Chapter 15

Head Injuries

Introduction

The prognosis of brain injuries is good in patients who respond to simple commands, are not deeply unconscious, and do not deteriorate. The prognosis is grave in patients who are rendered immediately comatose (particularly those sustaining penetrating injury) and remain unconscious for a long period of time. Any subsequent neurologic improvement may indicate salvageability and should prompt reevaluation.

Neurosurgical damage control includes early intracranial pressure (ICP) control; cerebral blood flow (CBF) preservation; and prevention of secondary cerebral injury from hypoxia, hypotension, and hyperthemia.

A motor examination of the most salvageable severely brain-injured patients will demonstrate localization to central stimulation and these patients will require expedited treatment. Immediate intubation with adequate ventilation is the most critical first line of treatment for a severely head-injured patient. Evacuation to the nearest neurosurgeon, avoiding diagnostic delays, and initiating cerebral resuscitation allow for the best chance for ultimate functional recovery.

Combat Head Injury Types

- Blunt (closed head injury).
- Penetrating.
  - Penetrating with retained fragments.
  - Perforating.
  - Guttering (grooving the skull).
  - Tangential.
  - Cranial facial degloving (lateral temple, bifrontal).

- Blast over-pressure CNS injuries.
  - o A force transmitted by the great vessels of the chest to the brain; associated with unconsciousness, confusion, headache, tinnitus, dizziness, tremors, increased startle response, and occasionally (in the most severe forms) increased ICP. Bleeding may occur from multiple orifices including ears, nose, and mouth.

A combination of multiple injury types are typically involved in combat-related brain injuries. Those injuries generally involve the face, neck, and orbit; entry wounds may be through the upper neck, face, orbit, or temple (Fig. 15-1).

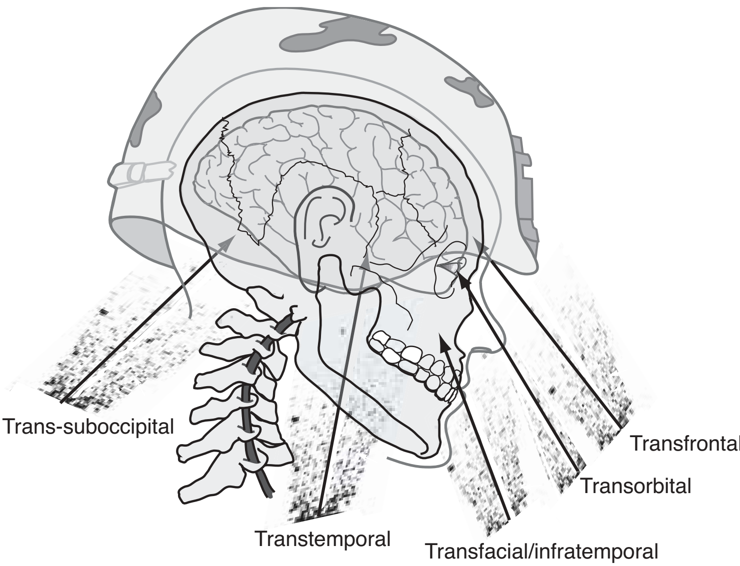

Fig. 15-1. Common vectors of penetrating injury.

The suboccipút, occiput, and retroauricular regions are overlooked most. Injuries to these areas can indicate underlying injury to the posterior fossa, major venous sinus, or carotid artery, as fragments pass through the skull base. Reconstructing the fragment path based on combination of plain films and computed tomography (CT) can be challenging. In transorbital, transtemple, or penetrating injuries that cross the midline, an underlying injury to intracranial vessels should be suspected with associated pseudoaneurysms, dissections, or venous sinus injury.

Explosion results in flying fragments, with possible vehicular-collision–associated blunt injuries. Depending on the proximity to the explosion, a blast over-pressure phenomenon may also result. In a severely brain-injured patient, more deficits than indicated by the CT scan may be due to possible underlying injury to brachiocephalic vessels, shear injury, or the effects of blast over-pressure with resulting cerebral vasospasm. Plain films, more useful in penetrating than blunt trauma, may reveal a burst fracture of the skull indicating the tremendous perforating force of a penetrating missile. Transventricular bihemispheric fragment tracts portend a poor prognosis.

Severe head injuries are often seen in combination with significant chest, abdomen, and extremity injuries. Very rapid hemorrhage control is the priority in the noncranial injuries; utilizing damage control concepts and focusing attention on the head injury. All efforts should be directed toward early diagnosis and intervention of the head injury.

Traditional Classification of Head Injuries

- **Open** injuries are the most commonly encountered brain injuries in combat.
- **Closed** injuries, seen more often in civilian settings, may have a higher frequency in military operations other than war.
- **Scalp** injuries may be closed (eg, contusion) or open (eg, puncture, laceration, or avulsion).
  - Any scalp injury may be associated with a skull fracture and/or underlying brain injury.
  - Open scalp injuries bleed profusely, even to the point of lethal blood loss, but usually heal well when properly repaired.
- **Skull fractures** may be open or closed, and are described as linear, comminuted, or depressed.
  - Skull fractures are usually associated with some degree of brain injury, varying from mild concussion, to devastating diffuse brain injury, to intracranial hematomas.

- o Open skull fractures are prone to infection if not properly treated.

Mechanisms of Injury

- **Primary injury** is a function of the energy transmitted to the brain by the offending agent.
  - o Very little can be done by healthcare providers to influence the primary injury.
  - o Enforcement of personal protective measures (eg, helmet, seatbelts) by the command is essential prevention.
- **Secondary injury** results from disturbance of brain and systemic physiology by the traumatic event.

Hypotension and hypoxia are the two most acute and easily treatable mechanisms of secondary injury.

- o Other etiologies include seizures (seen in 30%–40% of patients with penetrating brain injuries), fever, electrolyte disturbances (specifically, hyponatremia or hyperglycemia), and infection.
- o **All of the above conditions can be treated.**
- o Elevations of ICP may occur early as a result of a space-occupying hematoma, or develop gradually as a result of brain edema or hydrocephalus.
- o Normal ICP is 5–15 mm Hg, with normal cerebral perfusion pressure (CPP = MAP-ICP) usually around 70–80 mm Hg.
- o Decreases in perfusion pressure as a result of systemic hypotension or elevated ICP gradually result in alteration of brain function (manifested by impairment of consciousness), and may progress to global brain ischemia and death if not treated.

Patient Assessment and Triage

During the primary and secondary assessment, attention should be placed on a complete examination of the scalp and neck. Fragments that enter the cranial vault with a transtemple, transorbital, or cross midline trajectory should be suspected as having associated neurovascular injuries. Wounds are typically contaminated by hair, dirt, and debris and should be copiously irrigated clean with control of scalp hemorrhage **but not at the expense of delaying definitive neurosurgical treatment**! Scalp hemorrhage can be controlled with a head wrap, scalp clips, or surgical staples; a meticulous plastic surgical closure is only appropriate after intracranial injuries have been ruled out.

- The most important assessment is the **vital signs.**
- Next is the **level of consciousness**, best measured and recorded by the Glasgow Coma Scale (GCS) (see below).

GLASGOW COMA SCALE

Component	Response	Score
Motor Response (best extremity)	Obeys verbal command	6
	Localizes pain	5
	Flexion-withdrawal	4
	Flexion (decortication)	3
	Extension (decerebration)	2
	No response (flaccid)	1
	Subtotal	**(1–6)**
Eye Opening	Spontaneously	4
	To verbal command	3
	To pain	2
	None	1
	Subtotal	**(1–4)**
Best Verbal Response	Oriented and converses	5
	Disoriented and converses	4
	Inappropriate words	3
	Incomprehensible sounds	2
	No verbal response	1
	Subtotal	**(1–5)**
	Total	**(3–15)**

- Triage decisions in the patient with craniocerebral trauma should be made based on **admission GCS** score.
  - o A GCS ≤ 5 indicates a dismal prognosis despite aggressive comprehensive treatment and the casualty should be considered expectant.

- A GCS ≥ 8 indicates that a casualty may do well if managed appropriately.
  - ♦ In general, neurologically stable patients with penetrating head injury can be managed effectively in the ICU with airway and ventilatory support, antibiotics, and anticonvulsants while awaiting surgery.
  - ♦ An exception to this would be a deteriorating patient with a large hematoma seen on CT—this should be considered a surgical emergency.
- **Casualties with GCS 6–8 can be the most reversible, with forward neurosurgical management involving control of ICP and preservation of CBF.**

● Another important assessment is **pupillary reactivity**.

A single dilated or nonreactive pupil adds urgency and implies the presence of a unilateral space-occupying lesion with secondary brain shift. Immediate surgery is indicated.

- The presence of bilateral dilated or nonreactive pupils is a dismal prognostic sign in the setting of profound alteration of consciousness.

● **Radiographic evaluation.**
- Deployable CT scanners in standard ISO shelters are increasingly available in the field environment. **To keep the scanner operational, a qualified maintenance chief should be married to the scanner ("crew-chief" concept).**
  - ♦ CT is the definitive radiographic study in the evaluation of head injury, and should be employed liberally as it greatly improves diagnostic accuracy and facilitates management.
- Skull radiographs still have a place in the evaluation of head injury (**especially penetrating trauma**).
  - ♦ In the absence of CT capability, AP and lateral skull radiographs help to localize foreign bodies in cases of penetrating injuries and can also demonstrate skull fractures.
  - ♦ This can help direct otherwise "blind" surgical intervention initially to the side of the head where the fracture is identified.

- o Cervical spine injury is uncommon in the setting of penetrating head injury.
  - ♦ Closed head injury is commonly associated with injury of the cervical spine.
  - ♦ Assume the presence of cervical spine injury and keep the cervical spine immobilized with a rigid collar until standard AP, lateral, and open-mouth radiographs can be obtained to exclude injury.
  - ♦ CT once again is useful in evaluating casualties with a high suspicion for spinal injury.

Management

- **Medical.**
  - o Primary tenets are basic but vital; clear the airway, ensure adequate ventilation, and assess and treat for shock (excessive fluid administration should be avoided).
  - o In general, patients with a GCS $\leq$ 12 should be managed in the ICU.
  - o **ICU management should be directed at the avoidance and treatment of secondary brain injury**.
    - ♦ PaO_2 should be kept at a minimum of 100 mm Hg.
    - ♦ PCO_2 maintained between 35 and 40 mm Hg.
    - ♦ The head should be elevated approximately 30°.
    - ♦ Sedate patient and/or pharmacologically paralyze to avoid "bucking" the ventilator and causing ICP spikes.
    - ♦ Broad-spectrum antibiotics should be administered to patients with penetrating injuries (a third-generation cephalosporin, vancomycin or Ancef, Unasyn or meropenen if acinetobacter suspected).
    - ♦ Anaerobic coverage with metronidazole should be considered for grossly contaminated wounds or those whose treatment has been delayed more than 18 hours.
    - ♦ Phenytoin should be administered in a 17-mg/kg load, which may be placed in a normal saline piggyback and given over 20–30 minutes (no more than 50 mg/min, because rapid infusion may cause cardiac conduction disturbances).

    - ◊ A maintenance dose of 300–400 mg/d, either in divided doses or once before bedtime, should be adequate to maintain a serum level of 10–20 μg/L.
- ♦ Measure serum chemistries daily to monitor for hyponatremia.
- ♦ Monitor and treat coagulopathy aggressively.
- ♦ Monitoring of ICP is recommended for patients with GCS≤ 8 (in essence, it is a substitute for a neurologic examination).
    - ◊ A simple fluid-path monitor usually works well and allows CSF drainage. It may then be coupled to a manometer or to a multifunction cardiac monitor similar to a central venous catheter or arterial line.
        - ▪ Administer prophylactic antibiotic.
        - ▪ Make an incision just at or anterior to the coronal suture, approximately **2.5–3 cm** lateral to the midline (Fig. 15-2a,b).
        - ▪ A twist drill craniostomy is performed, the underlying dura is nicked, and a ventricular catheter placed into the frontal horn of the lateral ventricle (encountered at a depth of 5 to 6 cm) (see Fig. 15-2b,c). Catheter should be directed toward the medial epicanthis on the coronal plane, and the tragus in the sagittal plane.
        - ▪ Even small ventricles can be easily cannulated by aiming the tip of the catheter toward the nasion in the coronal plane.
        - ▪ Ventricular catheters are highly preferable; acceptable substitutes are an 8 F Robinson catheter or pediatric feeding tube.
        - ▪ A key feature of this technique is to tunnel the drain out through a separate incision 2–3 cm from the primary one, thus reducing the risk of infection.
    - ◊ The goal of management is to maintain a CPP of 60–90 mm Hg.
    - ◊ A sustained ICP > 20 mm Hg should be treated (Fig. 15-3).

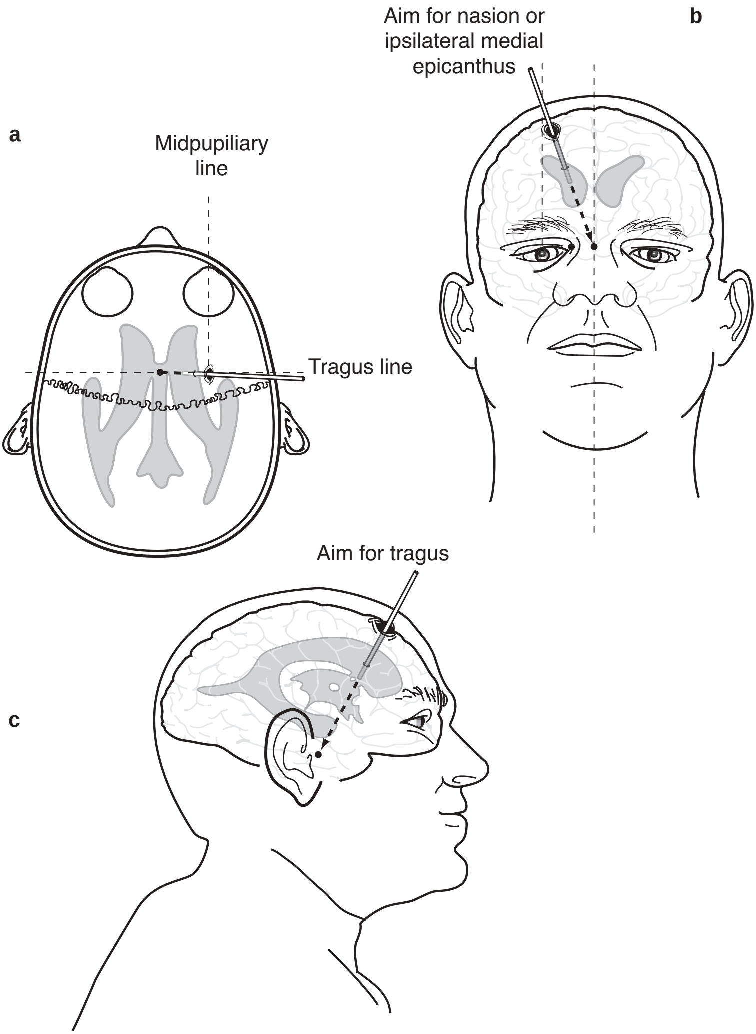

Fig. 15-2. Placement of intracranial ventricular catheter.

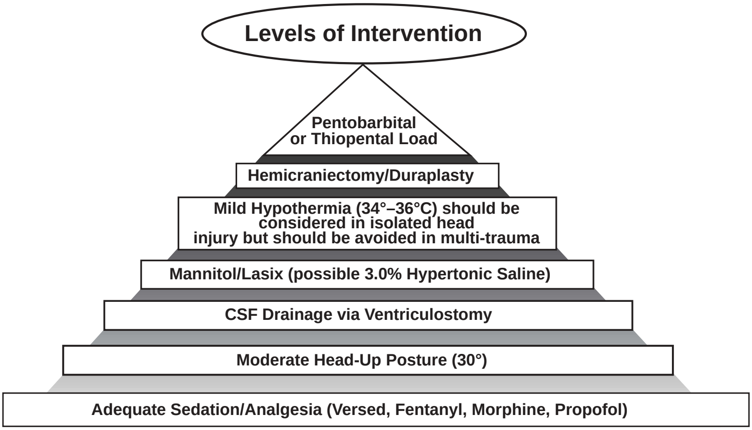

Fig. 15-3. Levels of intervention to reduce ICP.

- Sedation, head elevation, and paralysis.
- CSF drainage if a ventricular catheter is in place.
- **Hyperventilation to a P_{CO_2} of 30 to 35 mm Hg only until other measures take effect.** (Prolonged levels below this are deleterious as a result of small vessel constriction and ischemia.)
- Refractory intracranial hypertension should be managed with an initial bolus of 1g/kg of **mannitol** and intermittent dosing of 0.25–0.5 g/kg q4h as needed.
  - Aggressive treatment with mannitol should be accompanied by placement of a CVP line or even a PA catheter because hypovolemia may ensue.
- Any patient who develops intracranial hypertension or deteriorates clinically should undergo prompt repeat CT.

◊ Mild hypothermia may be considered in isolated head injury, but avoid in the multitrauma patient.

♦ Treat hypovolemia with albumin, normal saline, hypertonic saline, or other volume expanders to create a euvolemic, hyperosmolar patient (290–315 mOsm/L).

♦ Blast over-pressure CNS injuries.

◊ Supportive medical therapy is usually sufficient. Only in rare cases is an ICP monitor, ventriculostomy, or cranial decompression necessary. In the absence of hematomas the use of magnesium has been beneficial. Structures particularly sensitive include optic apparatus, hippocampus, and basal ganglia. Delayed intracranial hemorrhages have been reported. Additionally, these patients have a higher susceptibility to subsequent injury and should be evaluated at a level 4/5 facility. Repetitive injury and exposure to blast over-pressure may result in irreversible cognitive deficits.

- **Surgical**
  - o Goals: prevent infection and relieve/prevent intracranial hypertension.
  - o Indications for emergent exploration.
    - ♦ Space-occupying lesions with neurological changes (eg, acute subdural/epidural hematoma, abscess).
    - ♦ Intracranial hematoma producing a > 5 mm midline shift or similar depression of cortex.
    - ♦ Compound depressed fracture with neurological changes.
    - ♦ Penetrating injuries with neurological deterioration.
  - o Relief of ICP with hemicraniectomy/duraplasty/ventriculostomy.
    - ♦ A large trauma flap should be planned for the evacuation of a mass lesion with significant underlying edema in the supratentorial space.
    - ♦ The flap should extend a minimum of 4 cm posterior to the external auditory canal and 3–4 cm off midline. Exposing the frontal, temporal, and parietal lobes allows for adequate cerebral swelling and avoids brain herniation at the craniotomy edge.
    - ♦ A capacious duraplasty should be constructed with a subdural ICP/ventricular catheter in place, allowing monitoring and drainage from the injured hemisphere.
  - o Shave hair widely and scrub and paint the scalp with betadine.
  - o General anesthesia for major cases.

- o Administer empiric antibiotics (third-generation cephalosporin).
- o Positioning can be adequately managed with the head in a doughnut or horseshoe-type head holder. For unusual positioning of the head, such as to gain access to the suboccipt, use a standard three-point Mayfield fixation device.
- o Make a generous scalp incision to create an adequate flap.
  - ♦ The flap should have an adequate pedicle to avoid ischemia.
  - ♦ Retraction of the scalp flap over a rolled laparotomy sponge will avoid kinking the flap, which also may lead to ischemia.
- o The skull should be entered through a series of burr holes (Fig. 15-4) that are then joined to create a craniotomy flap (Fig. 15-5a).

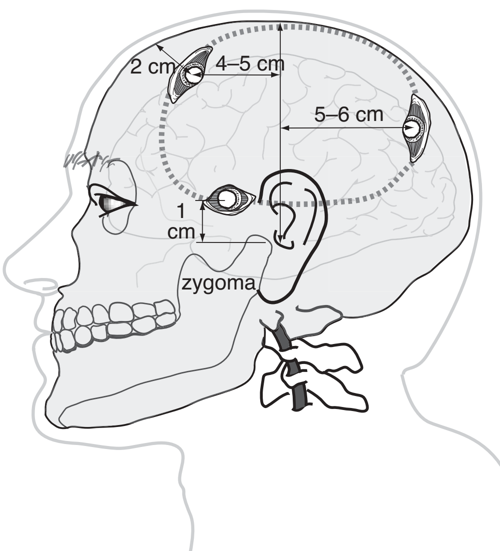

Fig. 15-4. Cranial landmarks and location of standard burr holes.

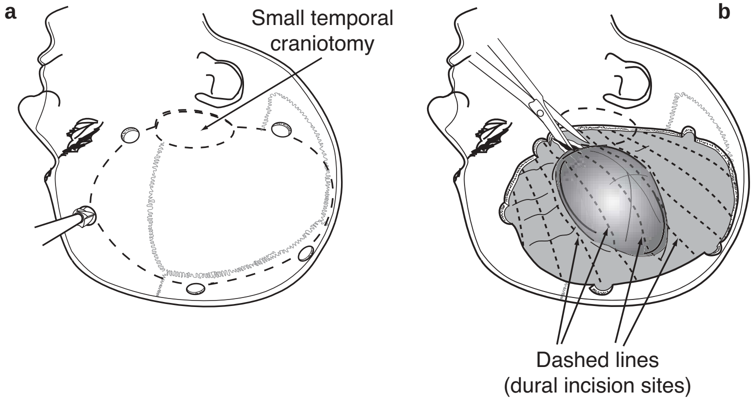

Fig. 15-5. Craniotomy flap and exposed hematoma.

♦ **Burr holes alone are inadequate to treat acute hematomas**, but are of diagnostic utility in the absence of CT scanner. Exploratory burr holes may miss subfrontal or interhemispheric hematomas (Fig. 15-6).

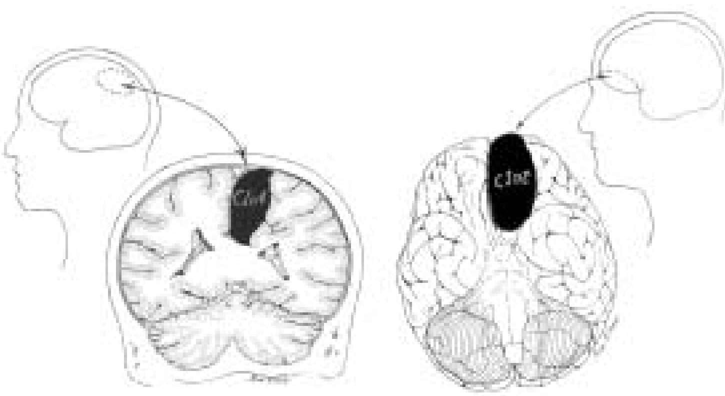

Fig. 15-6. Hematomas missed with routine exploratory burr holes.

  - ♦ The bone work may be done with a Hudson brace and Gigli's saw, though a power craniotome is certainly preferable if available (see Fig. 15-5a).
- o A dural opening, using the entire expanse of the cranial opening (with enough edge left to close the dura at the end of the case), should be created.
  - ♦ The base of the dural opening should be on the side near any neighboring major venous sinus to avoid injury to large draining veins and aggravation of cerebral edema.
- o The hematoma should then be gently evacuated with a combination of suction, irrigation, and mechanical removal (see Fig. 15-5b).
- o Meticulous hemostasis should be achieved and the dura closed.
- o Approach to **penetrating injury with neurologic changes** is aimed at removal of devitalized brain and easily accessible foreign bodies.
  - ♦ Perform copious irrigation with an antibiotic solution (such as bacitracin) and a concerted attempt made to achieve watertight dural closure (again, using pericranium, among others, as needed).
  - ♦ Tension-free scalp closure is also essential, but replacement of multiple skull fragments in an attempt to reconstruct the skull defect is not appropriate in the battlefield setting.
    - ◊ Excellent results can be achieved with cranioplasty after evacuation out of the theater and a sufficient delay to minimize risk of infection.
- o If a duraplasty is required, pericranium, temporalis fascia, or tensor fascia lata may be used.
- o Tack-up sutures should be placed around the periphery and in the center of the dural exposure to close the dead space and discourage post-operative epidural hematoma formation.
- o Replace bone flap and secure with wire or heavy suture.
  - ♦ If severe brain swelling precludes replacement of the bone flap it can be discarded or preserved in an abdominal-wall pocket.

- o The galea of the scalp should generally be closed separately with an absorbable suture, and with staples used to close the skin.
  - ♦ A single layer closure with heavy monofilament nylon is acceptable but should definitely include the galea, with the sutures remaining in place at least 10 days.
  - ♦ A subgaleal or epidural drain may be used at the discretion of the surgeon.
- o Apply a snug dressing using roller bandages around the entire head.

Evacuation of the Severely Head-Injured Patient

The trip is always longer than advertised. Transport only patients who can be expected to survive 12–24 hour movements, due to unexpected delays, route changes, or diversion in the tactical situation. A post-operative, craniotomy patient should first be observed for 12–24 hours prior to transport. Evacuating immediately may lead to the inability to treat delayed post-operative hematomas that may occur.

- o All patients with GCS < 12 are ventilated.
- o Patients with GCS < 8T require ICP monitoring.
- o Ventriculostomies should be placed, position confirmed, secured, and working prior to departure.
- o The critical care evacuation team must be confident in the ability to medically treat increased ICP and troubleshoot the ventriculostomy.
- o Medical management of ICP in flight is limited to the use of head-of-bed elevation (30°–60°), increased sedation, thiopental, ventricular drainage, and mild hyperventilation. Loading a patient head-of-bed first limits the effect of takeoff on ICP.
- o The escort of a severely head-injured patient must be able to manage the airway, ventilator, IV pumps, IV medicines, suction, in addition to ICP and CBF.
- o Patients with possible intracranial pathology who may deteriorate inflight should be neurosurgically maximized on the ground prior to departure (eg, placement of a ventriculostomy or evacuation of a hematoma).

- o If a head-injured patient (GCS > 12) deteriorates in flight and is not already intubated, intubation should be performed and planned. Ensure rapid sequence intubation medicines, IV access, and airway equipment (especially Ambu bag, ventilator) are working and available.
- o The most difficult part of an evacuation is from the CSH to the CASF/MASF. Typically, battery life of the ventilator and monitors, and supplies of oxygen can be depleted before the exchange of the patient to the CASF/MASF. Although electric power is available on Black Hawks and FLA (ground ambulance), it is rarely used.
- o Prior to departure from the CSH the following precautions must be taken by the escort:
  - ♦ Ensure knowledge of patient injuries and clinical course. (Have narrative summary and pertinent radiographs in hand.)
  - ♦ Ensure adequate medicines for minimum of 3 days.
  - ♦ Ensure monitors, ventilators, and suction and IV pumps all have adequate battery life.
  - ♦ Ensure adequate oxygen supplies, and that the escort has the familiarity with and the ability to switch oxygen tanks.
  - ♦ Have an alternate battery-operated, tactical light source to read monitors during transport.
  - ♦ Assemble patients on the stretcher to avoid iatrogenic injuries to limbs, organizing tubes, lines, electrical leads, and wires so as not to become snared during movements. (When available, a SMEAD shelf attached to the stretcher allows monitors to be secured and elevated off the patient's body.)
  - ♦ Ensure that limbs (toes and fingers) and torso are covered and insulated during the trip to prevent hypothermia.
  - ♦ During movements ensure central lines, a-lines, and ventricular catheters do not become dislodged. Ensure lines and tubes are sutured or otherwise secured.
  - ♦ Ensure the ventriculostomy does not develop an air-lock. Venting the tublet can be performed with a 21-gauge needle.