Management of Traumatic Brain Injury

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This document provides an overview of considerations and guidelines that are important in the evaluation and management of patients with traumatic brain injury (TBI). It is not intended to be used a rigid set of treatment instructions. Management of TBI must be individualized based on each patient's clinical situation and the clinical judgment of the providers responsible for directing this aspect of patient care.

Resuscitation and Basic Physiological Goals

The following physiological parameters should be maintained as part of goal directed TBI treatment:

- **Primary Parameters:**
    - Pulse Ox ≥ 90%
    - PaO_2 ≥ 100 mmHg
    - $PaCO_2$ 35-40 mmHg
    - SBP ≥ 110 mmHg and ≤ 160 mmHg
    - pH 7.35-7.45
    - ICP < 20 mmHg
    - Temp 36.0-38.3^{o}C
    - Glucose ≤ 160 mg/dL
    - INR ≤ 1.3
    - Sodium goal
        - Normonatremia (Na 135-145 mmol/L) vs permissive hypernatremia (Na 145-155 mmol/L)
- **Secondary Parameters**
    - Cerebral Perfusion Pressure (CPP)
        - Avoid aggressive use of pressors or fluids to maintain CPP $\geq$ 70 mm Hg
        - Avoid CPP < 60
        - Pediatrics: CPP 40-50 mmHg
    - $PbtO_2$ ≥ 15 mmHg
- Required monitoring/measurements in patients with severe TBI requiring mechanical ventilation

- Continuous SpO2 and EtCO2 monitors
- Indwelling urinary catheter to monitor UOP; may consider transition to external catheter after first 24 hrs
- Arterial catheter with continuous arterial pressure monitoring
- Hourly neurological exams

1. Airway Management

- Patients with a GCS < 8 should be intubated for airway protection
  - Patients with a GCS < 10 should be considered for intubation.
  - Intubation should be performed with in-line cervical spine immobilization.
  - Rapid sequence intubation (RSI) is the preferred method.
  - If clinical scenario allows, a baseline neurological exam should be obtained prior to intubation.
- Sedative and analgesic choices should favor short acting agents throughout the initial resuscitation, as temporal assessment of neurological status is critical. In general, the following agents are recommended:
  - Etomidate – sedation for induction
  - Succinylcholine – paralytic for induction
  - Propofol – maintenance of sedation and prevention of agitation. Propofol should not be used as an induction agent in the case of trauma and is to be discontinued if its use results in persistent hypotension requiring vasopressor agents.
  - Benzodiazepines – (i.e., midazolam or lorazepam) can be utilized as an initial or substitute sedative agent for propofol.
  - Dexmedetomidine (Precedex)—maintenance sedation and analgesia; can also cause hypotension and bradycardia
  - Fentanyl – can be used for PRN and maintenance analgesia as well as provide some sedation effects.

2. Oxygenation/Ventilation

- Avoidance of Hypoxia
  - Efforts should be made to avoid hypoxia at all times as it has been shown in significantly worsen outcomes in TBI patients.
  - Patients with TBI should have a pulse oximetry maintained at **SpO2 ≥ 90%** and an attempt for **PaO2 ≥ 100 mmHg**.
- Ventilation
  - Hyperventilation should be intensively monitored during the initial resuscitation.
    - Target **PaCO2 is 35-40 mmHg**.
    - Prophylactic Hyperventilation is not recommended (PaCO2 $\leq$ 25 mmHg)
    - An ETCO2 monitor and serial ABGs should be used as needed to prevent profound hypocarbia or hypercarbia.
    - Therapeutic hyperventilation may be necessary for brief periods when there is acute neurological deterioration that coincides with a cerebral herniation syndrome or for refractory elevations in ICP (see section on management of intracranial hypertension).

3. Blood Pressure, Volume Resuscitation

- Blood Pressure
  - Systolic blood pressure (SBP) and mean arterial pressure (MAP) readings should be recorded from a functioning arterial line, when present, or from non-invasive blood pressure (NIBP) cuff when arterial line is not present or presumed inaccurate.
  - Strict blood pressure monitoring and control is required in all TBI patients with care taken to avoid hypotension and hypertension.
    - Any patient with intra-cranial hypertension must have an arterial line.
    - SBP should be kept between 110 mmHg and 160 mmHg for the first 7 days following injury or until discharge if patient discharged prior to 7 days.
      - it should be noted that even one episode of hypotension (SBP<100mmHg) can significantly worsen outcomes in TBI patients.
    - It should be recognized that lower blood pressures can represent a “relative” hypotensive state in TBI patients (especially with elevated ICP)
    - Normal saline, PRBC, and FFP (when needed) should be used as the initial method of maintaining euvolemia to achieve the target blood pressure
    - Use of vasopressors should be considered for treatment of refractory hypotension ONLY AFTER appropriate volume resuscitation has been given.
    - Vasopressors and Inotropes including phenylephrine, norepinephrine, epinephrine, dobutamine, dopamine, and vasopressin should not be used to counteract the hemodynamic effects of propofol, Precedex or other sedating medications.
    - Labetalol or hydralazine as needed should be administered to treat SBP > 160 mmHg during the initial resuscitation phases.
    - If SBP > 160 mmHg is sustained, consider initiation of nicardipine gtt and/or scheduled beta blocker therapy and placement of arterial line, if not already present.
    - Review home medication lists and consider resuming anti-hypertensive medications as clinically indicated.
- Euvolemia
  - The primary target is euvolemia through resuscitation. In many cases, a bedside point of care ultrasound (POCUS) with evaluation of the IVC and cardiac function can give the clinician a reasonable assessment of volume status.
  - Avoid use of hypotonic fluids for volume resuscitation and maintenance fluid support.

4. Anemia and Coagulopathy

- Hematologic and coagulation panels (CBC, PT/INR, PTT, TEG, fibrinogen, anti-Xa levels, platelet mapping) should be followed closely, particularly in patients on anti-coagulation medications or pre-existing bleeding dyscrasias.

- Patients on anti-coagulant or anti-platelet medications or those with bleeding disorders should be reversed/corrected as clinically indicated to correct coagulopathy regardless of need for surgical intervention. Potential interventions include the following: FFP, vitamin K, prothrombin complex concentrate (PCC)/KCentra, platelets, DDAVP, and NOAC specific reversal agents.
    - For patients on antiplatelet medications (i.e. aspirin, Plavix, brilinta), 1 unit of platelets may be transfused if requested by Neurosurgery at the discretion of the trauma or surgical ICU attending. Decision to transfuse additional units of platelets should be based on results of TEG or platelet mapping.
- Target coagulation parameters:
    - Hb > 7 g/dL
    - Platelet count > 100 x 10^3/uL (if clinically feasible)
    - INR ≤ 1.5
    - Fibrinogen > 150 mg/dL
- INR and platelet count should be corrected in anticipation of operative intervention or bedside procedure such as placement of ICP monitor.

5. Imaging

- All patients with suspected or at high risk for possible TBI (i.e., LOC, significant mechanism, amnesia to event, use of anticoagulant/antiplatelet medications) must undergo urgent CT head (CTH) during the initial resuscitation barring need for emergent operative intervention for other life-threatening injuries.
- Repeat CT head will also be obtained at a specified time interval, per neurosurgery recommendations. (within 24 hours of presentation and/or with any significant deterioration in patient's neurologic status). Additional CT scans will be obtained as needed based on patient clinical condition.
- MRI brain scans should be utilized for assessment of ischemic CVA, DAI, tumors/masses or per certain research protocols. MRI brain can also be used to help prognosticate/determine potential for neurologic viability, particularly in patients with persistent vegetative states. Discussion between Neurosurgery, Neurology, and Trauma can help determine timing and value of the MRI.

6. Sedation and Analgesia for intubated TBI patients

- Sedation and analgesia agents will be chose and titrated at the discretion of the surgical ICU attending's discretion
    - Propofol – maintenance of sedation and prevention of agitation. Propofol should not be used as an induction agent in the case of trauma and is to be discontinued if its use results in persistent hypotension requiring vasopressor agents.
    - Benzodiazepines – (i.e., midazolam or lorazepam) can be utilized as an initial or substitute sedative agent for propofol.
    - Dexmedetomidine (Precedex)—maintenance sedation and analgesia; can also cause hypotension and bradycardia

    - Fentanyl/Dilaudid – can be used for PRN and maintenance analgesia as well as provide some sedation effects.
- Ideally, initial agents chosen should favor shorter acting agents so that serial neurologic exams can be obtained.
- In general, sedation will be titrated to RASS goal 0 to -2 unless deeper sedation deemed medically necessary by the surgical ICU attending. (i.e. intracranial hypertension, post-traumatic seizures, etc.)
    - If ICP monitor in place, sedation should be titrated to maintain ICP < 20 mm Hg.

Intracranial Pressure (ICP) Monitoring

- Placement of ICP monitoring should be considered in the following:
    - In patients with a salvageable traumatic brain injury (TBI) if the GCS is </= 8 following the initial resuscitation and the admission CT scan of the brain is abnormal (i.e., hematomas, contusions, edema, herniation or compressed basal cisterns).
    - Patients undergoing emergent surgical procedures (orthopedic interventions, exploratory laparotomy, etc.) in whom a moderate to severe brain injury is suspected (GCS 3-12) to help guide appropriate intraoperative ICP management.
    - Patients with a normal admission CT scan of the brain but have two or more of the following criteria,
        - Age >40 y/o
        - Unilateral or bilateral motor posturing
        - Documented episode of hypotension (SBP<90mm Hg)
- ICP monitors may include an intraventricular catheter (EVD) and/or parenchymal monitor (Bolt).
    - Patients with suspected increase in intracranial pressure and GCS ≤ 8 should receive an intraventricular catheter (EVD) or parenchymal monitor at the discretion of the treating Neurosurgeon as the clinical situation mandates.
- Ideally, ICP monitor should be placed within the first 12 hours following admission. ICP monitor placement may also occur later in the resuscitation if the patient's clinical status declines/changes so that ICP monitoring is now warranted.
- Relative contraindications to ICP monitor placement:
    - The brain injury is not felt to be salvageable/survivable.
    - Coagulopathy (INR>1.3)
    - Patient is awake/GCS ≥ 9
    - Mass lesion with mass effect at the site of the ventriculostomy site
    - Patient known to be post-ictal without obvious brain injury
    - Metabolic causes of coma including intoxication without good evidence of head injury
- Removal of the ICP monitor will be at the discretion of the treating neurosurgeon but should be considered when:
    - ICP within normal range
    - 48 to 72 hours after interventions for elevated ICP.

- Target parameters:
    - ICP < 20 mmHg
    - Cerebral Perfusion Pressure (CCP) ≥ 60 mmHg.

Treatment of Intracranial Hypertension

- Intracranial hypertension is defined as sustained elevation in intracranial pressure (ICP) of more than 15 to 20 mmHg sustained for greater than 5 minutes and occurs when the three intracranial components—blood, brain, and cerebrospinal fluid (CSF)—are no longer able to compensate for volume changes occurring within the cranium.
- Treatment for intracranial hypertension should be initiated when **ICP ≥ 20 mmHg** and is managed with a leveled algorithm with each level representing increasing levels of intensity. Patients should be initiated in Level 1, then staged through Level 3 as indicated. If the treatments in a given level have not sufficiently lowered the ICP within 20 minutes of implementation, then advancements to the next level should be promptly initiated.
    - **Level 1**
        - **Notify Neurosurgery**
        - **Positioning--** Elevate head of patient's bed to ≥ 30 degrees or reverse Trendelenburg position if the T/L spine has not been cleared or there is a known fracture precluding the upright position. Maintain head and neck aligned in a midline neutral position and ensure cervical collar is not restrictively tight.
        - **Optimize sedation and analgesia** using recommended agents (propofol, fentanyl and versed) in intubated patients.
        - **ICP monitor –** ensure ICP monitor is functioning properly. If EVD in place, lower and/or open to drain CSF to assess patency. If parenchymal monitor in place, consider converting to EVD if situation allows.
        - **If the above maneuvers have not resolved the elevated ICP, move to Level 2.**
    - **Level 2**
        - **Hyperosmolar agents**
            - **Hypertonic Saline** – intermittent boluses of 3% saline (250 mL) may be given in the setting of increased ICP and is preferred if the patient has hypotension or is hypovolemic. Serum sodium and osmolality must be assessed every 6 hours and additional doses should be held if the serum sodium exceeds 160 mEq/L or serum osmolality > 360 mOsm/L
            - **Mannitol** – intermittent boluses of mannitol (0.25-1gm/kg body weight) may also be administered Attention must be placed upon maintaining a euvolemic state as mannitol will induce an osmotic diuresis. The serum sodium and osmolality must also be assessed frequently (every 6 hrs) and additional doses should be held if the serum sodium exceeds 320 mOsm/L. Maintain a serum osm < 320 mOsm/L with a targeted serum Na of < 160 mEq/L.

    - **Neuromuscular paralysis**: pharmacologic paralysis with a continuous infusion of a neuromuscular blocking agent should be considered if the above measures fail to adequately lower the ICP and restore CPP. The infusions should be titrated to maintain at least two twitches (out of a train of 4) using a peripheral nerve stimulator. Adequate sedation must be utilized if pharmacologic paralysis is employed and can be confirmed with BIS monitoring.
    - **If the above maneuvers have not resolved the elevated ICP, move to Level 3.**
  - **Level 3**
    - CTV head should be considered to evaluate for cerebral sinus thrombosis
    - **Decompressive hemi-craniectomy or bilateral craniectomy** should be discussed and performed at neurosurgery attending discretion.
    - **Barbiturate coma** – an induced coma is an option for those patients who have failed to respond to aggressive measures to control malignant ICP including decompressive craniectomy. The use of BIS monitoring or equivalent is needed for assurance of adequate sedation and coma. Side effects include sudden hemodynamic collapse and a high incidence of pneumonia. Appropriate volume resuscitation and hemodynamic monitoring is mandatory. Utilizing vasopressor therapy may be warranted.

Adjunctive Medications and Prevention of Complications

- Antiseizure prophylaxis
  - Keppra (levetiracetam) is the preferred anti-seizure medication given its lower side-effect profile, fewer drug interactions, and less need for tight monitoring of serum levels. Phenytoin/Fosphenytoin (Dilantin) also as efficacy in preventing early post-traumatic seizures in patients with TBI. Seizure prophylaxis should be considered for discontinuation after 7 days if no seizure activity occurs. However, a longer duration should be considered with certain injury patterns or in the presences of post-traumatic seizures.

- Stress Ulcer Prophylaxis
  - Patients with significant TBI requiring mechanical ventilation as well as those with coagulopathies or a history of peptic ulcer disease should receive stress ulcer prophylaxis with either an H-2 block agent (famotidine) or proton pump inhibitor.

- Deep Venous Thrombosis (DVT) prophylaxis
  - All patients with TBI should receive DVT prophylaxis in the form of sequential compression devices upon admission. Chemoprophylaxis (subcutaneous Lovenox or heparin) should be initiated 48 hours following injury/procedure for most intracranial hemorrhages and after craniotomy OR 24 hours following last stable CT head unless specifically requested by the neurosurgical attending. (see guidelines for VTE prophylaxis in trauma patients)

- Early Tracheostomy
    - Tracheostomy within 7 days of admission is recommended in ventilator dependent patients to reduce total days of ET intubation. This is performed at the discretion of the trauma and neurosurgery services.

- Nutritional Support
    - Nutritional support should be initiated via enteral route within 48 hours post injury. Frequent assessment of residual volumes of gastric nutrition should be performed, as patients with TBI frequently do not tolerate intragastric feeding and are at risk for emesis and aspiration. Efforts should be made to obtain post-pyloric feeding access (i.e. Cortrak) when possible. Consider holding tube feeds if gastric residual volumes >500 ml.

Surgical Management of TBI

Surgical interventions for severe TBI will ultimately be performed at the discretion of the neurosurgery attending/service. However, there are certain criteria and situations where surgery should be considered.

- Epidural hematomas
    - An epidural hematoma (EDH) of greater than 30 cm^2 should be surgically removed regardless of GCS. Patients with an acute EDH, GCS <9 and anisocoria should undergo emergent EDH evacuation.
    - Continued non-operative management should be considered in posterior EDH of venous origin.
    - EDH of less than 5mm midline shift in patients with GCS >8 and no focal deficit can be closely monitored in an ICU with serial CT scans. Judicious use of narcotics and sedatives is important to minimize drug related alterations in the neurologic exam. Repeat CT head should be obtained within 6 hours if patients are to be managed non-operatively.

- Acute Subdural Hematomas
    - Acute subdural hematomas (SDH) with a thickness of greater than 10 mm or 5mm of midline sift on CT scan should be considered for emergent evacuation regardless of GCS. (Clinical judgement should be used in patients with significant underlying atrophy)
    - A SDH less than 10mm thickness and less than 5mm midline shift should be evacuated emergently if the patient has: GCS decrease by 2 points, asymmetric or fixed pupils, or ICP > 20 mmHg.
    - Repeat CT head should be obtained within 24 hours or sooner if there is deterioration in patient’s neurologic status.

- Subarachnoid Hemorrhage
    - In general, subarachnoid hemorrhage (SAH) is managed non-operatively. All patients with GCS ≤ 8 and SAH should have ICP monitoring with an EVD as the preferred monitoring of choice.

    - Repeat CT head should be obtained within 24 hours or sooner if there is deterioration in patient's neurologic status.

- Parenchymal lesions
    - Intraparenchymal hemorrhage (IPH) causing progressive neurological deterioration, medically refractory ICP elevations, or significant mass effect should be considered for emergent evacuation.
    - Frontal or temporal contusions with IPH > $3cm^3$ and >5 mm shift or cistern compression in patients with GCS < 8 should be considered for surgical evacuation.
    - Normal ICP should not preclude operative.
    - Repeat CT head should be obtained within 24 hours or sooner if there is deterioration in patient's neurologic status.

- Diffuse Medically Refractory Cerebral Edema and Intracranial Hypertension
    - Decompressive craniectomy (unilateral or bilateral) within 48 hours of injury should be considered for patients with elevated ICP (>20) refractory to medical management.
    - Ultra-early decompressive craniectomy prior to ICP monitoring is not recommended unless surgery is performed for a mass occupying lesion (hematoma) and the bone flap is not replaced.

- Depressed Skull Fractures
    - Open skull fractures depressed greater than the thickness of the inner and outer table should be considered for surgical management.
    - Referable symptoms attributed to the fracture site are an indication for operative management.
    - Open depressed fractures that are less than 1cm depressed and have no dural penetration, no significant intracranial hematomas, no frontal sinus involvement, no gross cosmetic deformity, no pneumocephalus, and/or no gross wound contamination may be non-operatively.
    - All open skull fractures should be considered for treatment with prophylactic IV antibiotics with CSF penetration.

References

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