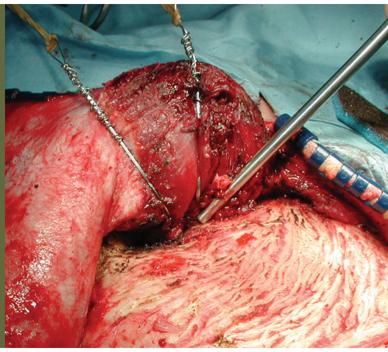
Chapter III
HEAD AND SPINE TRAUMA



III.1 Penetrating Head Injury With Subdural Hematoma

CASE PRESENTATION

This male soldier suffered a penetrating gunshot wound to the head. The patient arrived at the combat support hospital (CSH) intubated. He failed to open his eyes, and he withdrew upper and lower extremities symmetrically to pain. His pupils were equal in size, midpoint, and reactive. A single entrance wound was identified in the right temporal region (Fig. 1). Skull images showed the tip of a large bullet (Fig. 2). CT showed the bullet embedded in the skull base at the right temporal tip, as well as a right subdural hematoma with midline shift (Fig. 3). No other injuries were identified. The patient was taken to the operating room for emergent craniotomy. The entire right hemisphere of the skull was exposed by reflecting the scalp and temporalis muscle anteriorly (Fig. 4). A trauma craniectomy was fashioned and the bone elevated from the underlying dura mater (Fig. 5). The dura was opened in parallel strips to expose and aspirate an acute subdural clot while preventing malignant swelling of the brain (Fig. 6). The bullet was not visible, and no attempt was made to recover it. Closure was performed without replacement of the bone flap. Duraplasty was performed by sewing ellipses of bovine pericardium into the dural openings using 4-0 braided nylon suture. After achieving a watertight closure, the scalp was approximated over an epidural drain and an intracranial pressure (ICP) monitor was placed on the uninjured side. Empiric broad-spectrum antibiotics and phenytoin were administered. The patient was left intubated postoperatively and evacuated to a level IV medical treatment facility. After prolonged intensive care, he recovered to independent living.

TEACHING POINTS

1. During the primary and secondary surveys, attention should be placed on a complete examination of the scalp and neck. Fragments that enter the cranial vault with a transtemporal, transorbital, or cross-midline trajectory should be suspected of having associated neurovascular injuries. Multiple wounds are typically involved in combat-related brain injuries, and these injuries generally involve the face, neck, and orbit. Entry wounds may be through the upper neck, face, orbit, or temple (Fig. 7). Scalp hemorrhage should be initially controlled using rapid, simple techniques. After addressing the patient's airway, breathing, and circulation, the level of consciousness should be determined.

FIGURE 1. *Entrance wound in the right temporal region.*

2. The level of intact neurological function is best assessed by determining the Glasgow Coma Scale (GCS; see Appendix C) score and pupillary function. A GCS score of 8 or greater indicates a good prognosis. The finding of unilateral acute pupillary dilation should raise immediate concern of ipsilateral brain herniation. Patients exposed to explosive blasts may experience iridoplegia (paralysis of the pupil), which is not indicative of herniation.
3. Acute intervention has the greatest effect on casualties with a GCS score of 6 to 8, if ICP can be controlled and cerebral blood flow maintained until the patient receives the required neurosurgical management. Casualties with a GCS score of 5 or less do poorly, and expectant management may be considered.
4. A single, dilated or nonreactive pupil adds urgency and implies the presence of a unilateral (usually ipsilateral), space-occupying lesion with secondary brain shift. Immediate surgery is indicated.
5. Any attempt to retrieve intracranial missiles must be made on a case-by-case basis, weighing the risk of further neurological injury.

CLINICAL IMPLICATIONS

If the determination has been made that emergency surgery is needed because of a space-occupying lesion with neurological changes, an intracranial hematoma producing a greater than 5-mm midline shift or similar depression of cortex, a compound depressed fracture with neurological changes, or penetrating injuries with neurological deterioration, the following principles apply:

1. The GCS score and pupils should be evaluated as soon as tactically possible. Both should be regularly reassessed thereafter. The finding of acute pupillary dilation should raise immediate concern of brain herniation.
2. Intracranial hypertension should be relieved with hemicraniectomy, duraplasty, and ventriculostomy. A large craniectomy flap for wide exposure is recommended. A series of 1- to 2-cm parallel slits in the dura is a technique for relieving dural tension and removing a subdural hematoma.
3. Broad-spectrum antibiotics should be administered.

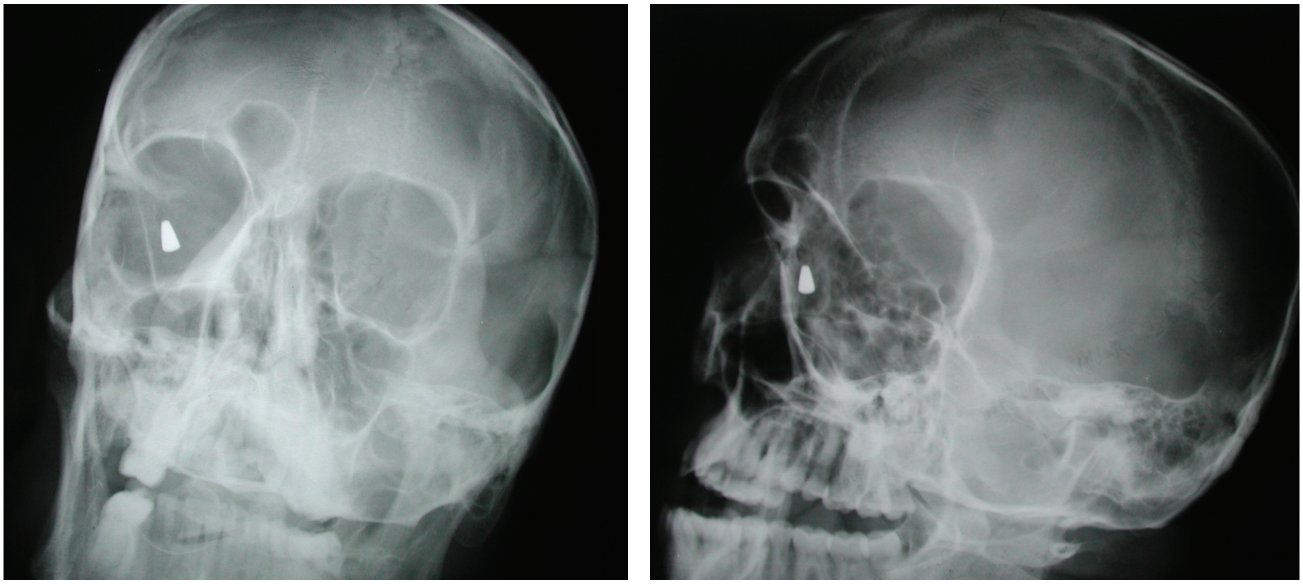


FIGURE 2. *Skull radiographs (PA and oblique) show the tip of a large bullet.*

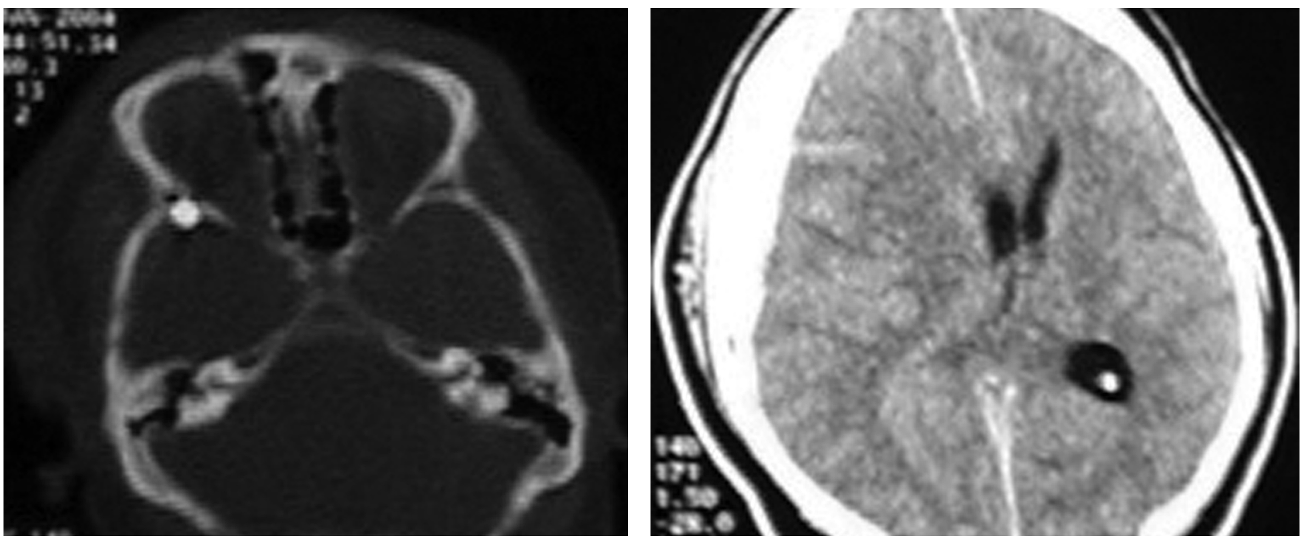


FIGURE 3. *CT image showing the bullet embedded in the skull base at the right temporal tip* (Left), *as well as a right subdural hematoma with midline shift* (Right).

4. Hematoma should be evacuated and bleeding controlled.
5. For penetrating injury, remove devitalized brain and accessible foreign bodies, and irrigate with antibiotic solution.
6. A watertight closure of the dura should be attempted. If duraplasty is required, pericranium, temporalis fascia, or tensor fascia lata may be used.
7. The galea of the scalp should be closed.
8. Tension-free closure of the scalp should also be performed.
9. If the bone flap cannot be replaced, it may be discarded or preserved in an abdominal wall pocket. If the bone flap is unsalvageable, it can be replaced later by a polyetheretherketone (PEEK) cranioplasty.
10. Meticulous debridement of the scalp and subcutaneous tissues is important to prevent infection.
11. A decision to attempt retrieval of intracranial missiles has to be individualized, weighing the serious risk of increasing neurological injury. Sequelae due solely to bullet migration are uncommon.

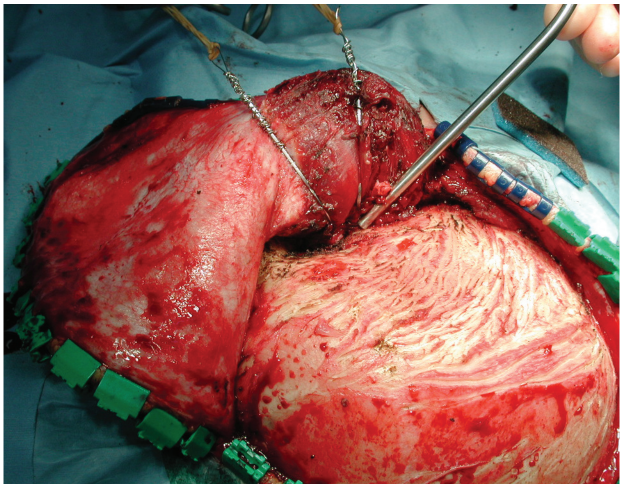


FIGURE 4. *The entire right hemisphere of the skull was exposed by reflecting the scalp and temporalis muscle anteriorly.*

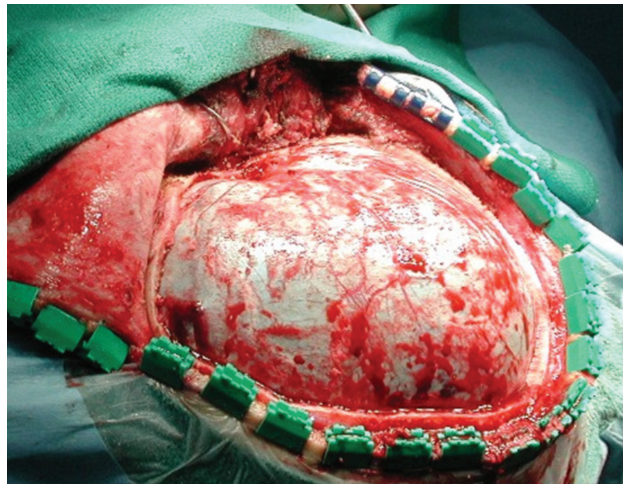


FIGURE 5. *Trauma craniectomy. Bone removed from the underlying dura mater.*

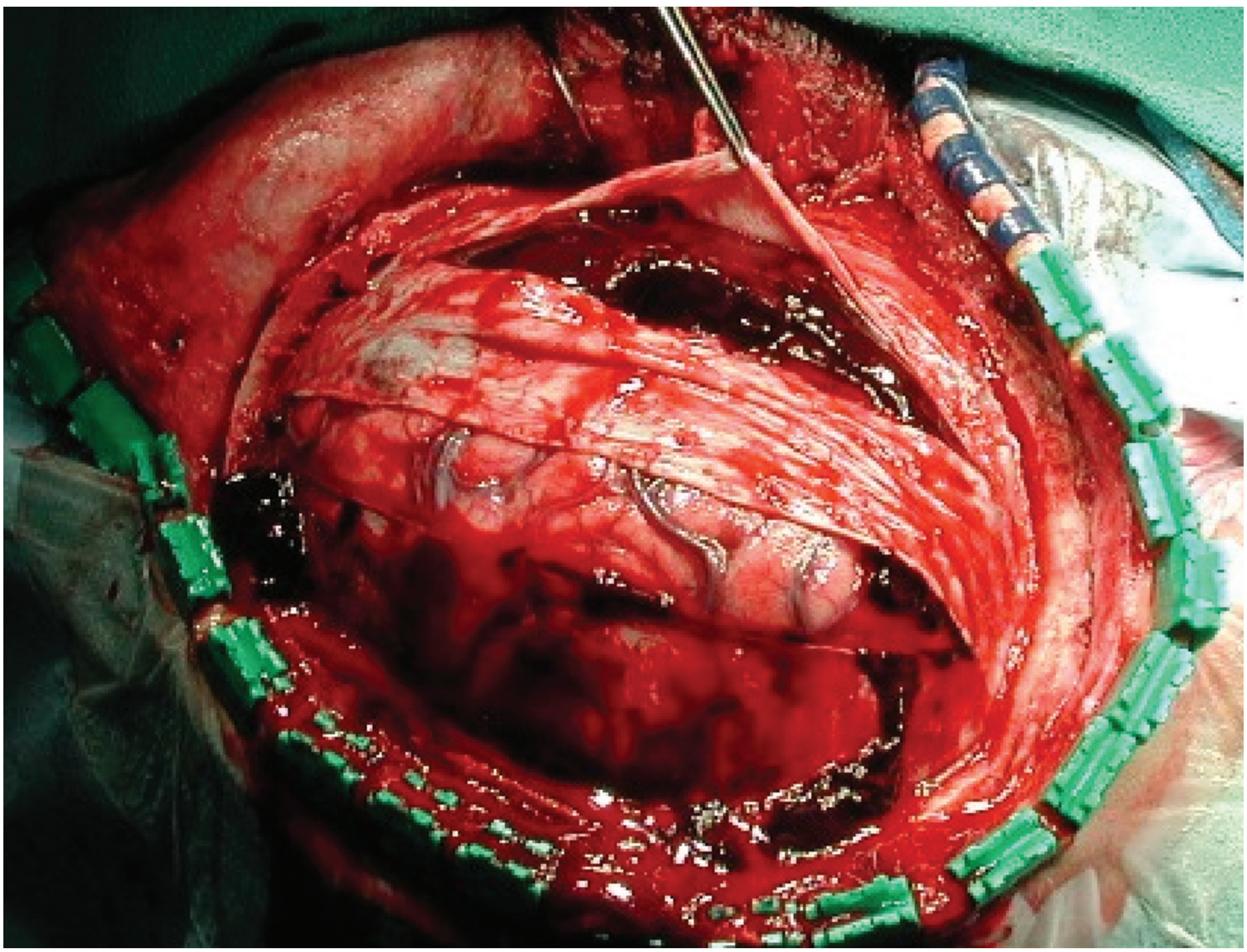


FIGURE 6. *Dura mater opened in parallel strips exposing acute subdural clot.*

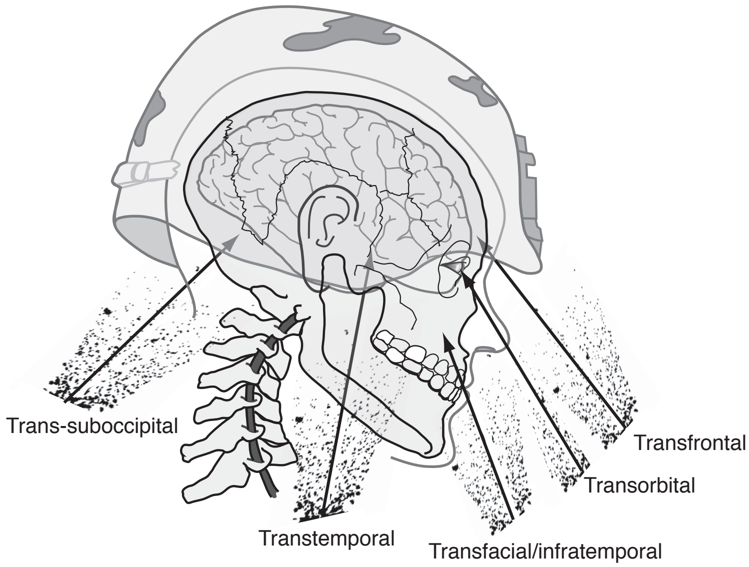


FIGURE 7. *Common vectors of penetrating injury in which the projectile has not traversed the helmet.*

INTRACRANIAL PRESSURE (ICP)

Elevation of the pressure within the skull is often a common complication of serious neurological conditions. The average ICP in adults ranges from 0 to 10 mm Hg. The maximal upper limit of desirable ICP is 20 mm Hg. Pressures more than 40 mm Hg are considered extremely elevated. ICP may be high because of:

- A rise in the cerebrospinal fluid (known as *hydrocephalus*).
- Brain swelling caused by fluid leaking into the brain (known as *cerebral edema*).
- Intracranial hemorrhage.

Regardless of the underlying cause, elevated ICP is a severe medical problem that should be treated immediately. Classic symptoms of ICP include Cushing's triad (named after Harvey Williams Cushing [1869–1939], an American neurosurgeon):

- Hypertension.
- Bradycardia.
- Irregular respirations.

12. Tension-free scalp closure is essential, but replacement of multiple skull fragments in an attempt to reconstruct the skull defect is not appropriate in the battlefield setting.

DAMAGE CONTROL

If CT is not available—and the patient has neurological injury and a deteriorating neurological examination without localizing signs—burr holes may be of diagnostic utility, but are usually inadequate to treat acute hematomas. Neurosurgical damage control includes early ICP control, cerebral blood flow preservation, and prevention of secondary cerebral injury from hypoxia, hypotension, and hyperthermia.

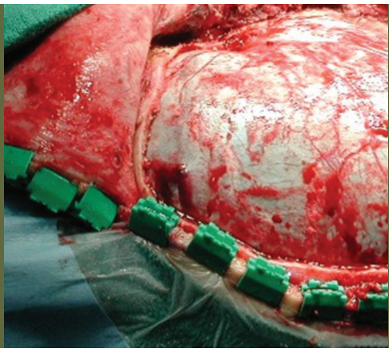
SUMMARY

This case demonstrates large craniectomy exposure of the cerebral hemisphere and evacuation of a subdural hematoma. Although duraplasty and watertight closure of the dura are ideal, a gel foam or gel-film barrier may be laid in the subdural and epidural planes if primary closure of the meninges is technically impossible. The bone flap may be discarded or stored in a subcutaneous abdominal pouch for replacement after 30 days. A large craniectomy exposure of the cerebral hemisphere for evacuation of a subdural hematoma is demonstrated. A dural opening using the entire expanse of the cranial opening should be created.

SUGGESTED READING

Brain Trauma Foundation. *Summary of the Guidelines for Field Management of Combat-Related Head Trauma*. New York, NY: Brain Trauma Foundation; 2005.

Chapter 15: Head injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.



III.2
Basilar Skull Fracture With Pneumocephaly

CASE PRESENTATION

This 21-year-old male sustained a traumatic head injury from a mortar attack. He was initially comatose and during transport, he was bag-ventilated with a face mask. The patient presented to the combat support hospital (CSH) alert but confused, with a Glasgow Coma Scale (GCS) score of 14. His chief complaint was nausea, and he vomited twice. He was intubated for airway protection and bag-ventilated. His physical examination revealed a blood-tinged, clear fluid discharge from his left ear, and his neurological examination was significant for confusion. Cranial nerve exam was normal, as were his gross motor and sensory exams. CT of his head revealed a basilar skull fracture and severe pneumocephaly (Fig. 1). The discharge from his ear had a high glucose content consistent with cerebrospinal fluid (CSF). The patient was placed on 100% oxygen continuous positive airway pressure and seated in an upright position. Four hours later, there was marked improvement in his pneumocephaly. He was extubated and continued treatment with a 100% oxygen face mask. The following day, his mental status was normal. Over the next 2 days, he was encouraged to sit upright and, when sleeping, place his right ear down. His CSF leak improved and resolved spontaneously by the time the patient was evacuated.

TEACHING POINTS

1. Pneumocephaly is a condition in which air enters the cranial vault. This finding on neuroimaging is indicative of a violation of the skull integrity. Most often, it is seen following craniotomy. However, in this case, the diffuse extent suggests air entrance through the basilar skull fracture exacerbated by vigorous bag ventilation through a face mask during transport.
2. Basilar skull fracture results from closed-head injury and high-velocity penetrating head injury when a force applied to the skull causes a transient dysmorphic change in skull shape. The most common clinical signs include CSF otorrhea and Battle's sign for petrous bone fractures, and CSF rhinorrhea and raccoon eyes for anterior cranial vault fractures.
3. There can be fractures through the wing of the sphenoid bone, the sella, sphenoid sinuses, the clivus, and ethmoid air cells—all of which can contribute to pneumocephalus and a CSF leak. A fracture through the posterior wall of the frontal sinus, although not classically a skull base fracture, can also lead to the same clinical presentation.

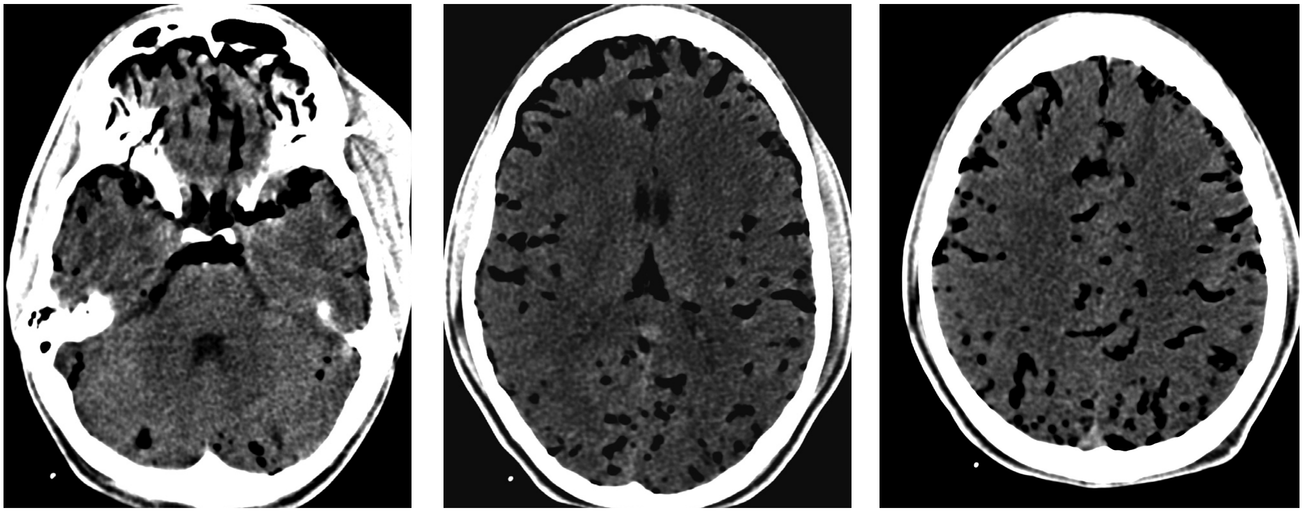


FIGURE 1. *Selected axial CT images demonstrating diffuse pneumocephaly from the skull base to the apex.*

4. Generally, pneumocephaly is asymptomatic and does not require treatment. However, if there is a sufficient burden of air, it can cause increased intracranial pressure as it adds volume to the confined space of the intracranial vault. Typically, the presenting symptoms include headache, nausea, and vomiting. This condition can also lead to mental status changes and focal neurological deficits (eg, motor paresis).
5. Treatment for pneumocephaly is inhaled oxygen. By placing the patient on 100% oxygen, nitrogen in the intracranial air will exchange with oxygen. The oxygen will, in turn, be consumed metabolically by the neurons and glial cells of the brain. In this way, the free gas inside the skull will be absorbed. This treatment can be simply the use of a 100% oxygen face mask. With proper treatment, recovery will be full and complete.
6. A CSF leak is a high-risk factor for subsequent infection. With head elevation and time, most traumatic CSF leaks will resolve spontaneously. However, if this condition persists, other treatment modalities should be considered, including the following:

    a. Ventricular or lumbar drainage.
    b. Packing of the middle ear, mastoid air cells, or eustation tube.
    c. Endoscopically packing the leak through the sinuses.
    d. Direct intracranial repair.

CLINICAL IMPLICATIONS

1. Triage decisions in the patient with craniocerebral trauma should be based on the admission GCS score and pupillary exam.
2. A basilar skull fracture can be caused by penetrating or blunt trauma mechanisms. The most common clinical signs include the following:

    a. CSF otorrhea, often associated with Battle's sign.
    b. CSF rhinorrhea, often associated with raccoon eyes.
    c. Pneumocephalus.
    d. Headache.
    e. Nausea and vomiting.

BATTLE'S SIGN

Named after William Henry Battle (1855–1936), an English surgeon, this sign suggests fracture at the base of the posterior portion of the skull (fractura basis cranii) and may also suggest underlying brain trauma. It consists of bruising immediately behind the ears. Another common sign of a skull injury is **raccoon eyes**, a purplish discoloration around the eyes following fracture of the frontal portion of the skull base. Battle's sign is seen several days after a basilar skull fracture.

3. CT is the definitive radiographic study in the evaluation of head trauma and should be used liberally. Deployable CT scanners in standard ISO (International Organization for Standardization) shelters are increasingly available in the field environment.

DAMAGE CONTROL

Initial treatment of basilar skull fracture with pneumocephalus consists of the following actions:

1. Head elevation.
2. 100% oxygen delivery.
3. Use of antibiotics when evacuating the patient to a medical facility (with a neurosurgeon) for further treatment.

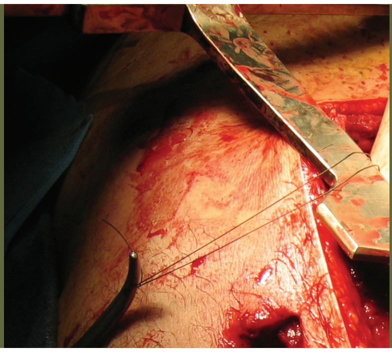
SUMMARY

This is a case in which trauma resulted in a basilar skull fracture with a CSF leak. This injury, combined with aggressive bag ventilation, produced severe pneumocephaly associated with confusion, nausea, and emesis. Treatment with 100% oxygen and head elevation resulted in rapid improvement of symptoms and pneumocephaly. Upon discharge of the patient, the CSF leak had resolved.

SUGGESTED READING

Chapter 13: Face and neck injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 15: Head injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.



III.3 Right Hemisphere Fragment Wound

CASE PRESENTATION

This middle-aged, host nation male presented to the combat support hospital (CSH) with a severe brain injury. Neurological examination was significant for eyes that opened to noxious stimuli and pupils that were equal and reactive. He had a left hemiparesis and was localizing to pain with his right upper extremity. Examination of the scalp was significant for a right frontal entrance wound (Fig. 1) and a parietal exit wound. He was intubated. A lateral skull film showed retained fragments (Fig. 2) and a CT of the brain revealed a right frontal extracranial fragment, traumatic subarachnoid hemorrhage, and a right parietal parenchymal fragment (Fig. 3). He was taken to the operating room. The head was positioned in Mayfield pins to expose the right hemisphere. A trauma flap was fashioned by reflecting the scalp and temporalis muscle anteriorly. The dura mater was reflected forward, and parenchymal bleeding was stopped using bipolar electrocautery and topical fibrillar (Figs. 4–7). Because there was little swelling, the dura was reflected back and closed primarily over a subdural drain. The bone was secured using microplates and screws, and the temporalis fascia was closed with 0-VICRYL suture, followed by 2-0 VICRYL for the galea aponeurotica. Scalp edges were approximated with surgical staples, and an intracranial pressure (ICP) monitor was placed opposite the injured side. The patient was extubated within a week and recovered with residual left hemiparesis and no speech deficits.

TEACHING POINTS

1. Patients who present with nondominant hemisphere brain injury have a better prognosis than patients who have dominant brain injury. This case emphasizes the often better prognosis seen in nondominant hemisphere injuries.
2. Other presenting signs and symptoms that indicate a favorable prognosis in this case include the following:

   a. The admission CT showed no midline shift.
   b. The ventricles were not penetrated.
   c. There was no injury to deep structures of the brain.

CLINICAL IMPLICATIONS

Brain injury is common in combat environments and may occur secondary to penetrating blast or blunt mechanisms. Initial medical management

FIGURE 1. *Right frontal entrance wound and parietal exit wound* (arrows).

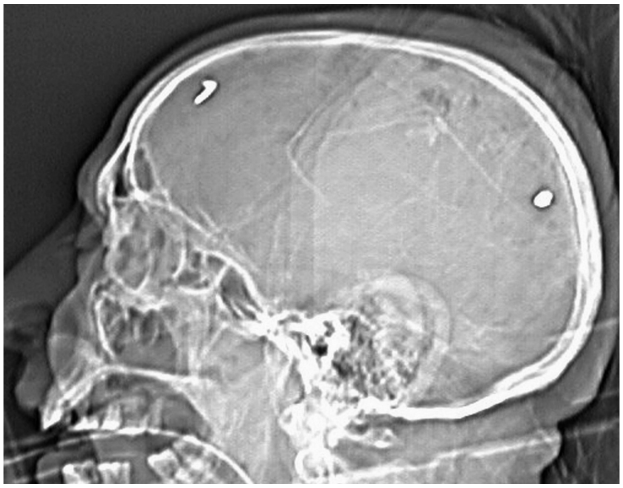
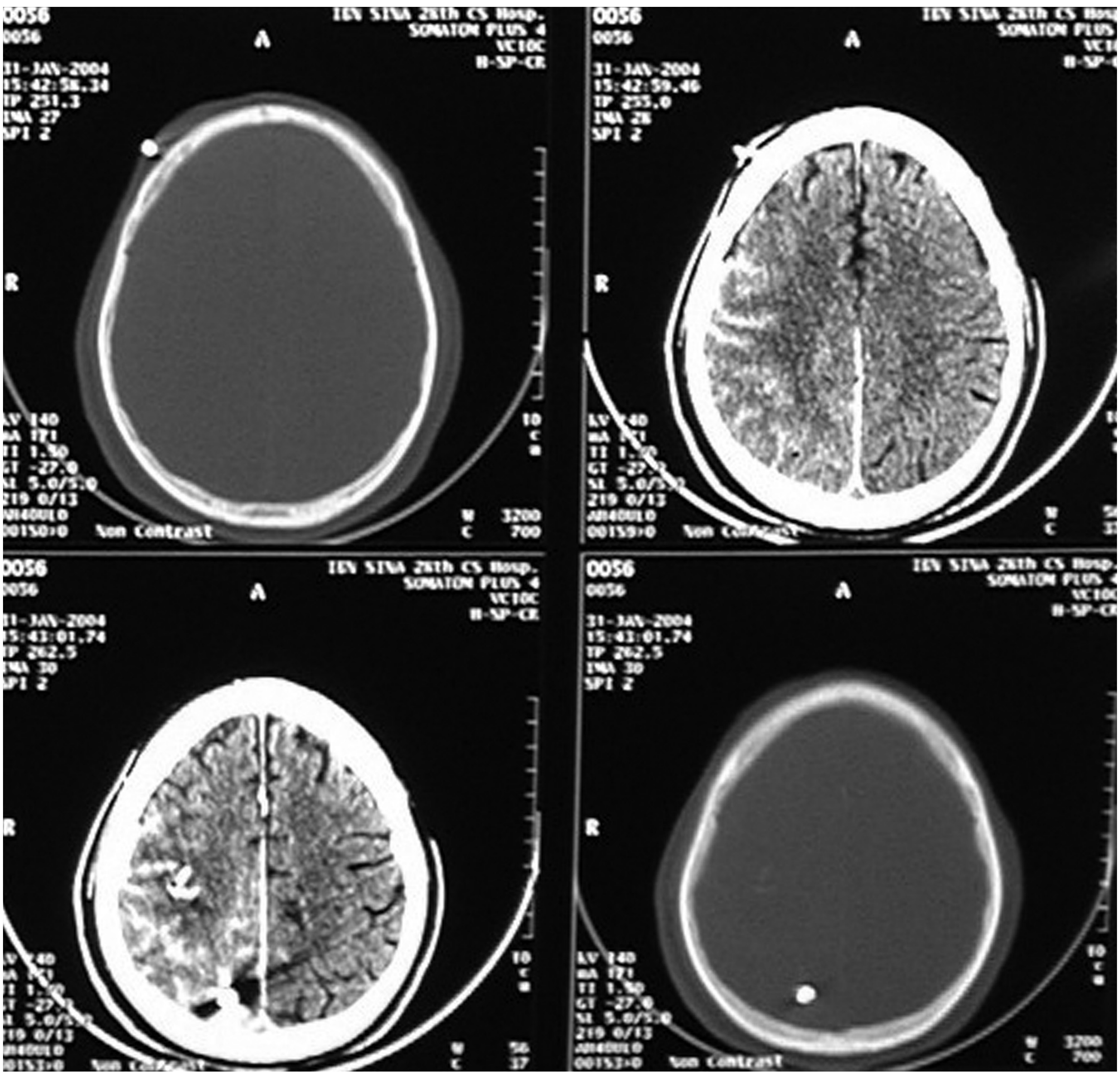


FIGURE 2. (Left) *Lateral skull radiograph showing metallic fragments in the frontal and parietal regions of the skull.*

FIGURE 3. (Bottom) *Series of axial CT images demonstrate a right frontal extracranial fragment, traumatic subarachnoid hemorrhage, and a right parietal lobe parenchymal fragment.*



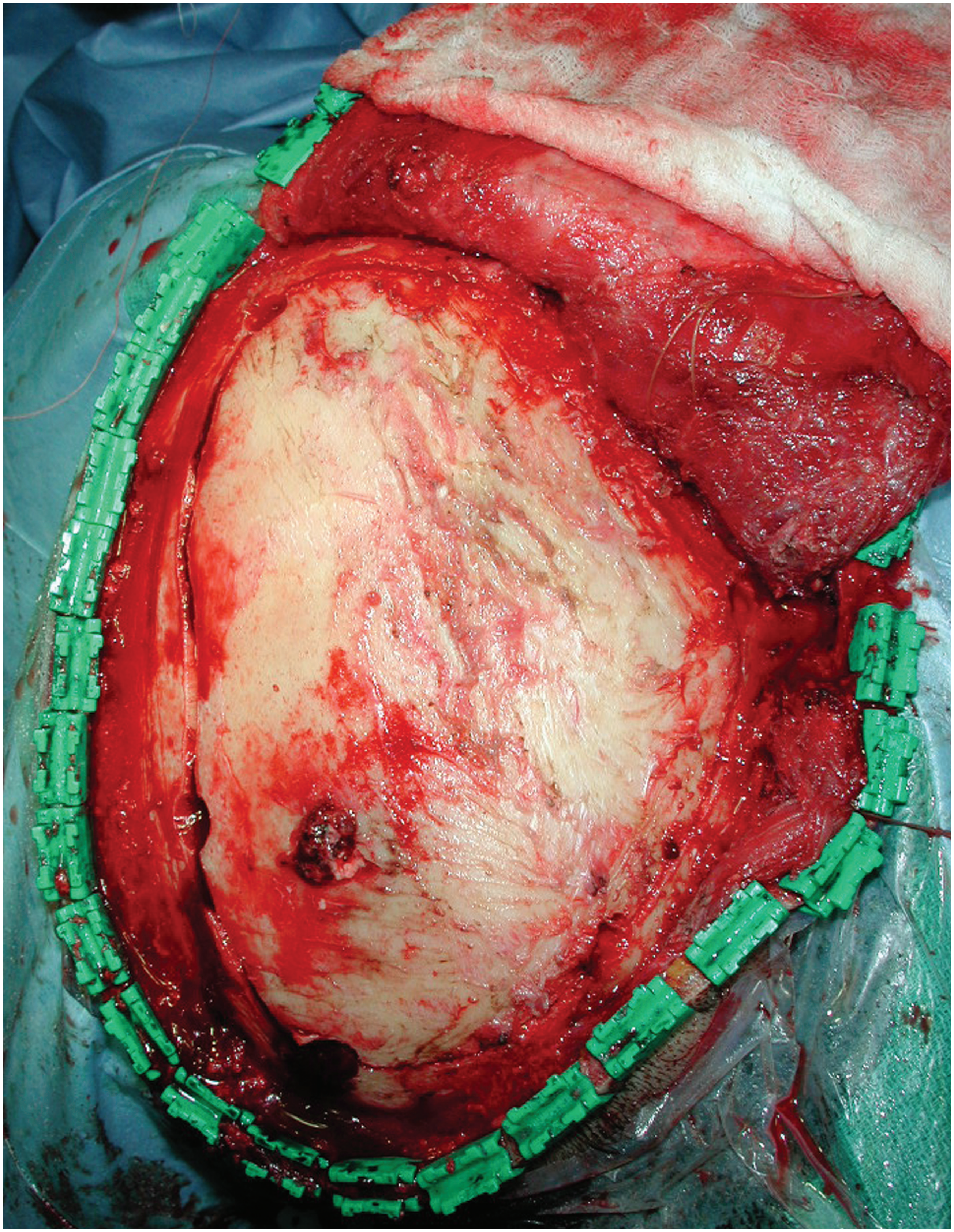


FIGURE 4. *A trauma flap was fashioned by reflecting the scalp and temporalis muscle anteriorly. The bone flap was fashioned using multiple burr holes and a craniotomy footplate high-speed drill attachment.*

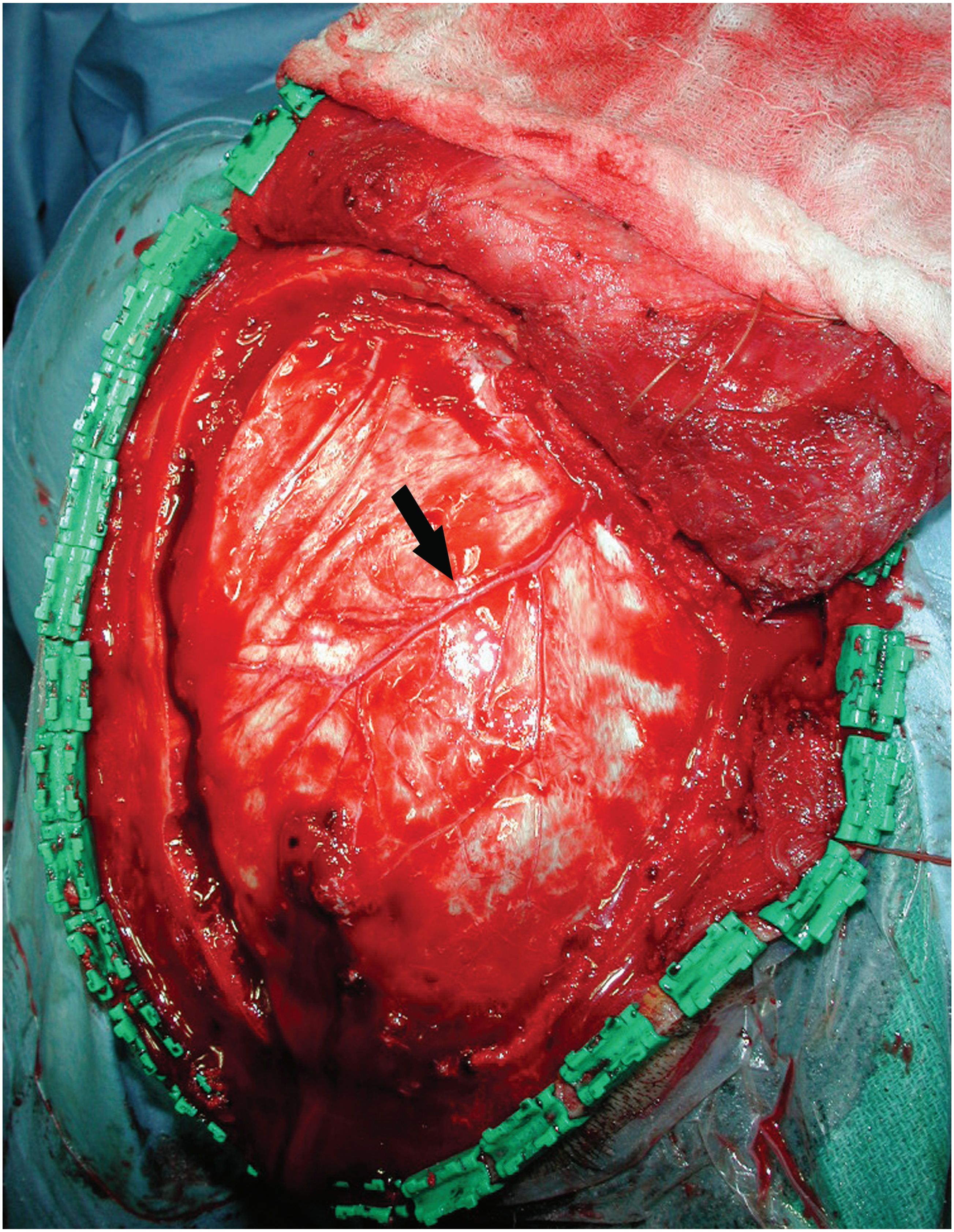


FIGURE 5. *The dura mater—note the prominent, middle meningeal artery* (arrow).

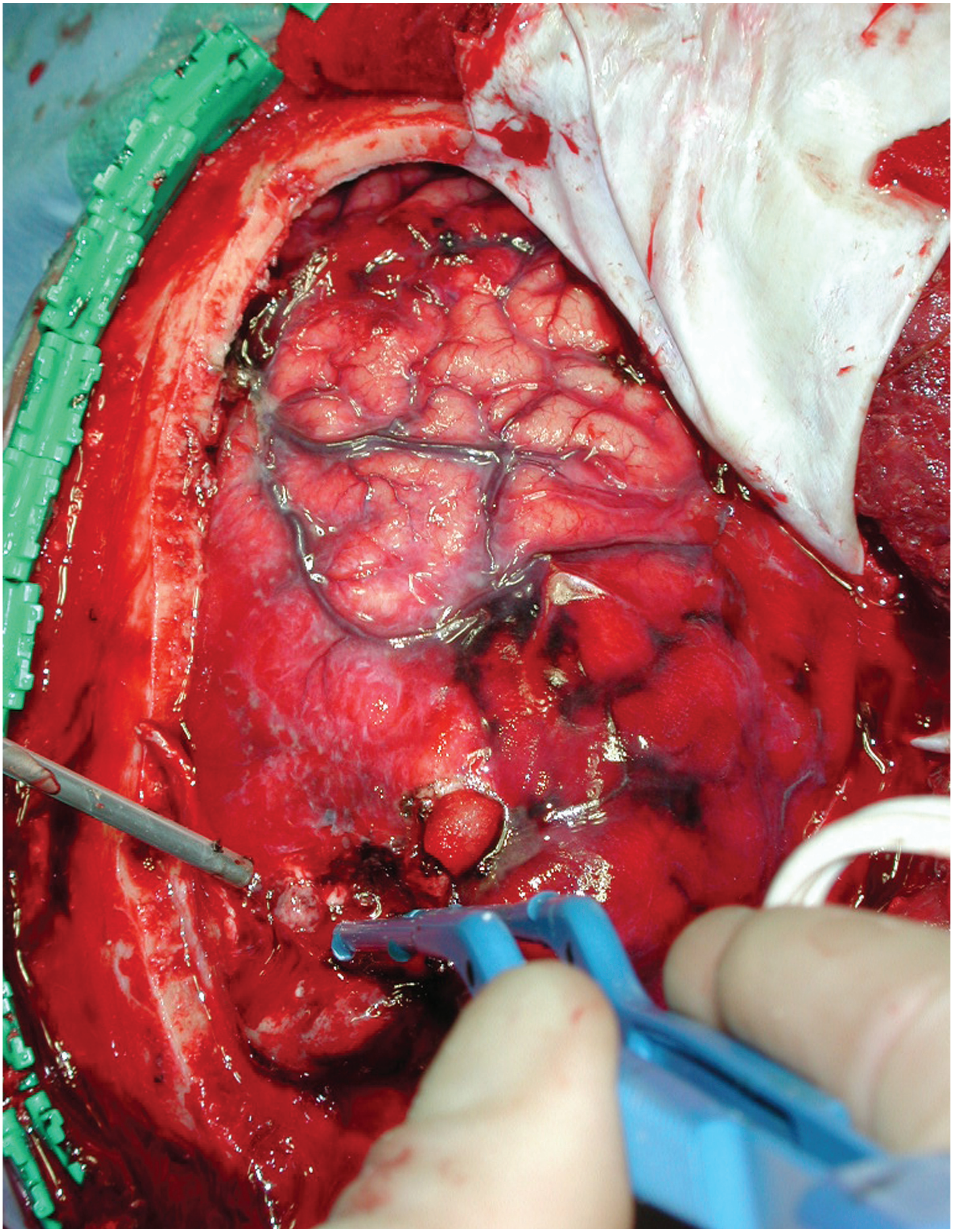


FIGURE 6. *The dura mater was reflected forward, and parenchymal bleeding was stopped using bipolar electrocautery.*

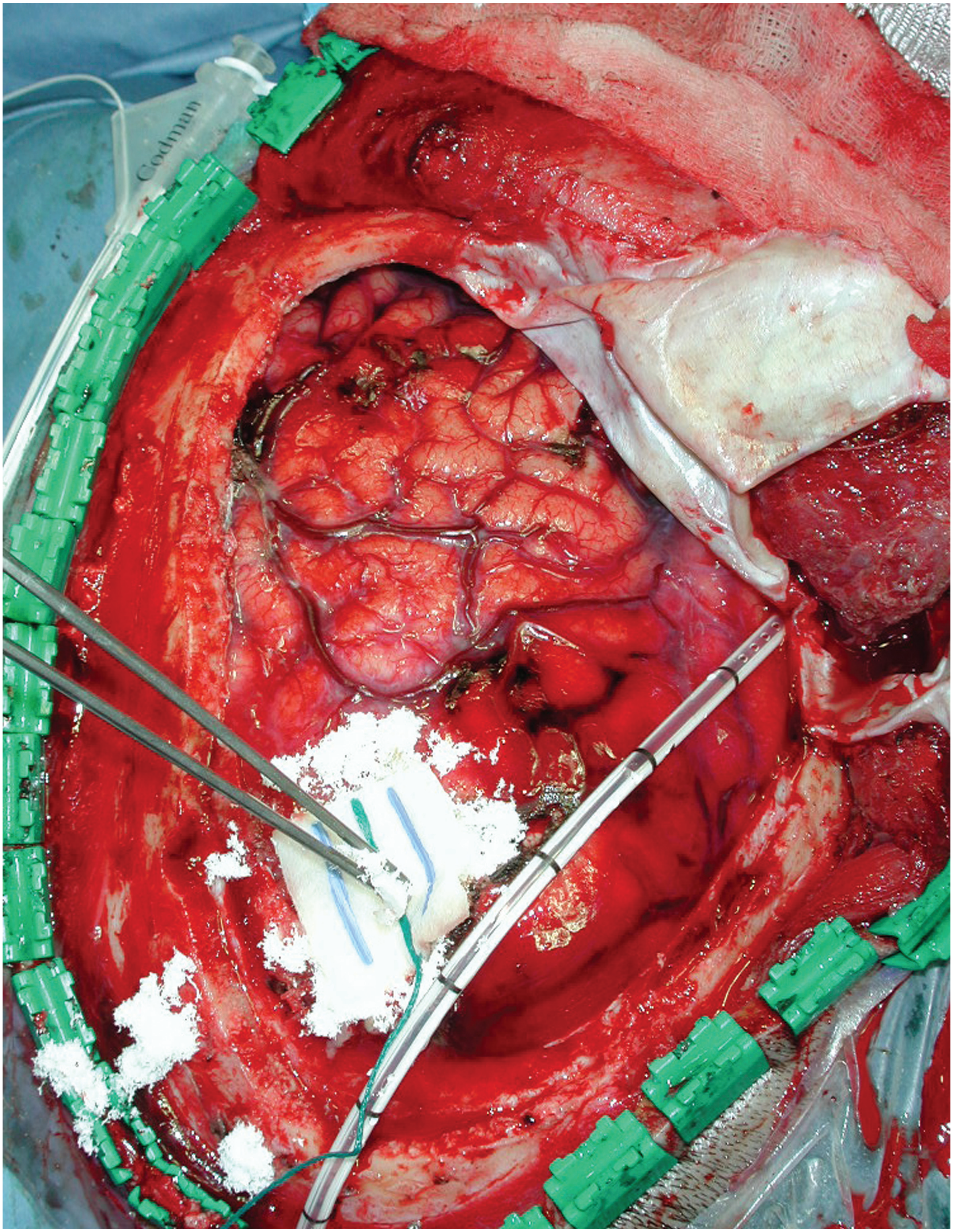


FIGURE 7. *Topical fibrillar was placed inside the bullet tract and tamponaded with a cottonoid patty.*

TOPICAL FIBRILLAR

This topical, hemostatic agent is a microfibrillar collagen that is made from beef skin. Topical hemostasis is facilitated by virtue of its fibrillar structure, which forms a sticky matrix for platelet aggregation.

is critical to prevent secondary brain injury due to physiological derangement and includes:

1. Managing patients with a Glasgow Coma Scale score of 12 or less in an intensive care unit, if available.
2. Avoiding hypoxia and maintaining a PaO_2 of 100 mm Hg or greater.
3. Maintaining the PCO_2 between 35 to 40 mm Hg.
4. Elevating the head of the bed to about 30 degrees.
5. Sedating (or pharmacologically paralyzing) intubated patients.
6. Administering broad-spectrum antibiotics to patients with penetrating injuries.
7. Administering phenytoin to prevent seizures.
8. Administering mannitol to patients with a deteriorating neurological examination and suspicion of herniation.
9. Treating hypovolemia to help maintain cerebral perfusion pressure.
10. Evacuating the patient to a facility with a neurosurgeon as soon as possible.

DAMAGE CONTROL

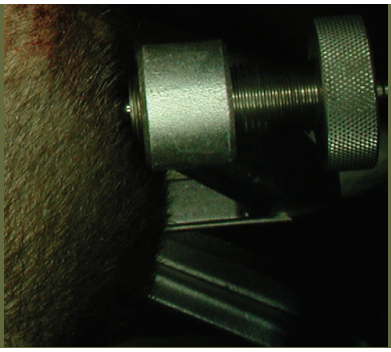
Neurosurgical damage control includes early ICP control, cerebral blood flow preservation, and prevention of secondary cerebral injury from hypoxia, hypotension, and hyperthermia. Intubation with adequate ventilation and control of hemorrhage with adequate resuscitation, followed by immediate evacuation to the nearest neurosurgeon, are critical. Unnecessary diagnostic delays must be avoided.

SUMMARY

This case demonstrates a patient with severe primary brain injury due to a penetrating mechanism. In this case, secondary injury was minimized by appropriate neurosurgical intervention, resulting in an excellent, functional outcome for the patient.

SUGGESTED READING

Chapter 15: Head injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.



III.4
Manual Craniotomy for Penetrating Head Injury

CASE PRESENTATION

A 22-year-old helmeted soldier suffered a forehead injury during the explosion of an improvised explosive device (IED). He was the front-seat passenger in a HMMWV (high-mobility multipurposed wheeled vehicle or "Humvee") when debris from the blast struck him. He arrived at the combat support hospital (CSH) fully awake, with a Glasgow Coma Scale score of 15 and no focal neurological deficits. Physical examination revealed a laceration on the right frontal region of the scalp (Fig. 1). CT showed depressed right frontal bone fragments and a 3-cm hematoma with minimal mass effect (Fig. 2). No other significant injuries were noted on secondary survey. The patient was taken to the operating room. He was positioned in Mayfield pins to expose the right frontal region of the head. Then the scalp and temporalis muscle were elevated together after incision just behind the hairline from the sideburn to the midline. A brace and bit were used to fashion a burr hole just anterior to the site of skull penetration (Fig. 3), and then two more burr holes were created to place the penetration site in the center of a triangle (Fig. 4). After developing the epidural plane with a no. 3 Penfield dissector, a Gigli saw guide was passed from one burr hole to another (Fig. 5). The Gigli saw blade was then drawn through the epidural plane and used to cut the bone edges on all three sides of the triangle (Fig. 6). The bone flap was removed to expose the underlying dural laceration, which was enlarged in stellate fashion. After irrigation, the acute hematoma was spontaneously expressed by the swollen surrounding brain. After removal of the hematoma, the cavity was irrigated and visible bleeding stopped with bipolar electrocautery (Fig. 7). Hemostasis was then completed using fibrillar hemostatic agent. After hemostasis, a pledget of gel foam was laid in the epidural plane to create a barrier above the unclosed dura mater (Fig. 8). The bone flap was replaced using burr hole covers and screws to maximize his cosmetic outcome (Fig. 9). The galea aponeurotica was reapproximated using 2-0 VICRYL in inverted interrupted fashion, and the scalp edges were approximated with staples (Fig. 10). The forehead laceration was closed with 5-0 monofilament nylon. The patient was extubated at the end of the case, ambulated that evening, and ate a regular breakfast the following day. He was evacuated to a level IV medical treatment facility shortly thereafter and recovered without neurological deficit.

Figure 1. (Top) *Right frontal scalp laceration.*

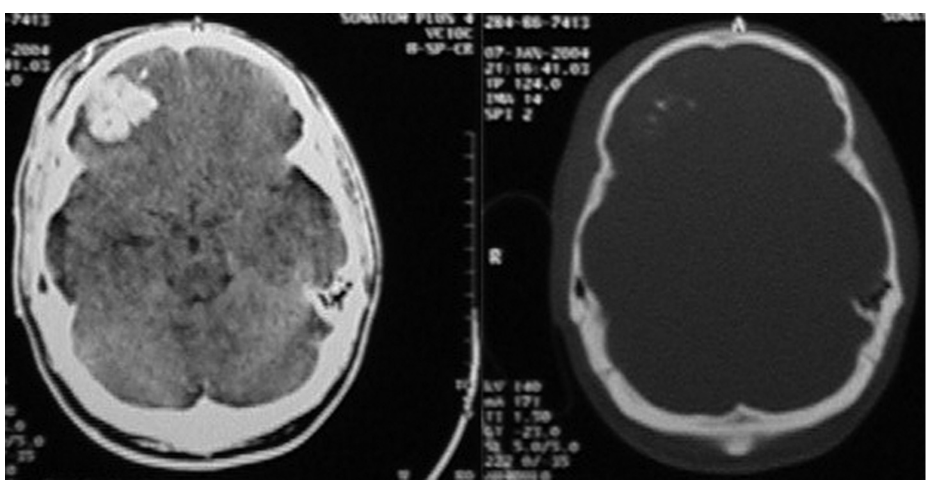


Figure 2. (Bottom) *These images show right frontal bone fragments and a 3-cm hematoma with minimal mass effect. There is overlying soft-tissue edema.*

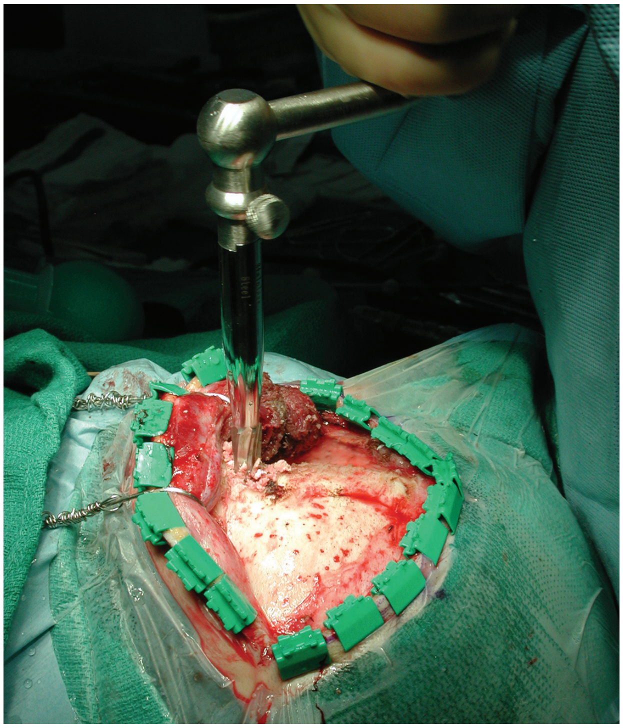


Figure 3. *A brace and bit were used to fashion a burr hole just anterior to the site of skull penetration.*

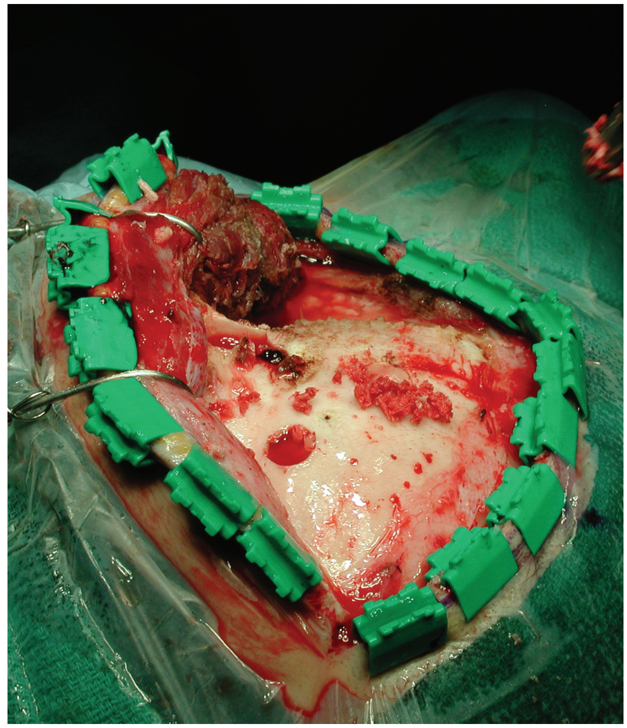


Figure 4. *Three burr holes have been created, with the entrance wound centered between them.*

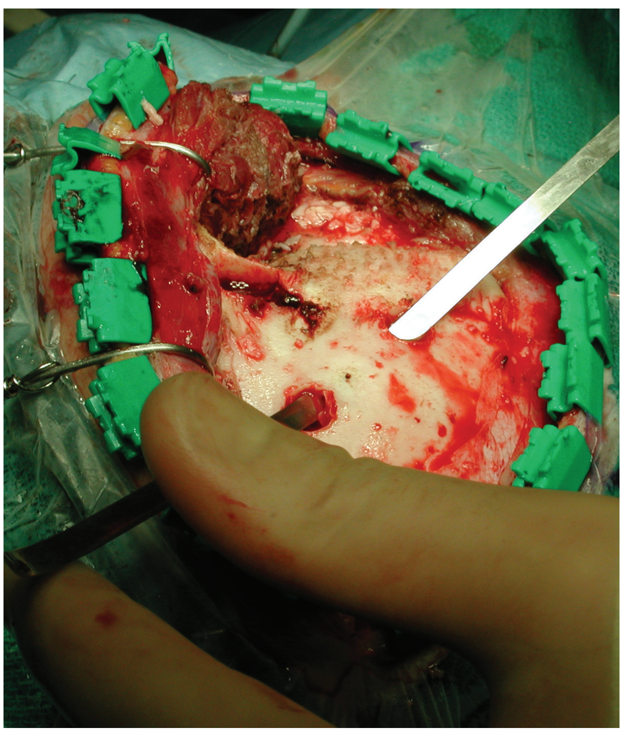


Figure 5. *A Gigli saw guide has been passed between two burr holes.*

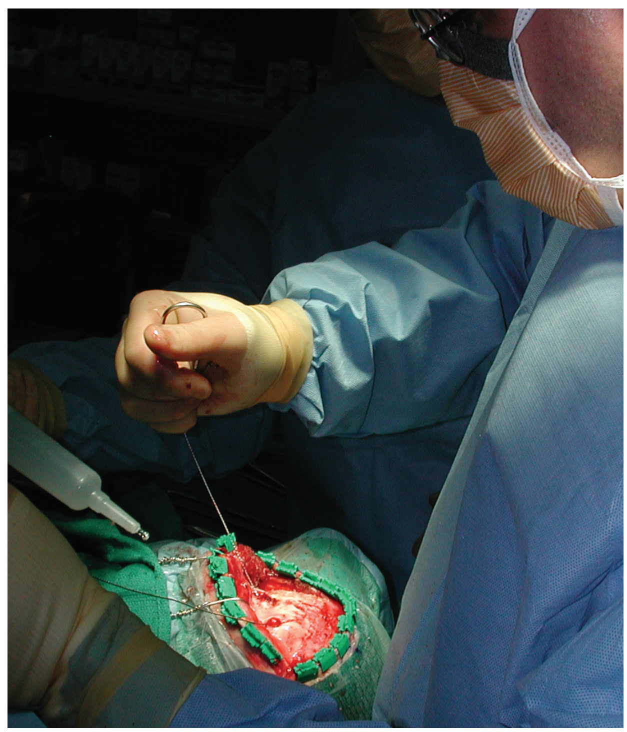


Figure 6. *The Gigli saw is used to cut the bone edges between burr holes.*

MEDICAL RAPID PROTOTYPING IN COMBAT CASUALTY CARE
Using Duplicate Anatomical Structures in Orthopaedic Reconstructions

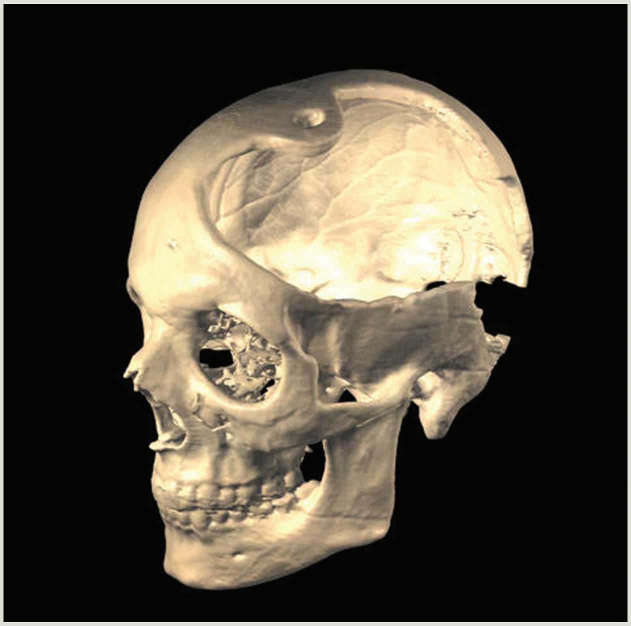


FIGURE 1. *Three-dimensional CT of patient s/p craniectomy.*

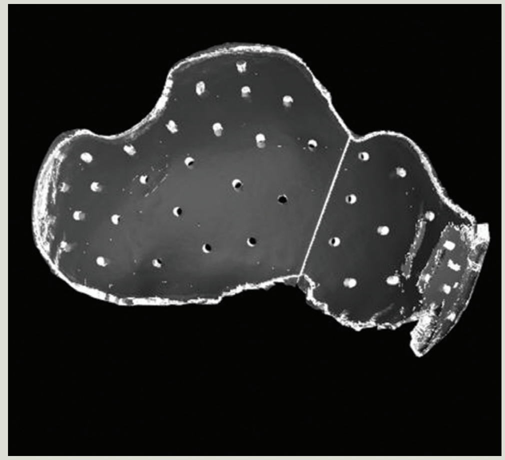


FIGURE 2. *PMMA cranial plate (implant).*

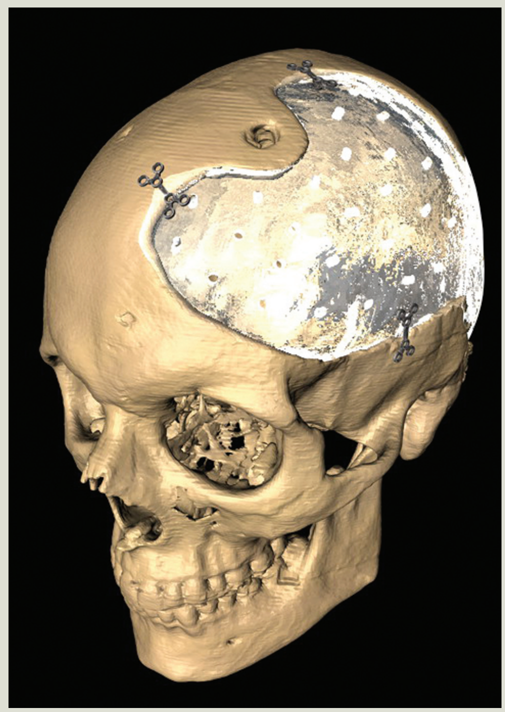


FIGURE 3. *Craniectomy model with implant in place.*

Modeling of craniofacial and other orthopaedic injuries (see Heterotopic Ossification sidebar on page 294), and the creation of custom implants and fixation devices are accomplished at Walter Reed Army Medical Center's 3D Medical Applications Center. Presurgical models are produced by a process known as stereolithography and delivered within 48 hours of receipt of appropriate CT scans. These duplicate anatomical structures are made available to any military medical center where they are used in preoperative planning, as well as in prosthetic fabrication. Custom cranial implants are also produced in-house at Walter Reed and sterilized, ready for implantation. Approximately 45% of models fashioned at Walter Reed are craniofacial.[1]

Case Presentation

A soldier on foot patrol in Iraq was struck by a sniper's bullet punching through his helmet just above the left ear. Fragments of Kevlar, bullet, and bone were driven into his brain and through the torcula. An initial craniotomy and debridement were performed at a deployed Combat Support Hospital (CSH). A second operation at another CSH was required to expand the craniectomy due to increases in intracranial pressure. After the patient was stable, he was medevaced to the level IV medical facility in Landstuhl, Germany, and, subsequently, to the National Naval Medical Center in Bethesda, Maryland. Two months after the

FIGURE 4. *Patient and his wife 5 months post-op.*

injury, extensive rehabilitation therapy was begun. Approximately 5 months from injury, a custom-made, two-piece, polymethyl methacrylate (PMMA) cranial plate was prepared and surgically implanted (Figs. 1–3). The plate was retained by small titanium fixation plates and screws. The patient was discharged postoperatively to continue rehabilitation therapy that included physical and cognitive functions. He shows minimal physical evidence of the injury and has demonstrated significant improvement in all neurological functions (Fig. 4).

—STEPHEN L. ROUSE, DDS

1. Walter Reed Army Medical Center 3D Medical Applications Center Web site. Available at: http://www.wramc.amedd.army.mil/Patients/healthcare/3dapp/. Accessed November 13, 2007.

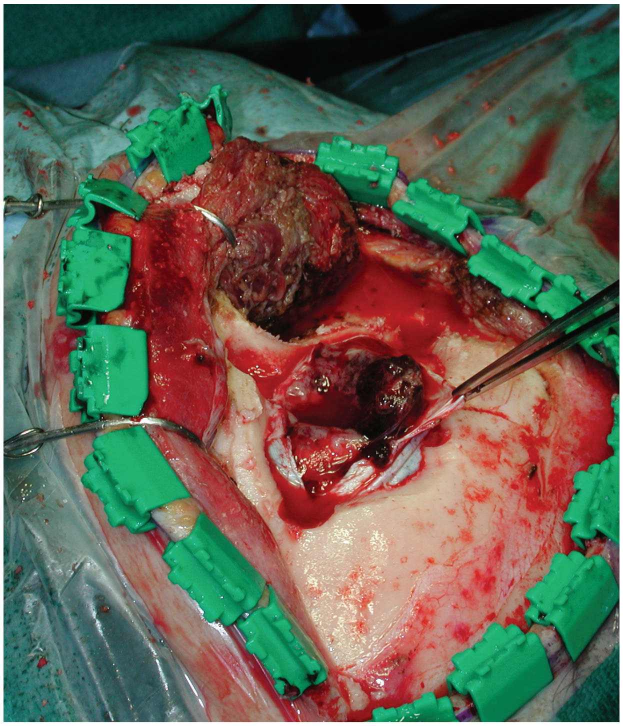


FIGURE 7. *Wound after the dura mater has been opened and the hematoma evacuated.*

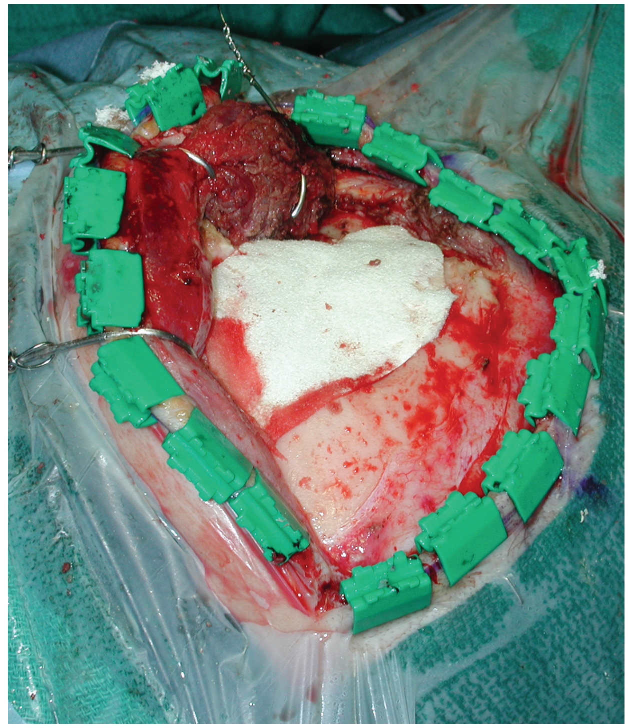


FIGURE 8. *A pledget of gel foam was laid in the epidural plane to create a barrier above the unclosed dura mater.*

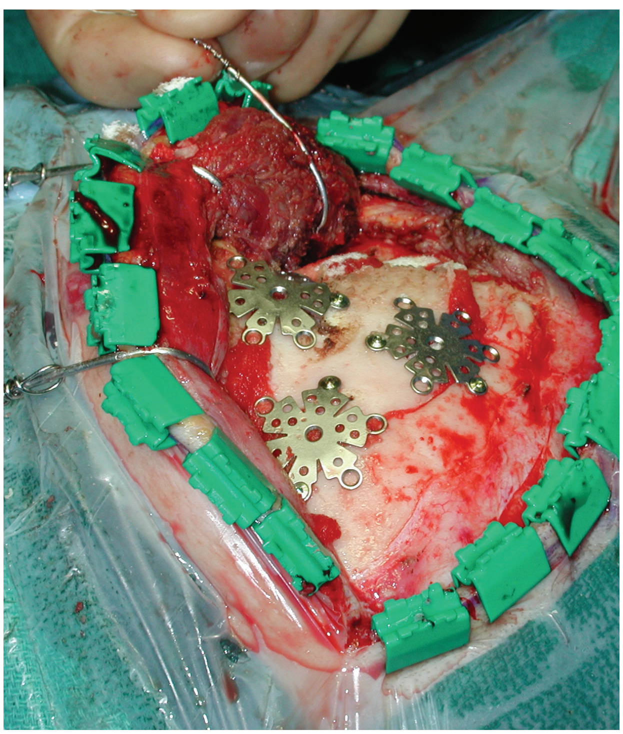


FIGURE 9. *The bone flap was replaced using burr hole covers and screws to maximize the patient's cosmetic outcome.*

FIGURE 10. *After closure of the galea aponeurotica, surgical and entrance wounds are closed.*

TEACHING POINTS

1. In general, patients should not decline neurologically during surgery of the brain. Outcomes are closely associated with presenting neurological examination.
2. This case shows the manual technique of fashioning a bone flap when a high-speed drill is unavailable. A brace, bit, and Gigli saw kit require no external power source and are extremely portable in a single, small sterilization tray.
3. Standard closure techniques are also shown. In this case, the dura mater was not reapproximated and a drain was unnecessary. In general, primary closure of the dura mater should be performed if technically possible. A patch may be fashioned from pericranium, which can be harvested during elevation of the scalp.

CLINICAL IMPLICATIONS

In the combat environment, neurosurgeons may not be available or circumstances may prevent evacuation of patients to facilities with neurosurgical capability. If a neurosurgeon is not available, general surgeons may need to perform this surgery. Indications for emergent surgical management include the following:

1. Space-occupying lesions with neurological changes:
    a. Acute subdural hematoma.
    b. Acute epidural hematoma.
    c. Abscess.
2. Intracranial hematoma producing a greater than 5-mm midline shift or similar depression of the cortex.
3. Compound depressed fracture with neurological changes.
4. Penetrating injuries with neurological changes.

DAMAGE CONTROL

Severe head injuries are often seen in combination with significant chest, abdomen, and extremity injuries. Hemorrhage control and damage control techniques should be used to treat the cranial injury as soon as possible. It is often possible to operate in a major body cavity and on the brain simultaneously.

SUMMARY

This case is an example of an excellent outcome in a patient with a penetrating brain injury using a manual craniotomy technique. This technique can be used in austere environments when faced with a deteriorating patient with penetrating brain injury and should be studied by all deploying general surgeons.

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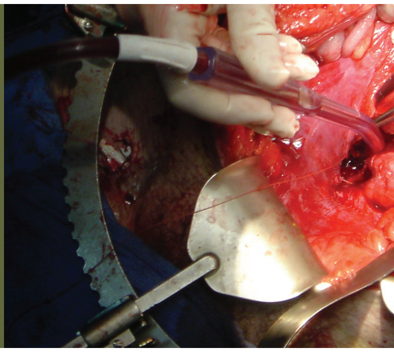


III.5 Spinal Cord Injury Without Paralysis

CASE PRESENTATION

This 5-year-old host nation male sustained injuries after multiple weapons were discharged into a vehicle that was attempting to run a checkpoint. His vital signs were stable. However, he was persistently tachycardic despite fluid resuscitation. The patient complained of persistent, severe abdominal pain. His neurological motor examination was intact. A large entrance wound was apparent on his lower back. He was taken to the operating room (OR) where exploratory laparotomy revealed a small bowel laceration, which was repaired. No other abdominal injuries were found. The patient was placed in the prone position to determine the extent of dorsal damage. He had an exposed spinal cord (at the L3 level) with a cerebrospinal fluid leak (Fig. 1). The spine was stable, with only posterior spinal column involvement. Because of extensive tissue damage around the spinal cord, a gluteal flap was created and rotated over the spinal canal to prevent cerebrospinal fluid leakage and infection (Fig. 2). A wound vacuum-assisted closure (VAC) device was placed over the wound, and the patient was taken to the intensive care unit (ICU) for continued resuscitation. His postoperative course was unremarkable, and he returned to the OR on subsequent occasions for tissue debridement, wound VAC placement, and eventual wound closure. After prolonged rehabilitation, the patient was discharged and able to walk without assistance.

TEACHING POINTS

1. Wounds to the back may involve any anterior body compartment. High-velocity fragments may travel to any part of the body. It is imperative that a full-body radiological evaluation be performed to rule out injuries distant from the obvious entry wounds.
2. ICUs must have the equipment necessary to provide care to pediatric patients. It is essential that the deployed level II and level III medical treatment facilities (combat support hospital [CSH]/Forward Surgical Team [FST]) have the necessary equipment and trained personnel to manage pediatric surgery patients.
3. Wound VAC dressings have proven useful in sealing cerebrospinal fluid leaks.

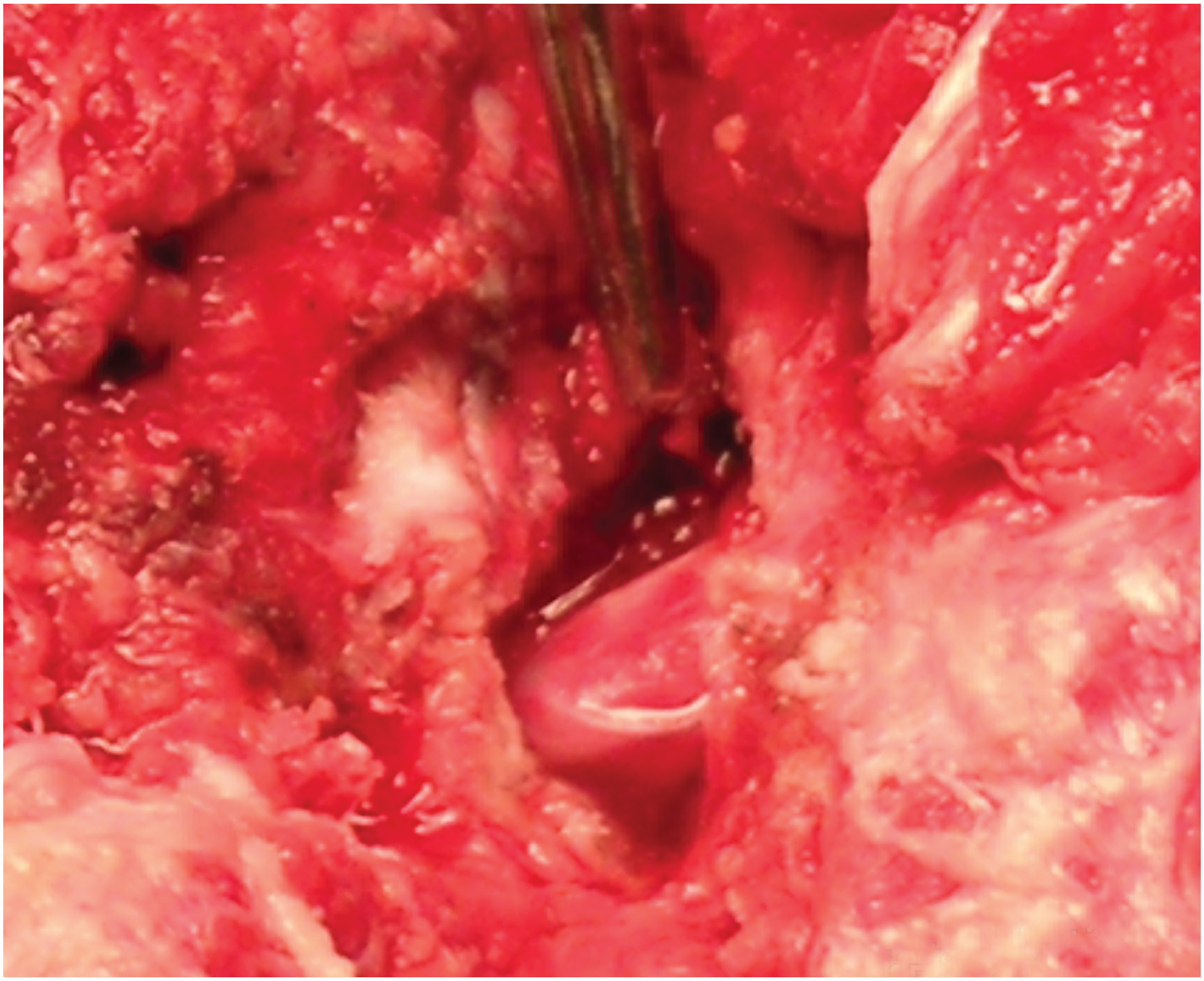


FIGURE 1. *Close-up of the exposed spinal cord.*

CLINICAL IMPLICATIONS

1. When complex wounds involving the head, thorax, abdomen, or extremities coexist with vertebral column injuries, lifesaving measures take precedence over the definitive diagnosis and management of the spinal column and spinal cord. The spine must be immobilized to prevent neurological deterioration until the extent of spinal stability is determined. However, unlike blunt force mechanisms, penetrating spinal trauma often results in no spinal column instability. Removal of fragments from the spinal canal is indicated in patients with neurological deterioration.
2. Combat injuries of the spinal column, with or without associated cord injury, differ from those routinely encountered in civilian practice. They are often open, contaminated, and associated with other organ injuries.

DAMAGE CONTROL

1. Emergent spine surgery for penetrating or closed injuries of the spinal cord is only indicated in the presence of neurological deterioration.
2. In neurologically stable patients with fragments in the cervical canal, delaying surgery for 7 to 10 days reduces problems with dural leak and makes repair easier.

SUMMARY

This case demonstrates the association of hollow viscus injury associated with penetrating back injury. Remarkably, this patient made a good, functional

FIGURE 2. *The exposed spine covered with gluteal muscle.*

recovery because trauma tenets were rigorously followed. Specifically, the patient was appropriately resuscitated, intraabdominal injuries were repaired, and the exposed spinal cord was then covered with a muscle flap and wound VAC. Bony structures in this penetrating injury remained stable. It is imperative that all treatment team members understand the likelihood of providing care to individuals of all ages. In addition, high-velocity wounds can travel throughout the body.

SUGGESTED READING

Chapter 17: Abdominal injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 20: Wounds and injuries of the spinal column and cord. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 33: Pediatric care. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

COMMENTARY

Hemicraniectomy

by LTC Rocco A. Armonda, MD

A major paradigm shift has occurred in the far-forward treatment of neurotrauma patients. Prior historical practices of radical debridement and minimal decompression have been replaced by minimal debridement and radical decompression (Fig. 1). This is especially true in the presence of blast-induced penetrating brain injury or under body armor injury. Because of the combination of improved body armor, advanced combat casualty care at the site of wounding, and rapid evacuation, a higher proportion of neurotrauma casualties benefit from early neurosurgical intervention. Theoretically, the far-forward neurosurgeon has modern imaging capability, electric drills, and all the equipment necessary for cranial-spinal decompression and resuscitation. In some cases, the deployed neurosurgeon may receive casualties in less than an hour after injury, due to the heroic efforts of the tactical MEDEVAC. On arrival, these patients may have already been intubated, chemically paralyzed, and without a sensorimotor examination. In such cases, the neurosurgeon is dependent on the axial CT imaging of the brain to determine if the casualty will benefit from aggressive cranial-spinal decompression; invasive cranial monitoring with medical management; or compassionate, nonheroic palliative care. Those penetrating injuries that course through the diencephalon (hypothalamus/thalamus) or brain stem (known as the central core of the brain or in some cases "zona fatalis") uniformly do poorly. Patients are more likely to survive in a minimally responsive state, without the ability to interact with their environment. They eventually succumb to delayed infections and the morbidity of a dependent, bedridden life. However, this is not the case for those patients with focal mass lesions, localized or hemispheric edema, or penetrating trauma above the diencephalon or above the ventricular level, with a motor examination demonstrating withdrawal or localization to stimuli. These patients may benefit greatly from a decompressive hemicraniectomy and hematoma evacuation. The focus of a far-forward neurosurgeon is to decompress the brain stem, obtain hemostasis, and stabilize the patient for a 7,000+ mile transport to the United States. Given this mission, the neurosurgeon seeks to avoid complications associated with delayed hydrocephalus, diffuse cerebral edema, or delayed hematoma formation. Preferably, this is done by placing a ventriculostomy when indicated in theater prior to transport; performing a large (12 cm or more) hemicraniectomy when delayed swelling is suspected (ie, postblast injury); and ensuring hemostasis, as confirmed by a postoperative, pre-MEDEVAC CT scan before transport to the continental United States. A summary of the typical complications and respective treatment during the first 6 months is listed in Table 1.

FIGURE 1. *Historical evolution of treatment paradigms for penetrating brain injury.*

Table 1. *Complications of Wartime Penetrating Brain Injury*

Time	Type of Complications	Treatment	Typical Location
0–24 hours	ICP increased	Hemicraniectomy	Level III (FST/CSH)
	Hematoma	Evac/coag correction	
	Ischemia	Decompression/identity occlusion (angiography)	
	Anatomical defect	Anatomical closure	
	Hypoxia	Airway/pulmonary correction	
		Overt or occult EBL	
	Hypotension	PRBCs/FFP/PLTs vs whole blood vs hypertonic saline	
24–48 hours	ICP increased	Hemicraniectomy	Level III (CHS)
	Hematoma	Evac/coag correction	
	Hydrocephalus	Ventriculostomy	
	Edema	Decompression	
	Seizures	Antiepileptics/EEG monitoring	
72 hours–1st week	Edema	Medical/surgical decompression	Level IV/V (LRMC)
	ICH (contusion)	Correct coagulopathy	
	Hydrocephalus	Ventriculostomy	
	CSF leak	Repair/CSF diversion	
	Ischemia	Medical/endovascular Tx	
	Pseudoaneurysm	Surgical/endovascular Tx	
	Seizures	Antiepileptics/EEG monitoring	
2nd–3rd week	Infection	R/O abscess, repair CSF leak	Level V (NNMC, WRAMC)
	Vasospasm	Multimodal monitoring (transcranial Doppler, brain tissue oxygen, EEG, CBF monitoring) *Treatment*: microballoon angioplasty intraarterial nicardipine	
	Pseudoaneurysm	Endovascular vs microsurgery Tx	
	Seizures	Antiepileptics	
	Delayed hydrocephalus	VP shunt (low-pressure; consider use of a programmable valve)	
1–6 months	Infection	R/O abscess, meningitis, and ventriculitis	Level V VA-civilian rehabilitation, polytrauma center
	Low-pressure hydrocephalus	VP shunt (programmable valve)	
	Syndrome of the Trephine	Reconstructive cranioplasty	
	Seizures	Antiepileptics	
	Cranioplasty complications:		
	Temporalis atrophy	Resuspension/implant/fat graft	
	Infection	Prosthesis removal	
	Hydrocephalus	VP shunt	
	Epidural/subgaleal hygroma/hematoma	Drainage	
	ICH	Evacuation	
	Scalp necrosis	Free flap	

CBF: cerebral blood flow; coag: coagulopathy; CSF: cerebrospinal fluid; CSH: combat support hospital; EBL: estimated blood loss; EEG: electroencephalogram; evac: evacuation; FFP: fresh frozen plasma; FST: Forward Surgical Team; ICH: intracranial hemorrhage; ICP: intracranial pressure; LRMC: Landstuhl Regional Medical Center; NNMC: National Naval Medical Center; PLTs: platelets; PRBCs: packed red blood cells; R/O: rule out; TCD: transcranial Doppler; Tx: treatment; VA: Veterans Administration; VP: ventriculoperitoneal; WRAMC: Walter Reed Army Medical Center.

COMMENTARY

Traumatic Brain Injury

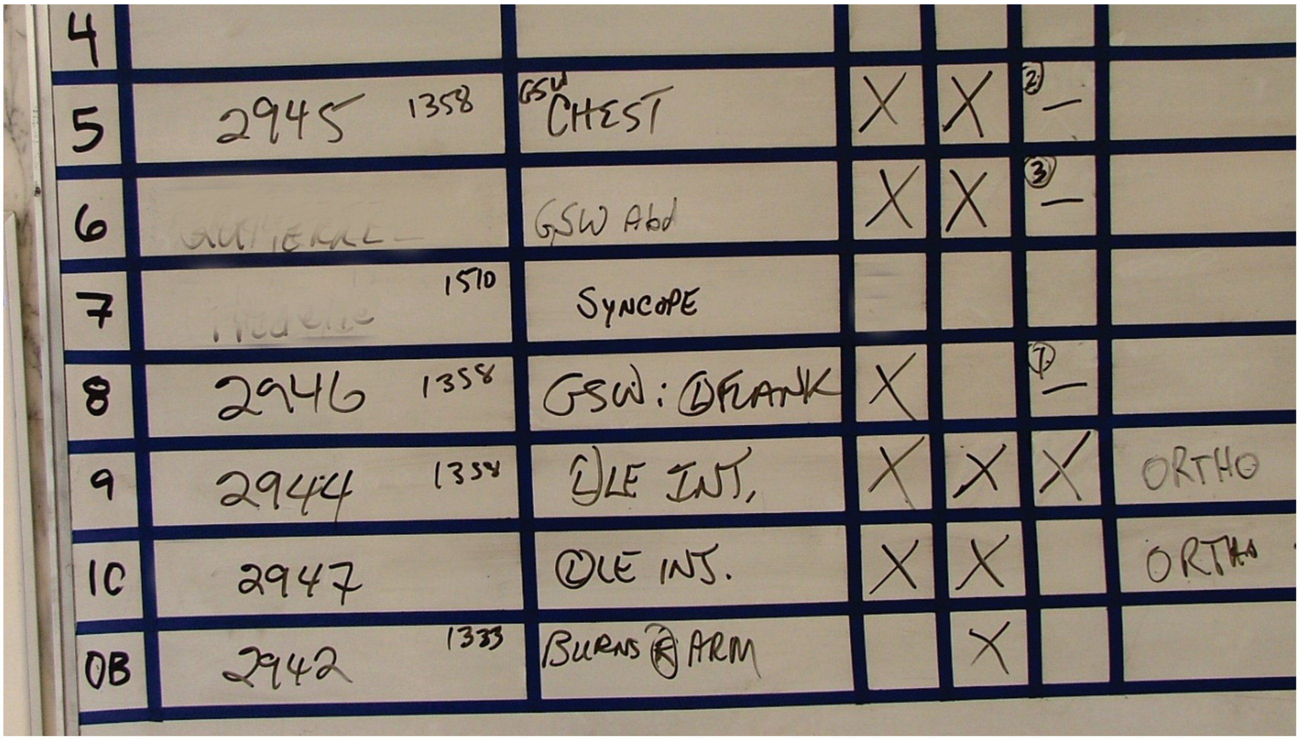
by Katherine M. Helmick, MS, CNRN, CRNP, and Deborah L. Warden, MD

Traumatic brain injury (TBI) has been called the signature injury of the current conflicts in Afghanistan and Iraq.[1] TBI can be subclassified into blunt (closed) injury and penetrating brain injury. Troops with penetrating brain injury are usually identified and cared for immediately because of the overt nature of their intracranial lesions, as exemplified in the case studies in Chapter III. Neurosurgical intervention was necessary in all cases, and excellent recovery outcomes were also reported. Historically, in times of military conflict, penetrating brain injury has been well reported. However, in the context of the current conflict, closed-brain injury (specifically mild TBI) has emerged as a real concern and potentially threatening healthcare problem. Approximately 29% of Operation Iraqi Freedom/Operation Enduring Freedom battle-injured casualties, who were medically evacuated through Walter Reed Army Medical Center, sustained at least a mild TBI.[2] Several peacetime military studies have helped to elucidate the physical and cognitive sequelae occurring after mild TBI or concussion. Delays in reaction time and declines in arithmetic calculation abilities have been shown to affect concussed cadets up to 7 days after injury.[3,4] In addition, neurocognitive impairment has been found in athletes who did not lose consciousness while sustaining a concussion.[5] For these reasons, there is concern that a soldier who has sustained a mild TBI may become sufficiently impaired as to affect personal and unit readiness. A concussion is suspected in anyone exposed to or involved in a blast, fall, vehicle crash, or direct head impact who becomes dazed, confused, or loses consciousness, even momentarily.

The operational setting provides a unique set of circumstances that prompts special considerations in the assessment and management of mild TBI in order to arrive at an optimal plan for both the injured and the mission. Certain variables that are present in current theater operations make the identification of mild TBI even more critical. Many troops experience numerous deployments that increase their risk of sustaining more than one concussion. In addition, the unconventional nature of current operations has translated into an increased likelihood of exposure to blast during a tour of duty. In Operation Iraqi Freedom, blast-induced brain injury is the primary mechanism that produces TBI. Blast injury may cause TBI through multiple mechanisms, including injury from energized debris that may cause blunt or penetrating brain injury, as well as displacement of the person that may result in a closed-brain injury pattern. The potential to cause brain injury from primary blast is under current study.

The assessment and management of implications from mild TBI differ from the neurosurgical patients portrayed in the case studies. In these patients, the Glasgow Coma Scale (GCS) score was assessed and influenced the management process to include neurosurgical intervention. Unfortunately, the GCS is not a sensitive assessment tool for mild TBI because many individuals score 15 and appear uninjured; however, they may have significant physical or neurocognitive signs and symptoms. A brief, yet valuable, tool that can be used to assess deficits after mild TBI is the Military Acute Concussion Evaluation (MACE). Embedded within MACE is the Standardized Assessment of Concussion[6] (SAC), a validated tool used extensively in the sports realm to assess neurocognitive functioning.

Concussion management guidelines have been developed and disseminated for field operational use.[7] These guidelines specifically address the assessment and management of mild TBI occurring in the context of a military operational setting. Assessment is based on


4
5 2945 1358 GSW CHEST X X 2 —
6 GSW Abd X X 3 —
7 1510 SYNCOPE
8 2946 1358 GSW: L FLANK X 1 —
9 2944 1358 L LE INJ. X X X ORTHO
10 2947 L LE INJ. X X ORTHO
OB 2942 1333 BURNS R ARM X


CAUTION

utilizing MACE, as well as identifying red flags that would prompt an urgent evacuation to a higher echelon of care. Treatment algorithms are based on symptomatic relief, as well as protection of the soldier until asymptomatic. An educational intervention emphasizing the anticipated course of recovery has been demonstrated to reduce morbidity.[8] Various cognitive tests may be utilized to gain more objective information with regard to cognitive deficits after TBI. Prior to return to duty, troops are exertionally tested (eg, running in place for 5 minutes, doing sit-ups for 5 minutes, etc) to evaluate them for a possible return of TBI symptoms. (See Appendix D for the MACE form.)

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