However, the surgeon must not delay in resorting to

suctioning or even bronchoscopic aspiration for the removal of secretions. Patients who cannot ventilate adequately will require the assistance of a volume cycled respirator. Surgeons should be aware that arterial blood gas determinations may not be available for guiding the management of such patients. Furthermore, reliance on clinical judgment rather than invasive monitoring will be necessary to minimize the possibility of fluid overload during the early postoperative period. Diuretic agents may be necessary to decrease pulmonary extravascular water. In a recent Israeli experience, as many as 25% of severely wounded casualties were inadvertently volume overloaded and needed diuretics or even phlebotomy. It is unwise to attempt to evacuate casualties who still require ventilator-y support from the combat zone. Patients should not be evacuated by air until at least three days have elapsed following removal of chest tubes. In one series, about 20% of the Vietnam chest casualties evacuated by air developed a recurrent pneumothorax, and arterial hypoxia was a common finding.

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## CHAPTER XXIX

# Wounds of the Abdomen

### INITIAL EVALUATION

The goal of the initial evaluation is to allow the surgeon to determine the probability of an intra-abdominal injury. There is no overriding need for a more specific diagnosis. There are no clearly defined minimally acceptable standards for success. The surgeon must simply do the best that he can for the most patients under the existing circumstances. The "best" is defined as no missed intra-abdominal injuries with the fewest possible negative exploratory laparotomies.

The combat surgeon can consistently achieve this goal by consciously taking four actions. These actions are systematic evaluation of the patient, classification of the patient, consideration of extenuating circumstances, and preparation for operation. Each of these acts is of equal importance. They must be performed simultaneously.

### SYSTEMATIC EVALUATION

Evaluation of the combat casualty differs from evaluation in civilian practice. First, there always is a possibility of early evacuation secondary to factors beyond the surgeon's control. The military surgeon cannot assume that he will be able to reexamine the patient at a later time. A decision must be reached each time the surgeon and patient are separated. Procrastination, reflection, and consultation are luxuries seldom enjoyed by the forward surgeon. Second, sophisticated studies, such as arteriography and CT scans, will generally not be available in the forward hospital. Third, the surgeon must deal with distractions such as multiple casualties, massive wounds, logistics breakdowns, the possibility of hostile fire, and the general confusion of war. He must maintain a high index of suspicion and an appreciation of the subtle nature of the signs of serious intra-abdominal injury. All of these

casualties can be evaluated rapidly yet carefully if the examination is performed in a systematic manner. The surgeon must appreciate that rapid pulse, narrowed pulse pressure, lowered blood pressure, poor capillary refill, and decreased urinary output are evidence of hypovolemia. In the absence of external evidence of blood loss or evidence of intrathoracic blood loss, these signs are presumptive evidence of intra-abdominal injury.

### The History

In war, few individuals have an appreciation of anything beyond their own immediate environment. These conditions produce wildly inaccurate and often contradictory reports of time of wounding, weapons used, and location of injuries. The surgeon is exposed to reports of local and strategic military activities that may or may not be true. It is wisest for the surgeon to believe only what can be seen or felt. The history is of value when the patient identifies the presence, absence, or the location of pain; allergies, and time of last meal. Any other information must be carefully evaluated before being seriously considered. The history is useful when received from other medical personnel, but this should be confined to clinical information.

### Inspection

The casualty must be undressed. Mud and other material that can conceal a wound must be cleared. Illumination must be adequate. The surgeon must personally do the exam, but at least one person must assist him. The assistant must understand what the surgeon is trying to do. The surgeon must carefully inspect all of the abdomen from the nipples to the upper thigh, the flanks, the back, and the perineum. This cannot be done without turning the patient, abducting the lower extremities, and spreading the buttocks. The examining team must make allowances for other injuries while performing this examination.

Any evidence of a penetrating injury, no matter how innocuous, must be assumed to represent an intra-abdominal wound and treated accordingly. Missile tracts are unpredictable. Even though these wounds must be debrided, exploration of the wound itself is time consuming and more often than not reveals no definitive information. The surgeon must assume that a penetrating injury

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of the torso is evidence of an intra-abdominal wound unless the converse is proven. More discretion can be used if there is only evidence of blunt trauma.

Abdominal distension is abnormal in healthy soldiers and may be the only evidence of an intra-abdominal injury. The examining surgeon must consciously search for this most subtle of signs. Splinting of respiration is also abnormal and, excluding chest injury, should be considered strong evidence of intra-abdominal injury.

### Palpation

Tenderness must be searched for systematically. This may be **difficult** to accomplish in an excited, apprehensive young soldier who might well have other painful injuries. The surgeon must be certain that he has the patient's attention and cooperation. Each abdominal quadrant should be examined separately. The presence of involuntary guarding confirms intra-abdominal injury, but this sign may be hard to define under these circumstances. Medial and lateral pressure on the iliac spine and pressure on the pubic **symphysis** are used to search for pelvic fractures. The presence or absence of femoral pulses should be noted. Abdominal tenderness is more often due to intra-abdominal injury than to abdominal wall trauma. If tenderness is present, the surgeon should re-examine the abdomen after a urinary catheter and a nasogastric tube are in place. Urinary retention and acute gastric dilation are not uncommon in these patients.

### Auscultation

This is an essential part of the evaluation. Absent or significantly decreased bowel sounds are abnormal in a healthy young soldier and must be considered presumptive evidence of intra-abdominal injury.

## SECONDARY EVALUATION

If there is any reason to suspect an intra-abdominal injury, secondary evaluation is necessary. The surgeon must convince himself that there is clear and unequivocal evidence that there is no intra-abdominal injury. If this is the case, attention can be

directed to other problems.

### **Indwelling Urinary Catheter**

If there is no evidence of urethral injury, an indwelling urinary catheter should be inserted and the absence or presence of blood in the urine noted.

### **Nasogastric Tube**

A nasogastric tube should be passed and connected to some type of drainage. The absence or presence of blood in the aspirate should be noted.

### **Rectal Exam**

A digital rectal exam is of critical importance in patients with a lower abdominal or perineal wound. The presence or absence of blood in the rectum is determined. The value of a more sophisticated exam, such as endoscopy or barium enema, is limited by the usual presence of stool in the rectum of most of these patients and the time needed to perform the exam. The position of the prostate should be noted.

### **Re-examination**

The abdomen should be re-evaluated when these procedures are completed. An acutely distended urinary bladder or stomach can be the cause of abdominal pain or tenderness.

### **X-rays**

Simple KUB and lateral films of the abdomen are of great assistance in the search for radiopaque fragments. The films are of value only if positive. Normal X-rays do not rule out injury. If exploratory laparotomy is contemplated, a "single shot" intravenous pyelogram is important to determine if there are two functioning kidneys and if there is evidence of extravasation of urine.

Further studies, such as angiography, are not likely to be available. Other studies, such as peritoneal lavage, often require

more time than the surgeon has to devote to one patient.

It is best for the surgeon to base decisions on the information available at this point in the evaluation. Further studies can be valuable, but the forward surgeon in a mobile hospital must be able to function with the information obtained by this evaluation. The opportunity for more detailed and sophisticated evaluation should be used when available, but the dimension of time, the press of more casualties, and the resource limitations must be considered before resorting to these studies.

### CLASSIFICATION OF THE PATIENT

The surgeon must classify the patient at specific points during examinations. This allows "weighing" of the data collected during the exam. This classification applies to the patient at hand. This is not triage, even though these actions can be similar to the decision-tree used by a triage officer who is sorting multiple casualties. Mandatory classification of the patient at specific points forces even the inexperienced surgeon to safely and rapidly collect as much information as is needed to care for the patient. This allows the surgeon to act decisively and quickly, but without carelessness.

As each step in the collection of information is completed, the patient should be unequivocally classified as:

- Priority I            Definite intra-abdominal injury
- Priority II           High probability of intra-abdominal injury
- Priority III          Low probability of intra-abdominal injury

Priority I patients should be prepared for operation immediately. There is no need for further collection of data. Actions described as "Secondary Evaluation" (urinary catheter, nasogastric tube, rectal exam, and X-rays) must be completed.

Priority II patients should have "Secondary Evaluation" completed and then operated upon in most cases.

Priority III patients should be systematically examined according to the text, but secondary evaluation is seldom necessary. Any patient can be moved to a more urgent priority at any time. Each step in the evaluation must be used to prioritize these patients.

If there is evidence of hypovolemic shock and no other apparent injury, to include the chest, the patient is classified as Priority I. If there is hypovolemic shock and evidence of other injuries, no matter how severe, the patient is considered Priority II.

### Inspection

If there is evidence of evisceration, omentum, stool, bile, or urine leaking from a penetrating wound or if there is loss of tissue from the abdominal wall, the patient is classified as Priority I.

If there is evidence of penetrating wounds, significantly contused tissue, or abdominal distension, the patient is a Priority II. Patients with altered mental states are Priority II. If the abdomen appears normal, the patient is classified as Priority III.

### Palpation

A patient with significant tenderness, abdominal rigidity, or pelvic tenderness is Priority II.

### Auscultation

A patient with absent or significantly decreased bowel sounds is Priority II.

### Further Evaluation

A patient with bloody urine, bloody nasogastric aspirate, blood in the rectum, X-ray evidence of free air, or **intra-abdominal** foreign bodies is classified Priority I.

This simple approach to evaluation of the soldier with an **intra-abdominal** injury will ensure that each patient has the benefit of mature surgical judgment despite urgency and distractions.

The patient who is classified Priority II at the completion of the secondary evaluation presents a dilemma. There is no simple resolution; however, a third set of actions, namely, consideration of extenuating circumstances, may help the surgeon to decide whether or not to operate.

## CONSIDERATION OF EXTENUATING CIRCUMSTANCES

The third action represents the greatest departure from civilian practice because the unique features of combat surgery are considered. The surgeon must maintain concentration and attention to detail in the care of the individual patient at the same time that these conditions are considered. Consideration of these rules

often allows the surgeon to make a decision concerning the care of patients in the Priority II classification. The surgeon must keep several factors in mind:

1. There are no inviolable rules.
2. Any change in the patient's condition cancels all previous decisions.
3. The surgeon must know of the availability of blood or blood products. If they are not available or are available in limited supply, the surgeon should tend to classify the patients in a more urgent category. In other words, the surgeon should tend to operate earlier.
4. The surgeon must know the number of beds available for holding (re-evaluation) and postoperative care.
5. The surgeon must consider the available methods of evacuation. This may be prolonged surface evacuation or rapid movement by air.
6. The surgeon should be aware of the likelihood of movement of the hospital or the likelihood of the hospital coming under fire.
7. The surgeon must appreciate both the quality and quantity of anesthesia support.
8. Knowledge of the availability and sophistication of operative nursing support is critical.
9. The surgeon should know of the availability and sophistication of surgical assistance.
10. Knowledge of the availability of respiratory therapy support for the postoperative patient is essential.
11. Decrements in overall unit efficiency secondary to fatigue must be considered.

## PREPARATION FOR OPERATION

Preparation of the patient for operation must be accomplished simultaneously with the other actions. Well-briefed and well-trained nursing personnel are invaluable. Simple routines that are understood by all hospital personnel must be established.

Two large-bore intravenous catheters should be inserted as soon as the patient arrives in the receiving area. Blood must be taken for typing and cross-matching. Antibiotics and tetanus toxoid should be administered as soon as the patient arrives in the receiving area.

An indwelling urinary catheter should be in place. The volume

and character (i.e., bloody or hot) of the urine should be noted at the time of catheterization and the time recorded so that urinary output after catheterization can be determined later.

A nasogastric tube should be in place.

Associated injuries must be dealt with appropriately. This is especially true in cases of intrathoracic injuries or massive blood loss in which the patient's ability to survive the operation can be affected. It is important to remember that these patients can spend hours "out of sight" under operative drapes where significant extremity blood loss and the loss of distal pulses may go unappreciated.

Endotracheal tubes must be in place and properly secured. The neurological status must be known prior to induction of anesthesia.

Finally, accurate but succinct notes must be recorded. The ever-present possibility of evacuation makes this essential.

## TREATMENT

### Exploration

Before the operation begins, the surgeon should be certain that illumination is as good as it can be. The surgeon must understand the capabilities of the assistant. Mutual understanding between the surgeon and the assistant must be reached before the operation begins. This understanding must consider the ability of the assistant to obtain hemostasis as well as the assistant's understanding of anatomy, knowledge of general surgical principles, and operative exposure. The surgeon should understand exactly how much (or how little) suction will be available. The surgeon should consider all of these factors when planning the operation.

The incision should be a long midline incision, generally from the xiphoid to the pubic symphysis.

### HEMOSTASIS

The surgeon and the rest of the operative team must have a plan before the peritoneal cavity is entered. If there is a great deal of free blood, it is best to use several large laparotomy pads to evacuate the blood. Suction with irrigation is more effective after the bulk of free blood has been removed. The surgeon must

quickly decide which area of the abdomen demands first attention. Generally, the amount of hemorrhage will be the determining factor. Direct pressure on individual vessels such as the splenic artery, the great vessels, or the descending thoracic aorta through a limited thoracotomy might be necessary at this time. The first assistant's experience and knowledge of anatomy are critical in the plan for these actions.

### EXPOSURE

It is simpler to eviscerate the entire small bowel in complicated cases. The ligaments of the liver can be divided to obtain further exposure in the right upper quadrant. Access to the thoracic cavity should be obtained by extending the midline abdominal incision into a median sternotomy.

The surgeon must have a systematic plan to explore the abdomen. This is similar to an aviator's preflight checklist and serves the same purpose to insure that no important step is missed. The excitement and distractions of combat surgery dictate that no laparotomy is concluded until the entire abdominal cavity has been explored.

### LEFT UPPER QUADRANT

#### Distal Esophagus, Diaphragm, Stomach, Spleen, and Kidney

The principles for dealing with injuries to organs in the left upper quadrant of the abdomen are simple. Careful exploration should assure integrity of the diaphragm, the anterior and posterior wall of the stomach, and the esophageal hiatus. The surgeon must palpate the kidney and search for a retroperitoneal hematoma. Perforations of the stomach should be closed primarily with minimal, if any, debridement. Injuries to the lower esophagus should be closed primarily after adequate mobilization. All injuries of the diaphragm should be closed with a single layer of interrupted heavy, nonabsorbable sutures. Large injuries to the diaphragm with herniation of abdominal contents should be repaired transabdominally after the abdominal viscera have been returned to their normal location. The most common error made in the treatment of diaphragmatic injuries is missed diagnosis. All patients with gastric injuries should be treated with

nasogastric suction until normal bowel function returns, Enough gastric distention to disrupt a gastric repair is common in patients who are evacuated by air in the early postoperative period.

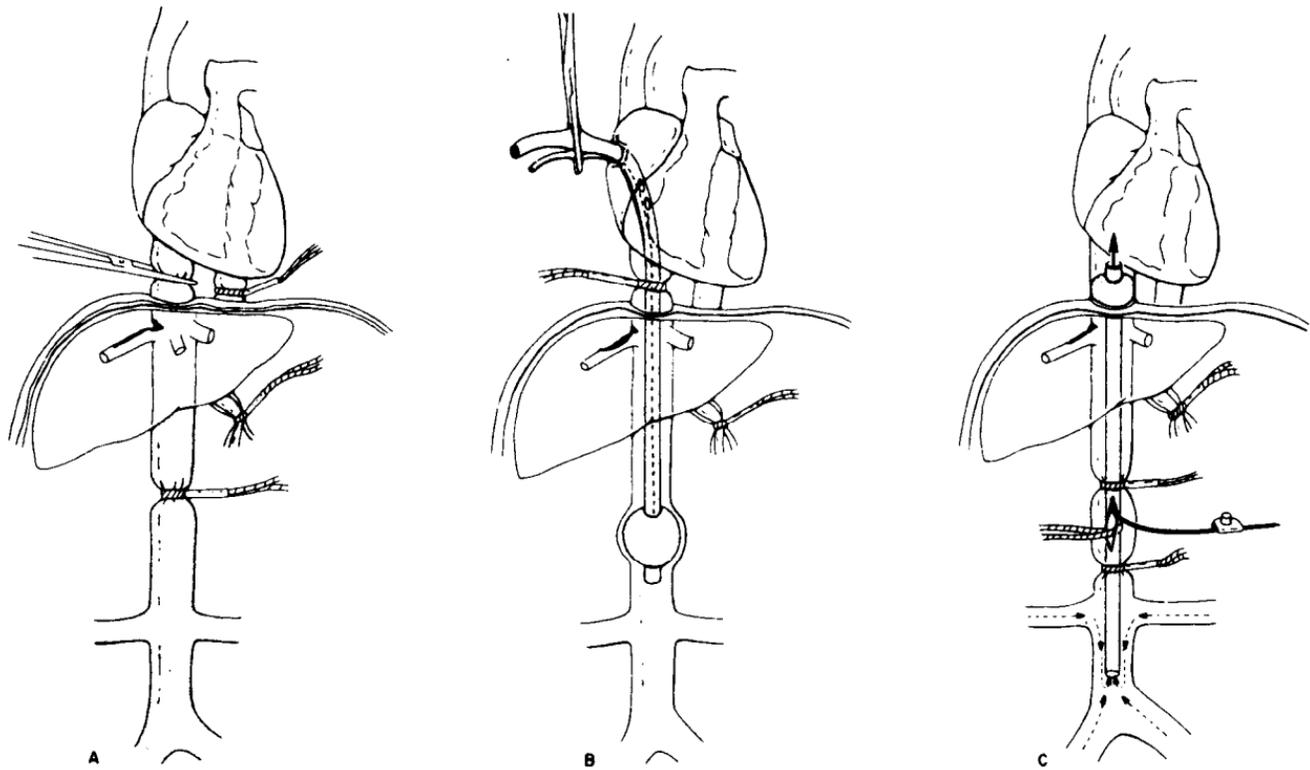
The diagnosis of renal injury depends on a high index of suspicion, hematuria, or evidence of fragments traversing the kidney. Penetrating injuries of the kidney should be explored and hemostasis obtained. In some cases, a nephrectomy is necessary to achieve hemostasis. Gerota's fascia, if intact, can effectively tamponade hemorrhage in the case of blunt injury to the kidney. In blunt trauma, this fascia should not be opened as hemorrhage is usually self limited.

The spleen should be inspected, but should not be mobilized unless there is evidence of bleeding. In civilian practice, the spleen is infrequently removed because of trauma. If hemorrhage can be controlled quickly and simply with confidence that it will not recur, the spleen can be preserved in combat surgery. If there is extensive injury to the spleen, the organ should be removed. The major difference between the management of civilian and combat injuries to the spleen is in the management of moderate injuries. If a moderate amount of effort is needed to secure hemostasis, it is best to remove the spleen of a combat casualty. The combat surgeon has neither the time required to preserve the moderately-injured spleen, nor the certainty of close personal postoperative observation required for such conservatism. Patients who have undergone splenectomy should be given antibiotic prophylaxis beginning at the time of surgery. This should be continued through the convalescent period. The patient should be vaccinated against those organisms which cause overwhelming sepsis as soon as possible.

## RIGHT UPPER QUADRANT

### Liver, Gallbladder, and Porta Hepatis

Injuries to the liver are usually trivial, but they can be difficult, complex, and fatal. The major concern in the treatment of liver injuries is hemostasis. Simple lacerations or perforations through the periphery of the liver that have stopped bleeding require no specific therapy. The surgeon must obtain hemostasis when treating deeper wounds of the liver that continue to bleed. If possible, the surgeon should ligate all bleeding vessels. Adequate



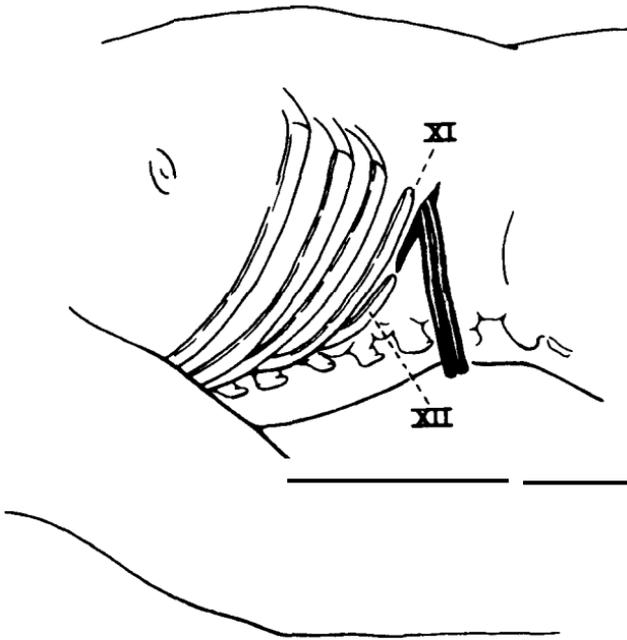
**FIGURE 33.**—Control of bleeding from caval and hepatic vein injuries associated with liver injuries. **A.** Four-clamp technique. **B.** Balloon tamponade via right atrium. **C.** Intracaval balloon catheter via the suprarenal vena cava.

suction and exposure are **essential**. Two suction units should be used. The cautery, clips, and ligature are equally effective. The surgeon should perform resectional debridement of significantly devitalized tissue. A formal hepatic lobectomy is never indicated. The Pringle maneuver, using a vascular clamp that will temporarily occlude the **porta hepatis**, might help control massive hemorrhage. This clamp may be applied for as long as 30 minutes with safety. The abdominal incision can be extended into the right chest to give better exposure of the retrohepatic **cava** or hepatic veins. Mobilization of the superior and anterior attachments of the liver allows mobilization of the organ. Only surgeons *with personal experience* in their use should consider using **caval** balloon catheters (Figure 33).

Hypothermia and coagulopathy frequently develop in patients with massive liver injury and hemorrhage. The liver pack can be lifesaving for these patients. Large absorbent pads are placed under tension behind, above, below, and in front of the liver. This maneuver allows the surgeon to explore and repair other areas of the abdominal cavity. Then the wound can be closed by placing a series of large towel clips through the skin and fascia with the packs left in place. A dressing is applied, and the patient is returned to the recovery room where his temperature is brought to normal and he is given appropriate blood component therapy and antibiotics. In 12-72 hours, the patient can be returned to the operating room where, under anesthesia, the abdomen is reopened, the packs are removed, and further hemostasis obtained if necessary. Frequently, bleeding will be found to have stopped.

Injuries to the gallbladder should be treated by cholecystectomy. Injuries to the hepatic artery or the portal vein should be repaired, if possible. Injuries to the common bile duct should be repaired over a small T-tube with a closed suction drain placed adjacent to the repair. The tissue surrounding all but the most innocuous injuries to the liver should be drained by use of closed suction (Figure 34).

Broad-spectrum antibiotics and blood component therapy to correct bleeding disorders should be given. Large mattress sutures in Glisson's capsule for deep liver injuries should not be used because **hemobilia** can develop later. A useful adjunct for hemostasis is the insertion of an intact vascularized pedicle of



**FIGURE 34.—Drainage of the abdomen. For adequate drainage of the abdomen, drains must be placed in the most dependent portion of the peritoneal cavity. This is best accomplished through the posterior flank utilizing sump drains.**

omentum into a liver injury with loose closure of the liver over the omentum.

### Duodenum and Pancreas

Injuries to the duodenum are easily overlooked. The surgeon should suspect duodenal injury if missiles or missile tracks are found in the region of the duodenum, if there is blood in the nasogastric tube and retroperitoneum, or if there is air in the region of the duodenum. All patients who have had blunt trauma, and all patients who have had penetrating trauma in the region of the duodenum must have both a generous **Kocher** maneuver to expose the duodenum and an opening into the lesser sac that will expose the anterior pancreas and duodenal sweep. Minimal debridement and repair should be done for perforations,

lacerations, and partial or complete transections. These patients need closed-suction drainage adjacent to, but not in contact with, the anastomosis. When more extensive injuries of the duodenum require more extensive debridement, the biliary, pancreatic, and gastric flow must be preserved. Missed injuries to the duodenum are often fatal. They may present late with signs of retroperitoneal abscess.

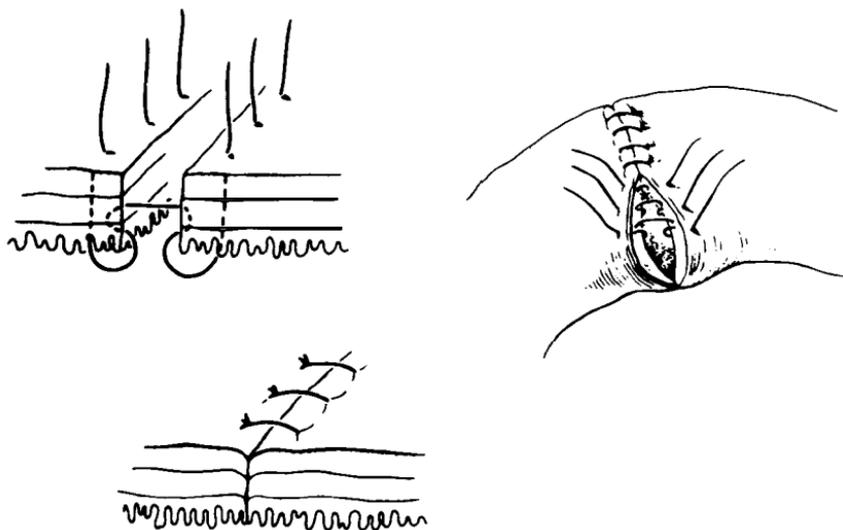
Injuries to the pancreas always require drainage, generally closed-suction drainage. This may suffice for simple, superficial, blunt, or penetrating injuries of the pancreas, but deeper injuries, particularly those that involve the major pancreatic ducts, require more aggressive therapy. This may include resection of the distal pancreas. Transection or near-transection of the **midbody** of the pancreas can be treated by ligation of the distal end of the proximal duct and a Roux-en-Y anastomosis of the distal remnant into the gut. The choice to divert or resect the distal portion of the divided pancreas depends on the experience of the surgeon and the presence of associated injuries. If there is severe destruction of the head of the pancreas and duodenum, a **pancreaticoduodenectomy** may be required to save the patient. This situation is uncommon. Postoperatively, these patients frequently develop external fistulae. Closed-suction drain ensure that **these fistulae** are controlled. They may persist. The skin must be protected from the activated enzymes in the drainage. Fistula can lead to significant nursing problems. These can be limited by attention to details early.

## MIDABDOMEN

### Small Intestine

Simple perforations, lacerations, or tears of the small intestine should be minimally debrided and closed primarily with a single layer of interrupted sutures (Figure 35).

The surgeon must carefully search for multiple injuries by examining the small intestine in a systematic fashion, beginning at the ligament of Treitz and proceeding distally, looking at **10"** segments of bowel on one side and then the other. The entire small bowel must be examined all the way to the cecum. The surgeon must carefully search for injuries to the mesentery at the edge of the bowel, since small tangential bowel perforations in the mesenteric surface may not be obvious on superficial **exami-**



**FIGURE 35.**—An inverting single-layer suture technique is satisfactory for repair of small bowel injuries and anastomosis of small bowel after resection.

nation. Use the “rule of twos” in treating penetrating injuries of the intestine and colon. Since fragments almost always perforate both walls of the intestine, they create an even number of injuries to the gut. Therefore, an even number of perforations can be expected. While this rule is not absolute, it is helpful in assuring that no injuries are missed. Rather than several individual repairs, a limited resection encompassing multiple injuries may be a safer and more expeditious approach in the patient with multiple injuries in close proximity. Injuries of the mesenteric vessels should be dealt with by ligation and bowel resection if there is nonviable or questionably viable bowel.

Injuries to the aorta and inferior vena **cava** are usually fatal. Those who survive to reach the hospital frequently require urgent laparotomy as part of their resuscitation. These patients will frequently deteriorate during resuscitation and transfusion. They must be identified, explored, and hemostasis must be achieved, if they are to survive. An occasional patient with a severe splenic or hepatic injury can present in a similar fashion and require urgent operation for hemostasis. In this sort of case, continued

transfusion and resuscitation in order to make the patient a better operative risk do not work, and death is the usual outcome. A senior surgeon must diligently search for these patients in the preoperative area and ensure early surgical intervention for hemostasis.

The intraoperative management of these injuries includes generous incisions, the obtaining of adequate proximal and distal control and then appropriate repair of the injury. Frequently, minimal debridement and primary closure will suffice. Autogenous tissue (vein graft) is better than synthetic material in the repair of the more extensive vascular injuries, but suitable vein grafts may not always be available.

Helpful maneuvers to achieve hemostasis in these patients include the insertion of a balloon catheter into the proximal and distal vessels through the injury site, use of a sponge stick to compress the aorta against the spine at the level of the diaphragm, and control of the aorta with a vascular clamp above the diaphragm via a limited thoracotomy.

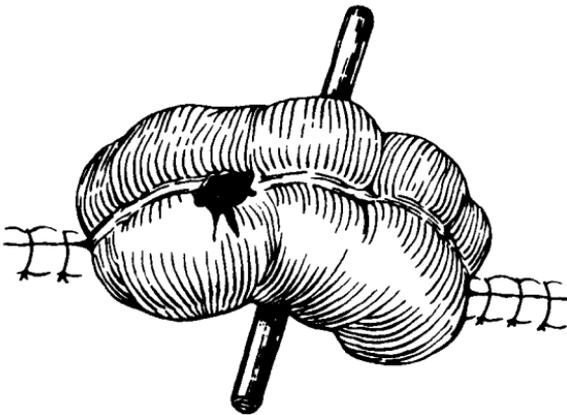
### Ureters

The ureters are infrequently injured. A ureteral injury usually causes hematuria. If this is noted preoperatively, an intravenous pyelogram will often provide a more secure diagnosis in these patients. Urine and blood will collect along the course of the ureter, particularly if there was a penetrating injury. These collections should prompt the surgeon to conduct a careful exploration of the entire course of the ureter.

Ureteral injuries can be repaired with fine absorbable sutures and closed-suction drainage close to, but not touching, the repair. Internal stenting is not required in simple injuries. In more extensive injuries with significant tissue loss, repair will depend upon the location and extent of the injury and the experience of the surgeon. If the lower third of the ureter is injured, it may be reimplanted into the dome of the bladder through a muscular tunnel. The kidney can be mobilized, if necessary, to provide some additional length. Repairs should be done transversely or on a bias to maintain the diameter of the lumen since strictures may otherwise result. Drainage of all urinary repairs is required. Closed suction is preferred.

## Colon

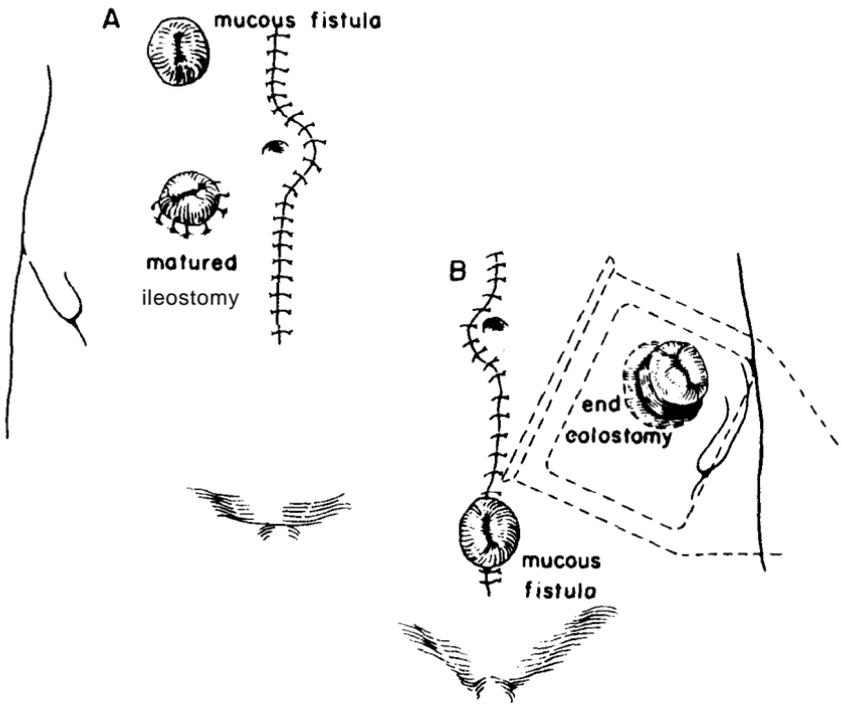
Injuries to the colon frequently result from penetrating abdominal injuries. The basic rule is that combat injuries of the colon should not be closed. The majority of these patients should have either a loop colostomy which includes the injury, or resection of the injured colon and proximal diversion (Figure 36).



**FIGURE 36.**—Under certain circumstances, exteriorization of colon wound is acceptable. The loop of colon is exteriorized over a glass rod or a rubber catheter.

Major injuries of the right colon should be treated by right hemicolectomy, with creation of a proximal ileostomy and distal mucus **fistula** (Figure 37). The reason for such a didactic approach is that these patients have an unprepared colon, usually have associated injuries, and it is unlikely that the operating surgeon will be able to follow the patient through the postoperative period. These particular lessons have been learned and relearned at great expense in previous conflicts.

An option that is consistent with these guidelines is **exteriorization** of certain colon repairs. Injuries to the transverse and sigmoid colon may be repaired and then exteriorized in continuity for 6-10 days. If healing takes place, as is the case approximately 50% of the time, the repaired colon can be replaced into the abdomen at a second procedure. If the repair fails to heal, it can be converted to a loop colostomy with no particular danger to the patient. If this method is chosen, the opening in the abdominal wall must



**FIGURE 37.-A.** Following severe injury to the right colon, especially with associated severe injury to contiguous organs, right colectomy is indicated. A matured ileostomy, which will accommodate an ileostomy appliance and the distal mucous fistula, are shown. **B.** The construction of an end colostomy and a distal mucous fistula that allows placement of an appliance over the proximal stoma is mandatory for diversion of the fecal stream in management of low sigmoid and rectal injuries.

be large enough to allow for the stool to progress into the repaired segment and back to the abdomen, This opening will be larger than that needed for the usual loop colostomy. Failure to allow for this can result in the buildup of pressure in the repaired segment that will cause failure of the repair.

Preoperative antibiotics are indicated when intestinal injuries are suspected; however, their postoperative use beyond 12 hours is questionable. As in suspected injuries of the small intestine, the surgeon must conduct a careful; methodical inspection of the

colon from one end to the other. Again, it is appropriate to emphasize that injuries on the mesenteric surface of the colon are difficult to diagnose and must be searched for diligently, particularly in the presence of hematoma.

### Pelvis

Injuries of the pelvis can be particularly difficult and frustrating. Hemorrhage from pelvic fractures or fragment injuries may not respond to the usual hemostatic techniques. A major advance in treatment of fracture dislocations of the pelvis associated with hemorrhage is the pelvic fixation device. This should be considered early in the management of these patients. Injuries of the bladder and rectosigmoid are easily overlooked. The surgeon must search for these carefully to avoid devastating complications.

### Rectum

The surgeon must suspect a rectal injury in any patient who has suffered a penetrating wound of the pelvis or in whom fragments could have traversed the pelvis. Anteroposterior and lateral roentgenograms, interpreted with the knowledge of entrance and exit wounds, are particularly helpful in determining if a rectal injury is likely to be present. Digital examination of the rectum is required. Endoscopy to determine the presence of intraluminal blood is indicated in these patients.

Blood in the rectum should be assumed to be evidence of a transmural injury. A search for the specific location of the injury must be made. Rectal injuries are difficult to diagnose at the time of laparotomy. If no injury can be found in a patient with frank blood in the rectum, the surgeon must treat the patient as if a rectal injury has occurred.

The treatment of patients with rectal injuries includes four components: first, a proximal, totally diverting colostomy; second, thorough cleansing and irrigation of the distal rectosigmoid; third, repair of the rectal tear, if accessible; and fourth, drainage of the presacral space with soft drains of the closed-suction type (Figure 38).

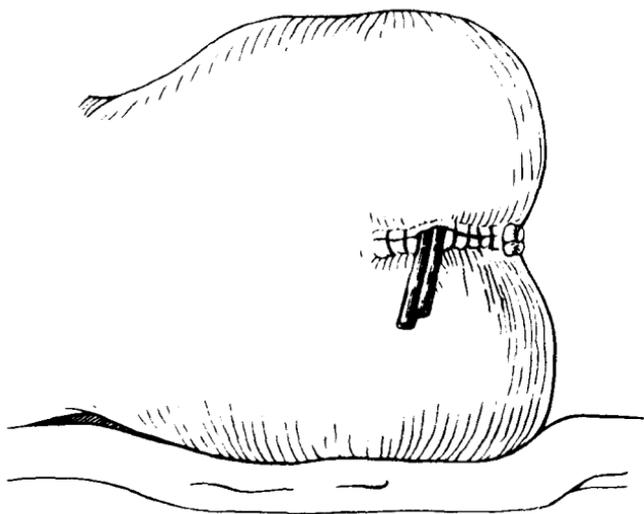


FIGURE 38.—Presacral drainage is best accomplished by direct vision through a posterior incision in a dependent position utilizing sump drains.

### Bladder

Injuries of the bladder are usually associated with hematuria. The surgeon should suspect a bladder injury when the entrance or exit wound, the two-plane roentgenograms, or hematuria suggest that this is the case. A cystogram is the definitive test. It is obtained by the instillation of contrast into the bladder via an indwelling urethral catheter. Two roentgen views should be taken, one with the bladder full and the other after voiding. Extravasation indicates bladder perforation and requires operation.

These injuries should be repaired with two layers of absorbable sutures, insertion of an indwelling suprapubic catheter, and placement of a soft closed-suction drain into the region of the repair. Bladder injuries will heal if the edges of the wound are approximated and adequate bladder decompression is maintained for ten days.

## Reproductive Organs

**Conservation** should be practiced in the management of injuries of the reproductive organs. Penetrating or crush injuries of the labia, penis, scrotum, and testicles are best treated by conservative debridement and primary repair, if practical. The scrotum should be drained with a soft rubber drain. Injuries to the uterus, ovaries, and fallopian tubes will require conservative debridement and repair. Drainage is seldom indicated.

## POSTOPERATIVE CARE

### Wound Closure

Reliability of the abdominal wound closure is of major importance. Patients are frequently moved in the early postoperative period. Generally speaking, a secure closure requires the use of a strong monofilament nonabsorbable suture which incorporates large "bites" of fascia. The closure may be interrupted or "running" but the latter is much more expeditious. Full-thickness retention sutures over bolsters are required in difficult closures and in most reoperative, complicated abdomens. When placed, they should be 2-3 cm apart and 3-4 cm from the edges of the wound. These sutures are usually left in place for three weeks. They may or may not be used in conjunction with a separate fascial closure. The skin and subcutaneous tissue in contaminated abdominal wounds should not be closed primarily. Delayed primary closure can be done in 4-5 days.

### Stomas

Intestinal stomas require some care in the site selection. Anatomy and abdominal wall injuries will influence this choice. The future fitting of an appliance must be considered. Vascularity of the stoma must be preserved, since failure will require another laparotomy. The Brooke type of "turn-back" ileostomy stomas with **1.5-2** cm of elevation is preferred for stoma fitting and nursing management.

Colostomies for rectal injuries should always be a "diverting" type of end colostomy with a separate **muscus** fistula. The stomas

may be flush. They should be-matured at the primary operation by sewing the ends of the colon circumferentially to the skin. Loop colostomies are seldom needed in combat casualties, but they are simpler to construct and need not be opened for several days postoperatively. All stomas should have an adequate opening in the abdominal wall at all levels. They should be fixed to the fascia by several interrupted sutures superficially in the wall of the intestine or colon. A patient with a stoma should remain under the observation of the same surgeon to ensure the viability and satisfactory performance of the stoma. This also allows the surgeon the opportunity to explain to the patient the necessity for the procedure, the stoma's function, its care, and when the patient can expect the stoma to be closed.

### **Ileus**

Postoperatively, the bowel undergoes a normal period of motor, but not secretory, inertia. This causes abdominal distention. The distention can be minimized by the use of nasogastric suction. Some patients may have a prolonged ileus. This may be due to contamination, bowel manipulation at operation, too rapid a resumption of feeding, an anastomotic leak, a missed injury, or **intra**-abdominal infection. Systemic nonabdominal sepsis and spinal cord injuries can also cause ileus. Treatment consists of nasogastric suction and parenteral fluid, and electrolyte and nutritional support. A search for the specific cause of the ileus should be ongoing, particularly if other findings are present.

### **Records**

Accurate and complete documentation is essential; it need not be wordy. Legible handwritten operation notes and hospital summaries performed by the surgeons should be concise and cover the important points. Important points include the indications for operation, the findings, what was done, what was not done, technical points if they represent a deviation from the usual or if likely to be relevant in the future care of the patient, how the patient did postoperatively, and what the management plan would be if the physician were to continue caring for him. Liberal use of sketches and diagrams are of value