

Chapter 10

Neurosurgery

Managing pediatric neurotrauma at medical treatment facilities (roles 1 to 3) requires a consolidated effort on the part of providers and administrators within the military healthcare system.

Mission Clarification

Pediatric neurotrauma patients require intensive resources. They may need prolonged mechanical ventilation and extensive rehabilitation, and few medical facilities in the developing world are capable of providing these services. Coalition healthcare providers are often unprepared for such limitations. It is essential to assess facility capabilities and address postresuscitation and posttreatment patient flow prior to the arrival of pediatric casualties; failure to make these assessments will result in poor patient outcomes, increased stress on healthcare providers, and potential erosion of relationships with local host-nation residents.

Head Injury in the Pediatric Patient

- Anatomical, physiological, cognitive, and social variances between adult and pediatric patients influence evaluation and treatment
 - Accurate neurological assessment is essential for appropriate patient triage and guides further management
 - ▶ Validity of the Glasgow Coma Scale (GCS; Table 10-1) is compromised in children due to the difficulty of accurately categorizing their verbal and motor responses
 - ▶ The Infant Face Scale (Table 10-2) is a validated clinical tool with a high degree of interrater reliability; it is a modified GCS for children
 - Triage decisions in pediatric patients in theater are difficult and can be emotionally charged
 - ▶ Although pediatric patients with neurological injuries are more likely to have favorable long-term outcomes than adults with similar injuries, their care is impacted

Table 10-1. Glasgow Coma Scale

Function	Score
Eye opening	
Spontaneous	4
Verbal stimulation	3
Painful stimulation	2
None	1
Motor	
Obeys commands	6
Localizes	5
Withdraws	4
Flexion	3
Extension	2
None	1
Verbal	
Oriented	5
Confused	4
Inappropriate	3
Incoherent	2
None	1

- by limited resources in theater
- ▶ The decision between treatment and palliative care for an injured child is a sobering but necessary aspect of care in an austere environment
 - ▶ Several factors can influence decisions on whether or not to proceed with treatment, such as:
 - ▷ A facility's capabilities
 - ▷ Options for later evacuation to military facilities with enhanced capabilities, or to a host-nation healthcare facility
 - ▷ Clinical factors
 - ▷ Physiological stability: abundant literature exists demonstrating poor neurological outcomes in patients following prolonged periods of hypotension and/or hypoxia; palliative care should be strongly considered for patients in these circumstances
 - GCS and Infant Face Scale scores correlate well with neurological outcome
 - Accurate in normotensive, nonhypoxic patients with no

Table 10-2. Infant Face Scale Modifications to Glasgow Coma Scale

Function	Score
Best Motor Response	
Spontaneous, normal movements	6
Hypoactive movements	5
Nonspecific movement to deep pain	4
Abnormal, rhythmic, spontaneous movements	3
Extension, either spontaneous or to pain	2
Flexion	1
Best Verbal Response	
Cries spontaneously to handling or pain, alternating with quiet wakefulness	5
Cries spontaneously to handling or minor pain, alternating with sleep	4
Cries to deep pain only	3
Grimaces only to pain	2
No facial expression to pain	1

Data source: Durham SR, Clancy RR, Leuthardt E, et al. CHOP Infant Coma Scale ("Infant Face Scale"): a novel coma scale for children less than two years of age. *J Neurotrauma*. 2000;17(9):729-737.

- pharmacologic agents compromising their examination
- After physiological stabilization, consider reversing sedation and neuromuscular blockade to facilitate a comprehensive neurological assessment
 - ▶ See Broselow tape for reversal-agent dosing
 - ▶ Muscle relaxation reversal should be confirmed with a peripheral nerve stimulator
 - ▶ A typical reversal regimen consists of **neostigmine** (50 $\mu\text{g}/\text{kg}$), **glycopyrrolate** (10 $\mu\text{g}/\text{kg}$), **naloxone** (10–20 μg), and **flumazenil** (10 $\mu\text{g}/\text{kg}$)
 - Patients with GCS scores > 8 will often benefit from treatment; when resources are available, they should be treated aggressively
 - Patients with GCS scores of 6–8 inhabit a "gray zone," and may proceed to treatment or palliative care, depending on additional clinical considerations and resource availability
 - Patients with GCS scores ≤ 5 will rarely benefit from treatment in a forward environment and should be managed

expectantly

- Pupillary reactivity
 - Findings convey important information about the function of the eye and cranial nerves 2 and 3
 - Pupillary function can be impaired by several medications, including intravenous atropine (often used for resuscitation)
 - Pupillary function is not impaired by muscle relaxants
 - In the absence of penetrating injuries to the globe, bilateral mydriasis (large, nonreactive pupils) is a strong predictor of poor neurological outcome; treat patients with bilateral nonreactive pupils expectantly
 - Unilateral pupil dilation
 - ▶ May result from direct trauma to the globe, orbit, or cranial nerves
 - ▶ Can indicate impending herniation
 - ▶ Should be considered in concert with other clinical factors
- A computed tomography (CT) scan is important when determining the salvageability of neurological patients; the following two findings are the most likely to determine patient salvageability:
 - Midline shift: easily measured by dropping a line from the anterior and posterior insertion of the falx cerebri
 - ▶ Allows for quantification of intercompartmental shift
 - ▶ A shift exceeding 5 mm is worrisome; in excess of 1 cm, it portends a poor prognosis
 - Patency of basal cisterns (Figure 10-1): the basal cisterns, small-volume spinal fluid spaces at the base of the brain, are visible on nearly any CT scan of the head
 - ▶ Anteriorly, they are shaped like a pentagon, and posteriorly like a smile
 - ▶ When patent, they indicate low intracranial pressure (ICP) and increased likelihood of salvageability
 - ▶ When absent, the patient's prognosis is poor

Medical Management

- Avoiding hypoxia and hypotension are the most important goals
- Seizure prophylaxis is appropriate in the first week (Figure 10-2)
 - Minimizes the deleterious effects of increased cerebral blood flow (accompanying a generalized seizure) in pa-

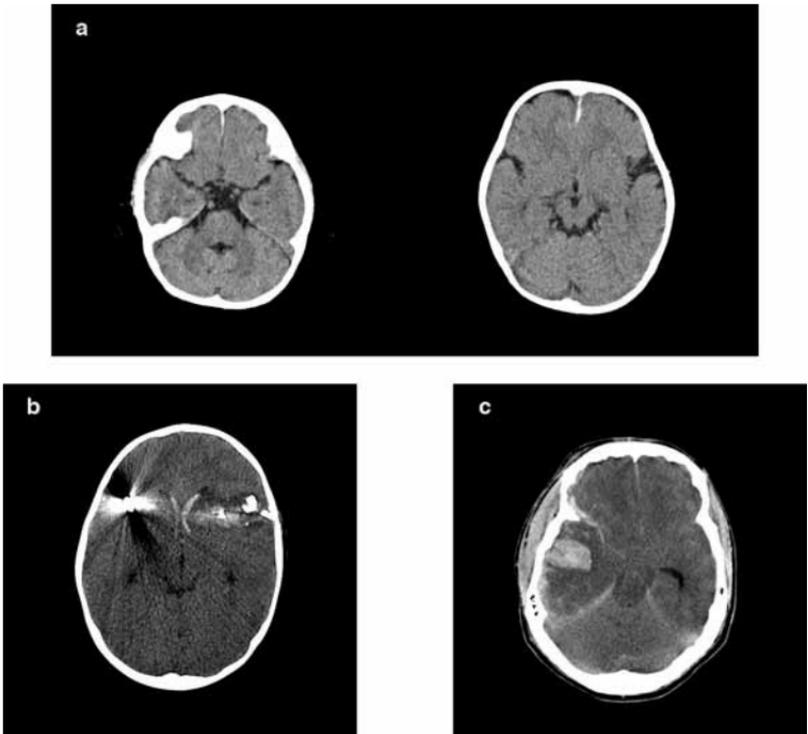


Figure 10-1. (a) Anterior and posterior basal cisterns on a normal computed tomography scan of the head. (b) Despite a fragment crossing the midline and ventricular system, no midline shift is present and the basal cisterns remain patent. The patient did well and was released from the hospital 4 days after admission. (c) Marked midline shift is present and the basal cisterns are effaced. Palliative care was elected, and the patient expired.

- tients with impaired intracranial compliance
 - Although phenytoin is an effective agent in adults, it is difficult to maintain therapeutic levels in infants and toddlers
 - **Phenobarbital** is the preferred antiepileptic agent in patients < 2 years old
 - ▶ Loading dose: 20 mg/kg
 - ▶ Maintenance dose: 3–5 mg/kg/day divided bid
- ICP monitoring (when available) is indicated for all patients with GCS (including modified Infant Face Scale) score ≤ 8
 - This includes infants with a patent fontanelle

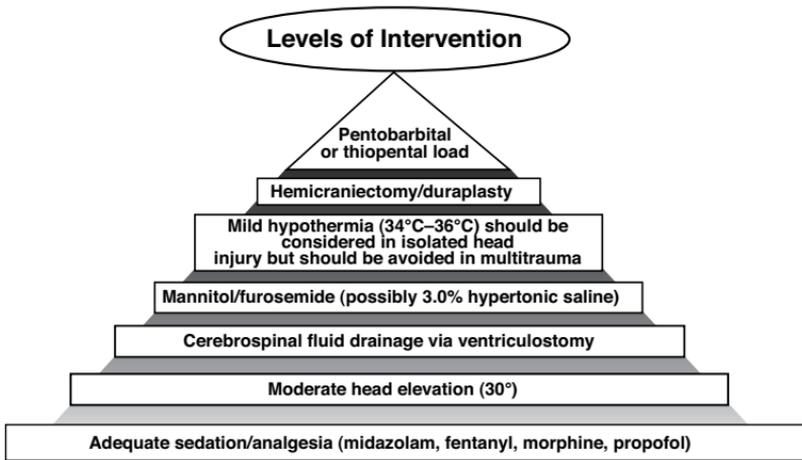


Figure 10-2. Levels of intervention in neurological injury.

- ▶ A patent fontanelle does not preclude elevated ICP
- ▶ There is no accurate, noninvasive means of estimating ICP
- ▶ Parenchymal monitors, which are available in the military supply system, accurately measure ICP
- ▶ Parenchymal monitors are easier to place and carry a lower infection risk, but provide no means of directly treating ICP
- ▶ Parenchymal monitors may be placed at a depth of 1–2 cm, regardless of patient’s age
- Ventriculostomy catheters (Figure 10-3) are also accurate ICP measures available in military supply
 - ▶ Ventriculostomy catheters have the added advantage of allowing treatment of ICP elevations with spinal fluid drainage
 - ▶ Disadvantages include elevated risk of infection and potential difficulties with placement in patients with severe injury
 - ▶ Ventriculostomy catheters lie within the ventricle at a depth of:
 - ▷ 3–3.5 cm in infants
 - ▷ 4 cm in toddlers
 - ▷ 5 cm in older children and adults
 - ▶ Depth of insertion and cranial access in infants must be

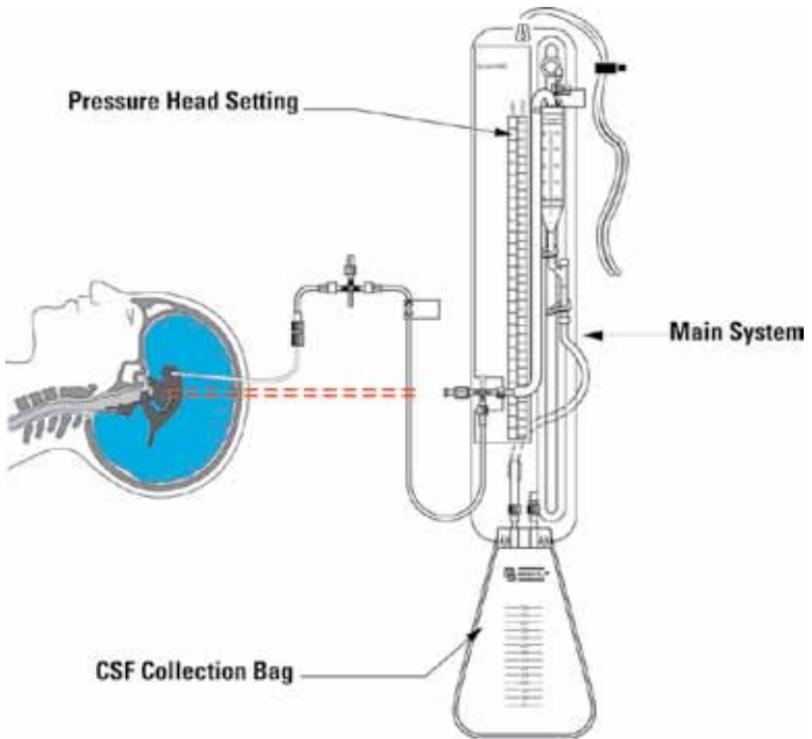


Figure 10-3. Schematic of ventriculostomy setup. Dashed red line represents the zero point of the system. Collection buretrol is set at desired height above the external auditory canal.

CSF: cerebrospinal fluid

Drawing courtesy of: Medtronic Neurosurgery, Goleta, California.

considered when placing ventriculostomy catheters in children

- ▶ For infants, the anterior fontanelle can be used instead of a craniostomy, provided the entry site is a minimum of 2 cm off the midline
- ▶ Drain setup is identical to that of any fluid-coupled system used in the intensive care unit, with the following exceptions:
 - ▷ Zero point for the system is the external auditory canal
 - ▷ The system should **never** be attached to a pressurized flush (such as that used for an arterial line)
 - ▷ When used for drainage purposes, one method is

- to set the drain open at a certain height (eg, 10 cm above the external auditory canal) and record hourly output
- To prevent hyponatremia and/or hypokalemia, each milliliter of cerebrospinal fluid (CSF) output should be replaced in infants and toddlers with a milliliter of 0.9% NaCl + 20 KCl
- Rapidly wean the patient from CSF drainage if possible; do not place a CSF shunt while the patient is in a forward environment. Inability to wean patient from ventricular drainage is usually grounds for palliative care
- ICP and cerebral perfusion pressure (CPP) thresholds
 - ICP: treat sustained values of greater than 20 mmHg with the goal of reducing below this threshold
 - CPP (mean arterial pressure – ICP), due to age-related variance in mean arterial pressure, is impacted by patient age
 - Minimum of 40 mmHg for infants, and up to 65 mmHg for adolescents and adults
 - Medical adjuncts
- Propofol infusion is **contraindicated** for long-term sedation (> 24 h) in pediatric patients due to the risk of fatal metabolic acidosis (propofol infusion syndrome)
- 3% saline has replaced mannitol/furosemide as the preferred hyperosmolar or diuretic therapy
 - 3% saline: initial bolus of 2–3 mL/kg, followed by infusion, ranging from 0.1–1 mL/kg/h
 - Target serum sodium of 150–155 mEq/dL is an effective means of reducing ICP in most patients
 - Higher serum sodium targets have been reported, provided isovolemia is maintained without deleterious results
- Therapeutic hypothermia has not been validated for head injury in pediatric patients and is rarely practical in a deployed environment
 - Reduce cerebral metabolic rate by avoiding hyperthermia
- Barbiturate coma effectively manages refractory ICP in children, but is impractical in a deployed environment; do

not use routinely

- Surgical management
 - The spectrum of surgical management of pediatric head injury is broad. This chapter provides limited guidance for surgically managing head injuries; it is not a substitute for more conventional surgical education. Surgeons are advised to remain within their own skill set
 - Repair of scalp lacerations and low-velocity penetrating head injuries
 - ▶ Understanding the anatomy of the scalp and principles of scalp closure is essential (Figure 10-4)
 - ▶ Watertight repair of penetrating injuries to the scalp is necessary for stopping blood loss and preventing CSF efflux and the potential for meningitis from retrograde infection
 - ▶ The only surgical intervention required in the majority of head-injured patients with GCS score > 8 may be as simple as the following:
 - ▷ Fully exposing the wound by shaving the scalp
 - ▷ Conservatively debriding devitalized tissue
 - ▷ Performing layered closure of the galea, followed by the skin
 - ▶ Definitive treatment for many patients (particularly those with a GCS score \geq 11) can be performed at facilities with limited surgical capabilities
 - **Craniotomy in the pediatric patient**
 - ▶ Positioning: a Mayfield headrest with pins is not appropriate for pediatric trauma patients in theater
 - ▷ A gel donut or cerebellar headrest (when available) helps avoid the potential for skull penetration in thinner pediatric skulls
 - ▷ A generous shoulder/hip roll can be used to maintain neutral positioning of the neck
 - ▶ Scalp incision: decreased absolute patient blood volume makes hemostasis imperative during scalp incision
 - ▷ Lidocaine (0.5% lidocaine with epinephrine 1:100,000) is a readily available, easy means of reducing blood loss at the time of skin incision
 - ▷ Lidocaine toxicity limits dosing to < 7.5 mg/kg

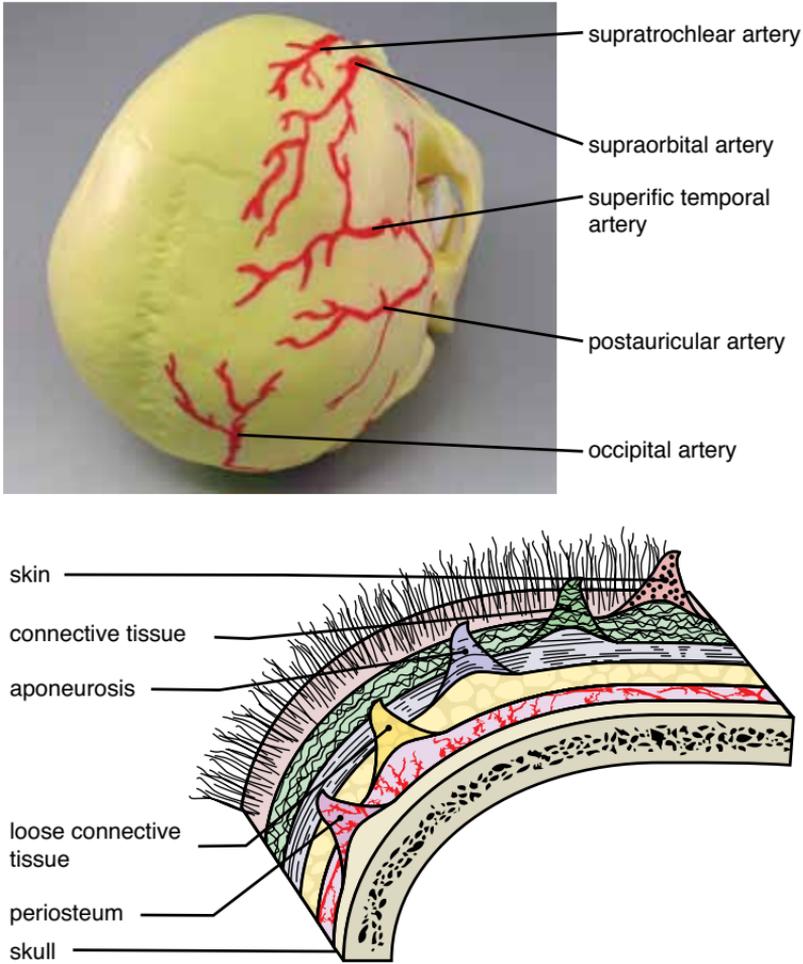


Figure 10-4. Scalp anatomy and blood supply.

- ▶ A **maximum** of 5 mg/kg of lidocaine or 7 mg/kg of lidocaine with epinephrine, injected intradermally, can be used in pediatric patients (1% lidocaine = 10 mg/mL)
- ▶ In children < 2 years old with decreased scalp thickness, Raney clips can be applied to achieve hemostasis
- ▶ Alternatively, apply hemostat to the galea during opening
- ▶ Consider extending the scalp incision through the

- dermal appendages only, and complete the opening with monopolar cautery
- ▷ A needle-tip bovie on settings of 7 cut/12 cauterize works well
 - ▶ Dural closure is rarely required, and often needlessly prolongs anesthesia for damage-control surgery
 - ▷ Onlay dural grafts are readily available and are the preferred tools in this setting for separating the brain from the scalp
 - ▷ Onlay repairs are effective in nearly all cases where the galea and scalp have been properly closed
 - ▶ Bone flap preservation: pediatric neurotrauma patients have limited options for reconstructive surgery following recovery in theater (Figure 10-5)
 - ▷ In acute injury, the bone flap is rarely replaced in the head at the time of surgery
 - ▷ Autologous “storage” of a flap that is not grossly contaminated is possible; at the time of cranial surgery, prepare the abdomen for subcutaneous bone-flap placement
 - ▷ The right lower quadrant is preferred to preserve the left upper quadrant for possible G-tube placement
 - ▷ The bone flap must occasionally be bisected and stacked to accommodate an expansive hemicraniectomy flap
 - ▷ The bone flap may become infected during the remainder of the patient’s hospitalization and beyond
 - ▷ Bone flap replacement can be considered 3–6 months after injury

Spinal Injury in the Pediatric Patient

The pediatric spine, particularly the cervical spine, differs from the adult spine both anatomically and in its response to injury. Differences are most pronounced in patients ≤ 9 years old, after which anatomy and injury patterns tend to parallel those of adult patients.

- Anatomical and biomechanical differences between the pediatric and adult spine
 - Pediatric spine

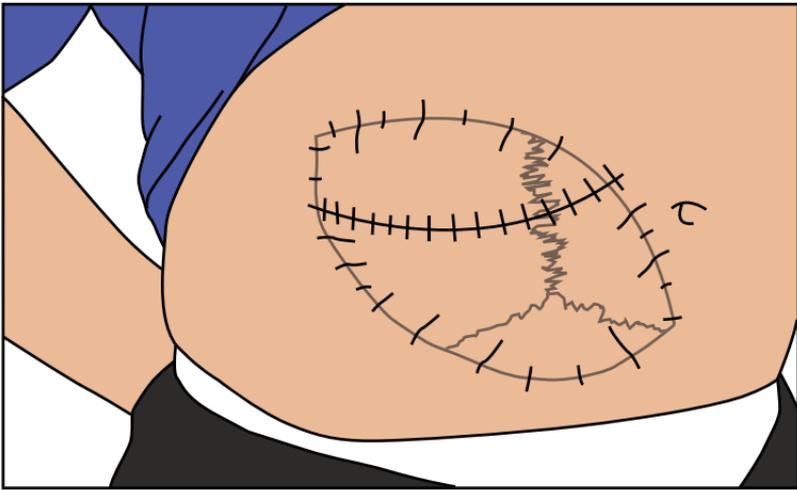


Figure 10-5. Subcutaneous abdominal placement of cranial bone flap.

- ▶ Contains more elastic ligaments
- ▶ Exhibits anterior wedging of vertebral bodies
- ▶ Facet joints are oriented more horizontally than in adults
- ▶ In cervical spine, absent uncinete processes decrease the stability of the spinal unit
- Children's proportionately larger heads increase the force applied to the upper cervical spine and cause neutral positioning differences when compared to adults
- The relative size of the spinal canal (which achieves near-adult cross-sectional area prior to the age of 9) presents a proportionately larger target for penetrating fragments in the thoracic and lumbar regions
- Pathophysiological differences between the pediatric and adult spine
 - The increased elasticity and proportionately larger head of a pediatric patient results in profound changes in observed injury patterns
 - Fractures are relatively uncommon in pediatric patients
 - The fulcrum of the cervical spine is shifted from C5–6 in adult patients to C2–3 in infants
 - ▶ Injuries most commonly occur between the occiput and

- ▶ Disruptions of unfused ossification centers, such as the C2 synchondrosis, are common (as are ligamentous injuries at the craniocervical junction)
 - ▶ Spinal cord injuries in the absence of plain radiographic findings are also more common in this age group
- Radiographic differences between the pediatric and adult spine
 - Radiographs and CT scans differ significantly between adult and pediatric patients
 - The large proportion of cartilage in the pediatric spine, coupled with primary and secondary ossification centers, are unfamiliar to most providers
 - Standard measurements, including the atlantodental interval and anterior soft tissue thickness at C2, are increased in pediatric patients in comparison to adults
 - Additional findings, such as C2–3 pseudosubluxation, also present challenges to the inexperienced provider
 - Providers likely to encounter pediatric patients in theater should familiarize themselves with these differences
- Transporting pediatric patients with suspected spinal injuries
 - A pediatric patient's proportionately large head size requires additional consideration at the time of transport
 - To maintain anatomical cervical lordosis and airway patency, the patient must be placed on a spine board with a bolster under the body at and distal to shoulder level, leveling the patient's face and allowing for proper spinal and airway positioning (Figure 10-6)
- Medical and surgical management of spinal injuries
 - Pediatric spinal injury management in current operational theaters is limited
 - ▶ Select US facilities in theater may have the prerequisite spinal instrumentation and intraoperative fluoroscopy
 - ▶ The majority of closed and penetrating injuries can be managed with resources available at facilities with less robust clinical and radiographic support
 - Closed injuries: management consists of restoring (near) normal anatomical alignment and immobilizing the patient

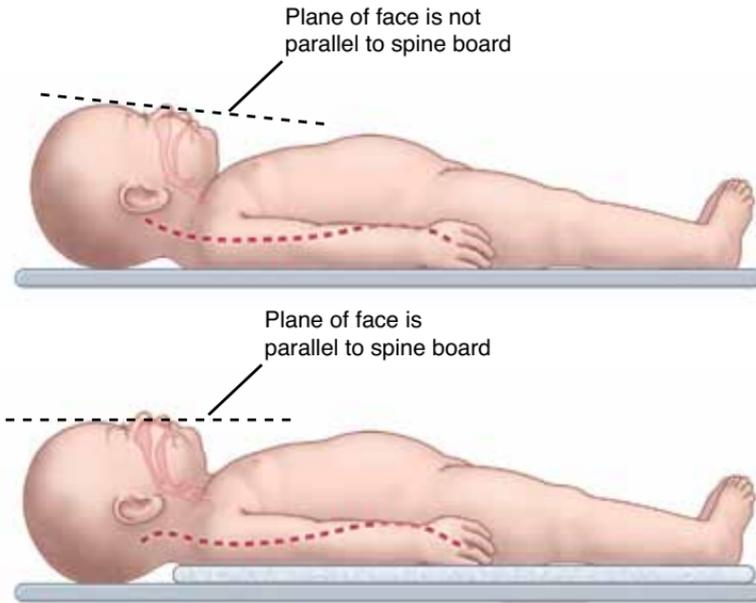


Figure 10-6. (top) Improper positioning of a child to maintain a patent airway. The disproportion between the size of a child's cranium and the midface leads to a propensity for the posterior pharynx to buckle anteriorly. The large occiput causes passive flexion of the cervical spine. **(bottom)** Proper positioning of a child to maintain a patent airway. Avoid passive flexion of the cervical spine by keeping the plane of the midface parallel to the spine board in a neutral position, rather than in the "sniffing position." Placement of a one-inch-thick layer of padding beneath a child's entire torso will preserve neutral alignment of the spinal column. Reproduced with permission from: American College of Surgeons. *Advanced Trauma and Life Support Student Course Manual*. 8th ed. Chicago, Ill: ACS; 2008: 230.

- ▶ Gardner-Wells tongs can be used for reduction in pediatric patients as they are in adults
 - ▷ Less weight is typically required to achieve reduction (2 lb per level in pediatric patients, as opposed to 5–10 lb per level in adults)
- ▶ Commercial cervical collars or expedient structural aluminum malleable (SAM) splints can be contoured to the patient to provide immobilization for cervical injuries

- ▶ In the exceptional case that an appropriately sized halo vest is available, apply 6–8 pins at a force not to exceed 4 ft/lb of torque
- ▶ Thoracolumbar fractures can be managed with 4–6 weeks of bed rest
- ▶ Studies investigating the use of high-dose steroid therapy (methylprednisolone) in pediatric patients have not been performed; routine high-dose steroid therapy for pediatric spinal cord injuries **cannot be recommended**
- Penetrating injuries
 - ▶ Frequently encountered in theater
 - ▶ The absence of body armor and the proportionately large size of the spinal canal in children produce complex injuries, often traversing multiple body cavities in addition to the spinal canal
 - ▶ Antibiotic coverage is guided by the body cavities traversed and the relative cleanliness of the fragment and wound
 - ▶ Steroid therapy is inappropriate, based both on age and the penetrating mechanism
 - ▶ Spinal stability is rarely impacted by penetrating injuries
 - ▶ Most injuries are managed either with 6 weeks of bed rest for immobilization, or without positioning restrictions if upright radiographs demonstrate stability (in younger patients, sedation may be required to restrict activity)
 - ▶ CSF fistula presents one of the most serious challenges in these patients
 - ▷ If cutaneous CSF leakage is noted, or if clear fluid is noted at a high output from a chest tube following a transthoracic gunshot wound to the chest, a spinal fluid drain **must** be placed postoperatively, either under direct vision intraoperatively or percutaneously at the L4–5 interspace
 - ▷ Anesthesia providers are often qualified to assist with drain placement in the absence of neurosurgical support
 - ▷ Height-controlled drainage of 10–15 mL/h is usually

- sufficient to stop drainage through the fistula
- ▷ 72 hours of drainage will often result in permanent closure of the fistula; clamp the drain for 24 hours to ensure successful resolution of the fistula prior to removal

Further Reading

1. Head injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army. Office of The Surgeon General, Borden Institute; 2004. Chap 15.
2. 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. Chap 20.