Traumatic Brain Injury

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Case Presentation

Forty two year old man is brought to the emergency department after he was hit by a car while crossing a street. Upon EMS arrival, he had normal vital signs and was awake and mumbling incomprehensible words. The patient deteriorated en route to the hospital and is now unresponsive with Glasgow Coma Scale (GCS) of 4 and extensor posturing. His blood pressure now is 205/120 mmHg with heart rate of 45 beats/min. Left pupil is fixed and dilated. CT scan of the head performed after endotracheal intubation showed large left temporal epidural hematoma with midline shift of 7 mm towards right and left uncal herniation. Additionally, there is evidence of bifrontal hemorrhagic contusions and thin layer of subarachnoid hemorrhage along cortical surface. Laboratory studies revealed normal hemoglobin and hematocrit and a Focused Assessment with Sonography in Trauma (FAST) study did not show signs of major extracranial bleeding. Bedside examination and imaging studies did not show any major cervical, extremities or thoracoabdominal trauma.

Question What is the most appropriate treatment for this patient with severe traumatic brain injury at this time?

Answer Emergent surgical evacuation of epidural hematoma.

This patient has suffered severe traumatic brain injury with no evidence of other significant extracranial injury. The patient is showing signs of increased intracranial pressure as evident from decreased level of consciousness and Cushing reflex caused by evolving epidural hematoma. Patient underwent emergent left temporal craniotomy and epidural hematoma evacuation. An intraparenchymal fiberoptic intracranial pressure monitoring device and a brain tissue oxygen tension ($PbtO_2$) monitoring device were inserted in the right frontal region. A target driven protocol-based treatment of intracranial hypertension and brain tissue hypoxia was initiated with goal ICP <20 mmHg, CPP >60 mmHg and $PbtO_2 > 20$ mmHg. On postoperative day 2, neurological examination improved slightly with patient withdrawing to painful stimuli on upper extremities, however still unable to follow commands. Patient had episodes of sustained elevations in intracranial pressure above 25 mmHg lasting longer than 15 min. Patient was treated with isotonic saline bolus to treat hypotension and

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Mannitol to treat intracranial hypertension. Sustained brain tissue hypoxia in the setting of normal CPP was treated with induced systemic hyperoxia by increase in FiO_2 and blood transfusion to increase oxygen carrying capacity. Patient developed intracranial hypertension refractory to hyperosmolar therapy and propofol sedation. Patient was placed on intravenous pentobarbital coma. Continuous EEG monitoring was used to assess the depth of sedation with goal of achieving burst suppression. Patient did not respond to medical therapy for treatment of refractory intracranial hypertension and a bifrontal decompressive craniectomy was performed.

Principles of Management

Primary and Secondary Brain Injury

TBI results in two distinct phases of brain injury. The primary brain injury that occurs at time of trauma is physical tissue injury resulting in shearing or compression of brain parenchyma. Severity of primary brain injury is a major determinant of outcome; however, it is generally irreversible and non-modifiable. Secondary brain injury that occurs hours to days after the traumatic event is the result of complex interaction between various intracranial and systemic factors. Brain ischemia resulting from secondary injury caused by decreased cerebral perfusion pressure from elevated intracranial pressure or systemic hypotension, hypoxia, hypocapnia, and brain herniation can significantly impact outcome and therefore, management of TBI focuses on reducing this secondary injury.

Severity of Traumatic Brain Injury

Classification of TBI based on initial severity helps in predicting likely outcome as well as understanding natural history. Severity of TBI is defined based on findings on neuroimaging, GCS within first 24 h of presentation, presence or absence and duration of loss of consciousness, post-traumatic amnesia and change in mental status. Table 40.1.

Prehospital and Emergency Department

Two major causes of secondary brain injury after TBI are cerebral hypoperfusion and hypoxia. Studies have shown that systolic BP < 90 mmHg and PaO_2 < 60 mmHg are associated with poor outcomes after TBI [1]. The prehospital treatment is focused toward establishing and maintaining adequate circulation, patent airway and oxygenation. Securement of airway by endotracheal intubation should be considered in patients with GCS <9 while ensuring hemodynamic stability. Crystalloids are preferred over colloids for fluid resuscitation as use of albumin resulted in increased mortality in a randomized clinical trial [2]. All patients with suspected moderate to severe TBI or GCS <15 should undergo neuroimaging evaluation. Non-contrast CT of head is preferred modality due to rapidity, wide availability and high sensitivity for detection of intra- and extraparenchymal hemorrhage and fractures. Common findings on initial CT of head in severe TBI include one or more of cerebral contusion (frontal and temporal lobes are common location), subdural hematoma, epidural hematoma, subarachnoid hemorrhage, intraventricular hemorrhage, diffuse cerebral edema, skull fracture and extracranial hematoma. Frequently, initial CT scan in comatose patients with severe TBI and diffuse axonal injury may be largely unremarkable. A follow up CT done 6–12 h after the initial CT may show development of new lesions or expansion of previously seen contusions. Early detection and treatment of intracranial hypertension should begin in emergency department as both duration and severity of low cerebral perfusion are associated with worse outcomes. Patients with severe TBI should be transferred to a tertiary center with emergent neurosurgical services once hemodynamic stability is established [3] (Fig. 40.1).

Mechanical Ventilation

Positive end-expiratory pressure should be kept to minimum to adequately oxygenate in patients with intracranial hypertension requiring mechanical

Table 40.1 Classification of severity of traumatic brain injury

Criteria	Mild	Moderate	Severe
Neuroimaging	Normal	Normal or abnormal	Abnormal
Initial GCS	13–15	9–12	<9
Loss of consciousness	Absent or upto 30 min	30 min to 24 h	More than 24 h
Post-traumatic amnesia	Absent or upto 24 h	1–7 days	More than 7 days
Change in mental status	Absent or upto 24 h	More than 24 h	

Adapted from VA/DoD clinical practice guideline for management of concussion/mild traumatic brain injury

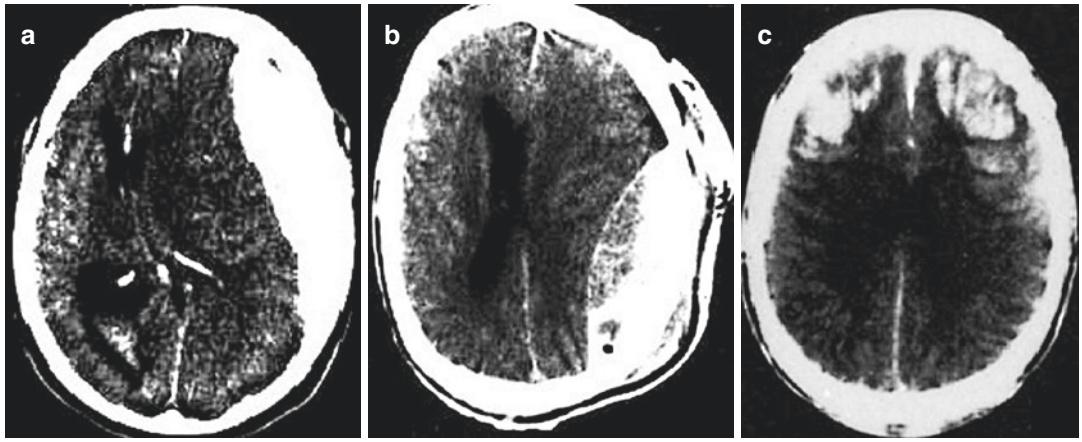

Fig. 40.1 CT scan of the head showing different findings in severe traumatic brain injury. (**a**) Crescent shaped hyperdensity in the suggestive of left sided acute subdural hematoma with mass effect and left to right midline shift. (**b**) Lenticular hyperdensity suggestive of acute epidural hematoma with effacement of left lateral ventricle. (**c**) Bifrontal traumatic cerebral contusions

ventilatory support. Prolonged hyperventilation induced hypocapnia increases risk of ischemia by cerebral vasoconstriction while permissive hypercapnia may lead to intracranial hypertension via cerebral vasodilation.

Analgesia, Sedation and Neuromuscular Paralysis

Inadequate pain control, agitation and anxiety may increase ICP and cerebral oxygen demand while unnecessary and excessive sedation results in inability to detect change in neurological exam. Therefore, judicious use of short acting opioids such as fentanyl, ramifentanyl or morphine is warranted for pain control and propofol or short acting benzodiazepine such as midazolam may be used to provide sedation. Non-depolarizing muscle relaxants should be used for patient-ventilator dyssynchrony causing refractory hypoxia and to treat intracranial hypertension caused by excessive coughing or straining.

Surgical Treatment

Epidural Hematoma

Patients with EDH and GCS score <9 should undergo surgical evacuation. Surgery is also recommended for patients with EDH volume ≥30 cc, thickness ≥15 mm or midline shift of ≥5 mm regardless of GCS. Patients managed nonoperatively should undergo serial CT imaging and frequent neurological monitoring where emergent neurosurgical treatment is available. Temporal location increases the risk of deterioration and therefore, threshold for surgery should be kept lower for patients with temporal EDH. Time from neurological worsening to EDH evacuation correlates more with outcomes than time from injury to evacuation. Therefore, in patients undergoing initial non-surgical treatment,

neurological deterioration as defined by worsening level of consciousness, abnormal papillary reflex, and appearance of new focality or worsening of existing focal deficits should prompt urgent surgical evacuation.

Subdural Hematoma

The indications for surgery in acute traumatic SDH include clot thickness >10 mm or midline shift >5 mm on initial CT imaging regardless of GCS. In patients with smaller SDH, GCS <9 or decrease in GCS by 2 points or more since presentation, presence of papillary abnormality or persistent elevation of ICP >20 mmHg should prompt surgical evacuation.

Intraparenchymal Hematoma/ Traumatic Cerebral Contusion

Patients with GCS of <9 with frontal or temporal hematoma of >20 cc with midline shift of ≥5 mm or cisternal compression and those with any hematoma of >50 cc should undergo evacuation. Also, patients with neurological deterioration thought to be related to intraparenchymal hematoma should also be treated surgically [4]. Neurologically stable patients with parenchymal contusion showing no significant mass effect on CT scan can be managed nonoperatively with close monitoring and serial imaging. Patients with medically refractory intracranial hypertension from diffuse cerebral edema may be treated with bifrontal or hemispheric decompressivecraniectomy.

Evidence Contour

Indication of Intracranial Pressure Monitoring and Pressure Threshold

Invasive ICP monitoring is not routinely indicated in all cases of TBI and the risks of monitoring such as infection and bleeding must be weighed against the benefit of additional information obtained by such monitoring. Patients with severe TBI with abnormal CT scan and GCS <9 should undergo ICP monitoring as they have high likelihood of transient or persistent elevation in ICP resulting in compromise in cerebral perfusion pressure and inability of serial clinical examinations to identify subtle changes related to intracranial hypertension due to poor baseline neurological status. Normal neuroimaging especially during early hours of TBI does not rule out intracranial hypertension. Patients with two or more of the following factors should undergo ICP monitoring in the absence of abnormal findings on CT scan of the head: age above 40 years, motor posturing, systolic blood pressure <90 mmHg. The ICP threshold above which interventions aimed at lowering the ICP should be implemented is unclear at this time. ICP of above 20 mmHg is generally recommended as the treatment threshold by several guidelines. Cerebral perfusion pressure (CPP = MAP-ICP) based threshold may provide for a more physiologically rational parameter and should be used in conjunction with ICP parameter with goal CPP >60–65 mmHg. Different devices used for ICP monitoring use any of available technologies such as fiberoptic sensor, microchip with internal strain gauge, air pouch or fluid filled catheter connected to pressure transducer. Devices also differ in terms of location of tip such as subdural, epidural, subarachnoid, intraparenchymal and intraventricular. Of these, fluid-filled transduced ventriculostomy catheter provides the most accurate ICP value and also allows for therapeutic CSF drainage and is therefore, preferred over other modalities.

Post-traumatic Seizures

Patients with moderate to severe TBI often have convulsive episode immediately after the impact. The issue of whether these 'impact seizures' represent true epileptic convulsion or convulsive concussion is not settled. Either way, these post-traumatic early seizures which can occur up to a week after the injury represent symptomatic events and have low likelihood of recurrence. Risk factors for early seizures are younger age, subdural hematoma, cortical contusions and penetrating head injury. Prophylactic use of AEDs in TBI is controversial. A pooled analysis of controlled trials showed that the use of prophylactic AEDs in selected TBI patients resulted in lower

incidence of early posttraumatic seizures [5]. However, in a placebo controlled randomized trial, phenytoin did not reduce the rate of early posttraumatic seizures in young patients with blunt head injuries [6]. Early seizures may degenerate in to status epilepticus with associated high mortality and both convulsive and non-convulsive seizures can worsen intracranial hypertension. Therefore, use of AEDs for 1 week to prevent seizures in patients at high risk for early seizures is recommended. Phenytoin is preferred agent because of stronger evidence and availability of IV formulation. However, Levetiracetam is an acceptable alternative to phenytoin based on similar outcomes in a large prospective study [7]. Long term prophylaxis is ineffective in preventing late posttraumatic epilepsy and later treatment should be started or continued on occurrence basis.

Therapeutic Hypothermia

High quality randomized trials have failed to show benefit of induced hypothermia after TBI [8, 9]. Use of therapeutic hypothermia was associated with risk of medical complications and its routine use to improve neurological outcomes in TBI is not recommended.

Advanced Neuromonitoring

Brain Tissue Oxygen ($PbtO_2$)

Partial pressure of oxygen in brain tissue can be monitored by an electrode placed in the brain region at risk for tissue hypoxia. Persistent brain tissue hypoxia defined as $PbtO_2 < 20$ mmHg has been shown to be associated with worse outcomes after TBI. It is unclear whether this association is an indicator of severity of injury or a potentially modifiable parameter to change the outcomes. Several non-randomized studies have shown that a protocol based $PbtO_2$ monitoring and interventions to minimize brain tissue hypoxia such as normobaric hyperoxia, elevation of CPP by reduction in ICP or hemodynamic augmentation and blood transfusion to increase O_2 carrying capacity is associated with better outcomes [10, 11]. A phase II randomized trial (BOOST-2) also showed that $PbtO_2$ monitoring and protocol based interventions are feasible, safe and associated with trend toward better outcomes compared to ICP monitoring based intervention alone [12].

Cerebral Microdialysis

Microdialysis consists of continuous sampling of the small molecules in the interstitial fluid via a small catheter placed within the tissue at risk for secondary injury. Analysis of various biochemical markers provides important information regarding metabolic milieu of the cerebral tissue. Tissue hypoxia leads to increased lactate production via anaerobic metabolism resulting in high lactate/pyruvate ratio and increase in glutamate due to decreased glial uptake as a result of ATP depletion. Advanced ischemia leads to increase in glycerol from decomposition of cell membrane. Tissue glucose concentration without parallel decrease in blood glucose may indicate a state of ischemia. These metabolic markers in microdialysis can aide in prognostication. Their role in interventions aimed at improving outcomes by affecting cerebral oxygenation, perfusion and glycemic state has not been established yet.

Jugular Bulb Oximetry

A popular monitoring technique in the past, Jugular bulb oximetry ($SjvO_2$) helps in determining the balance between cerebral blood flow and metabolic demand. Reduction in $SjvO_2$ indicates increase in oxygen extraction or decrease in cerebral blood flow as a result of decrease in CPP. The duration and the degree of abnormal $SjvO_2$ are associated with worsened outcomes after TBI.

Prophylactic Antibiotics

Penetrating brain injury has high risk of intracranial infection. Presence of CSF fistulae, transventricular injury and air sinus wounds increases the risk of infection further. Therefore, broad spectrum prophylactic antibiotics are recommended in all cases of penetrating brain injury [13].

Antibiotic prophylaxis is not indicated in non-penetrating basilar skull fractures with or without CSF leak [14].

Steroids and Neuroprotective Agents

Use of high dose intravenous corticosteroids following moderate to severe TBI was associated with increased risk of death within 2 weeks and is contraindicated [15]. A variety of neuroprotective agents have been studied in animals and humans for TBI. The results from early studies on use of Magnesium, Citicoline, progesterone and erythropoietin after TBI were promising, however, randomized clinical trials failed to show effectiveness of these strategies in TBI [16–21]. Effectiveness of routine use of hyperbaric oxygen and cyclosporine after TBI requires further confirmation by randomized clinical trials [22, 23].

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