Acute Management of Severe TBI
Neurovascular Center at St. Francis Hospital and Medical Center

Mark Landreneau, MD
Medical Director of Neurocritical Care
St. Francis Hospital and Medical Center
No Disclosures
TBI Epidemiology

• Major cause of Death and Disability in the US
  • 2.5 Million ED Visits
  • >280,000 Hospitalizations
  • >55,000 Deaths
  • 13.5 million individuals disabled
  • Long term disability from moderate to severe TBI estimated to be 3-5 million individuals, or 1-2 percent of the population

• Substantial economic impact
  • >$75 Billion in direct and indirect costs in the US
• Numbers likely underestimated due to those who do not seek medical attention

TBI Epidemiology

- Demographics
  - **Highest rates are at the extremes of age**
    - Adults >75 years old at ~2000 per 100,000
    - Young Adults 15 to 24 at ~1000 per 100,000
    - Children 0-4 years old ~1500 per 100,000
  - **Males** > Female at 950/100K versus 800 per 100k
  - Low socioeconomic status, EtOH and drug use, and underlying psychiatric or cognitive disorder are major risk factors

What is TBI?

- Traumatic brain injury is a heterogeneous disease with two phases of injury
  1. Primary Injury
  2. Secondary Injury
Primary Injury

- Mechanism
- Pathology
- Classification
  - Scoring Systems
  - Neuroimaging
- Intervention
Primary Injury

Mechanism

1. Direct Impact
2. Rapid Acceleration
3. Penetrating Injury
4. Blast Waves
Primary Injury

Mechanism

1. Direct Impact
Primary Injury

Mechanism

2. Rapid Acceleration
Primary Injury

Mechanism

3. Penetrating
Primary Injury

Mechanism

4. Blast
Primary Injury

- Mechanism
- **Pathology**
- Classification
  - Scoring Systems
  - Neuroimaging
- Intervention
Primary Injury

Pathology

1. DAI (Diffuse Axonal Injury)
2. Cerebral Contusions
3. Extra-axial hematomas
   • Epidural Hematoma (EDH)
   • Subdural Hematoma (SDH)
   • Intraventricular Hemorrhage (IVH)
   • Subarachnoid Hemorrhage (SAH)
Primary Injury

Pathology

1. DAI

Diffuse axonal injury

Case courtesy of Dr Matt Skalski, Radiopaedia.org, rID: 38437

Case courtesy of A.Prof Frank Gaillard, Radiopaedia.org, rID: 4851
Primary Injury

Pathology

2. Cerebral Contusions
Primary Injury

Pathology

3. Extra-axial Hemorrhage
Epidural Hematoma (EDH)
Primary Injury

Pathology

3. Extra-axial Hemorrhage
   Subdural Hematoma (SDH)
Primary Injury

Pathology

3. Extra-axial Hemorrhage

Intraventricular Hemorrhage (IVH)
Primary Injury

Pathology

3. Extra-axial Hemorrhage

Subarachnoid Hemorrhage (SAH)
Primary Injury

• Mechanism
• Pathology
• Classification
  • Scoring Systems
  • Neuroimaging
• Intervention
Primary Injury

Classification

1. Scoring Systems

Glasgow Coma Scale (GCS)

Mild 13-15
Moderate 9-12
Severe <9

<table>
<thead>
<tr>
<th>Eye opening</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Spontaneous</td>
<td>4</td>
</tr>
<tr>
<td>Response to verbal command</td>
<td>3</td>
</tr>
<tr>
<td>Response to pain</td>
<td>2</td>
</tr>
<tr>
<td>No eye opening</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Best verbal response</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oriented</td>
<td>5</td>
</tr>
<tr>
<td>Confused</td>
<td>4</td>
</tr>
<tr>
<td>Inappropriate words</td>
<td>3</td>
</tr>
<tr>
<td>Incomprehensible sounds</td>
<td>2</td>
</tr>
<tr>
<td>No verbal response</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Best motor response</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Obey commands</td>
<td>6</td>
</tr>
<tr>
<td>Localizing response to pain</td>
<td>5</td>
</tr>
<tr>
<td>Withdrawal response to pain</td>
<td>4</td>
</tr>
<tr>
<td>Flexion to pain</td>
<td>3</td>
</tr>
<tr>
<td>Extension to pain</td>
<td>2</td>
</tr>
<tr>
<td>No motor response</td>
<td>1</td>
</tr>
</tbody>
</table>
## Primary Injury

### Classification

#### 1. Scoring Systems

**Full Outline of UnResponsiveness (FOUR) score**

<table>
<thead>
<tr>
<th>Eye response</th>
<th>4</th>
<th>Eyelids open or opened, tracking, or blinking to command</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
<td>Eyelids open but not tracking</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Eyelids closed but opens to loud voice</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Eyelids closed but opens to pain</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Eyelids remain closed with pain</td>
</tr>
<tr>
<td>Motor response</td>
<td>4</td>
<td>Thumbs up, fist, or peace sign to command</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Localizing to pain</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Flexion response to pain</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Extensor posturing</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>No response to pain or generalized myoclonus status epilepticus</td>
</tr>
<tr>
<td>Brainstem reflexes</td>
<td>4</td>
<td>Pupil and corneal reflexes present</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>One pupil wide and fixed</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Pupil or corneal reflexes absent</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Pupil and corneal reflexes absent</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Absent pupil, corneal, and cough reflex</td>
</tr>
<tr>
<td>Respiration</td>
<td>4</td>
<td>Not intubated, regular breathing pattern</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Not intubated, Cheyne-Stokes breathing pattern</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Not intubated, irregular breathing pattern</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Breathes above ventilator rate</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Breaths at ventilator rate or apnea</td>
</tr>
</tbody>
</table>

Primary Injury

Classification

1. Neuroimaging
   a. Marshall scale
   b. Rotterdam scale
   c. DAI grade
      I, II, III

Marshall Scoring of TBI

<table>
<thead>
<tr>
<th>MLS</th>
<th>Cisterns</th>
<th>High or mixed-density lesion</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>None</td>
<td>Present</td>
<td>None</td>
</tr>
<tr>
<td>II</td>
<td>0-5mm</td>
<td>Present</td>
<td>None</td>
</tr>
<tr>
<td>III</td>
<td>0-5mm</td>
<td>Compressed or absent</td>
<td>None</td>
</tr>
<tr>
<td>IV</td>
<td>&gt;5mm</td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>V</td>
<td>Any</td>
<td>Any</td>
<td>Any</td>
</tr>
<tr>
<td>VI</td>
<td>Any</td>
<td>Any</td>
<td>Any</td>
</tr>
</tbody>
</table>

Rotterdam CT classification of TBI

<table>
<thead>
<tr>
<th>Basal cisterns</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>Compressed</td>
<td>1</td>
</tr>
<tr>
<td>Absent</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Midline shift</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>No shift or shift ≤ 5 mm</td>
<td>0</td>
</tr>
<tr>
<td>Shift &gt; 5 mm</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Epidural mass lesion</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>0</td>
</tr>
<tr>
<td>Absent</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intraventricular blood or SAH</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absent</td>
<td>0</td>
</tr>
<tr>
<td>Present</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sum Score</th>
<th>Total + 1</th>
</tr>
</thead>
</table>
Primary Injury

• Mechanism
• Pathology
• Classification
  • Scoring Systems
  • Neuroimaging
• Intervention
Primary Injury

**Intervention**

**Surgery**

**Epidural Hematoma:** >30cc or GCS <9 with pupillary abnormalities

**Subdural Hematoma:** >1cm thickness or >5mm MLS. If GCS <9, pupillary abnormality, or ICP >20mmHg

**Intracerebral Hemorrhage:** Significant mass effect, particularly in posterior fossa. >50cm³ in volume. GCS <9 with MLS >5mm

**Penetrating injury:** Superficial debridement and dural repair. Minimal utility for removal of deep foreign bodies. Use of broad spectrum antibiotics.

Secondary Injury

- Pathology
- Mechanism
- Intervention
  - Pre-Hospital
  - Emergency Department
  - NeuroICU
Secondary Injury

Pathphysiology

• Excitotoxicity
• Mitochondrial dysfunction
• Inflammatory Responses
• Apoptosis
• Secondary ischemia from vasospasm


Secondary Injury

- Pathology
- **Mechanism**
- Intervention
  - Pre-Hospital
  - Emergency Department
  - NeuroICU
Secondary Injury

Mechanism

- Hypotension/global ischemia
- Hypoxia and hyperoxia
- Fever
- Hypocapnia
- Coagulopathy
- Cerebral Edema
- Elevated ICP
- Hypoglycemia/hyperglycemia
- Sympathetic hyperactivity
- Seizures
Secondary Injury

- Pathology
- Mechanism
- Intervention
  - Pre-Hospital
  - Emergency Department
  - NeuroICU
Secondary Injury

• Guidelines from Brain Trauma Foundation, 4th Edition published 2017

• www.braintrauma.org
Secondary Injury

Intervention
Pre-Hospital

Major goals:
1) Prevent Hypotension!
   SBP <90mmHg triples risk of death, appropriate volume resuscitation

2) Prevent hypoxia!
   GCS <9, patients unable to protect airway, or low SpO2 should have RSI or supraglottic airway placed

Secondary Injury

Intervention
Emergency Department

Major goals: Resuscitate!

1) Secure the airway. Intubate all GCS <9 or persistent SpO2 <90%
   —Avoid hypoxia, hypoventilation, hyperventilation

2) Volume resuscitation with crystalloid. Check comprehensive labs including CBC, electrolytes, glucose, coagulation panel, EtOH and Urine Toxicology

3) Trauma assessment for systemic trauma

4) Neurological and Neurosurgical evaluation including clinical exam and imaging
   —Treat herniation or suspected elevated ICP with hyperosmolar therapy
   —CT Head without contrast for all GCS <15. If skull base fractures, consider CTA head and neck to evaluate for traumatic dissection
Secondary Injury

Intervention

ICU Management

• Hemodynamics
• Ventilation
• ICP
• Seizure
• Coagulopathy
• Glucose
• Temperature
• Sympathetic Hyperactivity
Secondary Injury

Intervention
ICU Management
Secondary Injury

Intervention
ICU Management

Hemodynamics
1) Fluids
   —Isotonic saline is preferred over ‘balanced fluids’

2) Blood Pressure
   —Avoid hypotension!
   —Goal SBP >100 for adults 50-70 and SBP >110 for all other adults

Ventilation
1) Oxygenation, keep PaO2 >60mmHg
2) Avoid hyperventilation—> causes cerebral vasoconstriction and can cause ischemia, PCO2 >35
3) Avoid hypoventilation—> causes cerebral vasodilation and elevated ICP, PCO2 <45
4) Avoid excessive PEEP, keep <20 cm H20

Secondary Injury

Intervention
ICU Management

Intracranial Pressure (ICP): Why Do We Care? Who to Monitor?
Secondary Injury

Intervention

ICU Management

Intracranial Pressure (ICP)
Secondary Injury

Intervention

ICU Management

ICP

Monroe Kellie doctrine
Secondary Injury

Intervention
   ICU Management

   ICP

   Cerebral
   Perfusion
   Pressure = MAP - ICP

   If ICP persistently exceeds MAP, intracranial circulatory arrest, ie Brain Death
Secondary Injury

Intervention

ICU Management

ICP
Treat >22mgHg
CPP 60-70
PRx <0.3

Stage 1
- Initial treatment measures
  - Head elevation
  - Ventilation
  - Sedation
  - Analgesia
  - Paralysis (optional)
  - Monitoring
  - Central venous pressure
  - Arterial blood pressure
  - Intracranial pressure

Stage 2
- Intracranial pressure >25 mm Hg
- Continue stage 1 treatments
- Barbiturates not permitted
- Optional treatments that can be added
  - Venticulostomy
  - Inotropes
  - Mannitol
  - Hypertonic saline
  - Loop diuretics
  - Hypothermia

Stage 3
- Intracranial pressure >25 mm Hg for 1–12 hr
- Surgical group
  - Decompressive craniectomy
  - Continue stage 1 and 2 treatments
- Medical group
  - Continue stage 1 and 2 treatments
  - Barbiturates permitted

Secondary Injury

Intervention

ICU Management

Seizure

- All patients GCS <9 receive anti epileptic drugs for at least 7 days. Preferred choice is Keppra 500-1000mg BID
- Incidence of post-traumatic seizures as high as 30 percent within one week with severe TBI
- Continuous EEG monitoring for impaired consciousness
- High seizure burden can increase CBF and ICP and exacerbate secondary injury
Secondary Injury

Intervention
ICU Management

Seizure
Secondary Injury

Intervention
ICU Management

Coagulopathy

- Reversal of systemic anticoagulation (Vit. K, PCC, Praxbind, Andexxa) to INR <1.4
- Consumptive thrombocytopenia common, keep platelets >75k.
- No role for Factor VII or aminocaproic acid
- Transexemic acid may be helpful
- Can safely restart prophylactic dose heparin at 24-48 hours after stable imaging
Secondary Injury

Intervention
ICU Management

Temperature
- Fever worsens outcome by increasing metabolic demand and ICP
- Induced hypothermia does not improve outcomes based on results of six RCTs (Level 3 evidence, weak)
- Treat aggressively in first 10 days
- Use of standing tylenol, buspirone
- Cooling blanket

Glucose
- Avoidance of hyper- or hypoglycemia
- Goal 140-180
Secondary Injury

Intervention

ICU Management

Paroxysmal Sympathetic Hyperactivity, “Storming”

• About 10% of patients with TBI
• Use benzos, opiates, beta-blockers, and alpha-2 agonists
Secondary Injury

Intervention

ICU Management

Advanced Neuromonitoring

• Brain tissue oxygen tension (PbtO2)—being studied in BOOST3 trial
• Cerebral microdialysis—measures glucose, lactate, pyruvate, glutamate
• Thermal diffusion flowmetry—measures cerebral blood flow
• Pressure reactivity index (PRx)—measures correlation between blood pressure and ICP.
Secondary Injury

Intervention

ICU Management

No evidence or negative evidence

- Factor VII and tranexamic acid for hemostasis
- Neuroprotection—numerous trials including progesterone, citicoline, EPO, dexanabinol, magnesium, etc all failed to show benefit
- Glucocorticoids—bad outcomes (CRASH)
# Secondary Injury

<table>
<thead>
<tr>
<th>Topic</th>
<th>Recommendation</th>
</tr>
</thead>
</table>
| Hyperosmolar therapy         | • Mannitol can be used to control elevated ICP but avoid hypotension (SBP<90 mmHg)*  
                                 | • Can use with signs of transtentorial herniation or progressive neuroworsening if no ICP monitor* |
| Hyperventilation              | • Avoid prolonged ppx hyperventilation, and within the first 24 hours        
                                 | • Hyperventilation can be used as a temporizing measure for elevated ICP*    
                                 | • If hyperventilation used monitor O₂ deliver with SjO₂ or BtpO₂*          |
| Anesthetics                   | • Avoid ppx use of barbiturates for intracranial hypertension                
                                 | • Can use barbiturates if ICP refractory to max standard medical and surgical means |
                                 | • Propofol can be used for ICP but not for improvement in mortality and 6 months outcomes |
| Steroids                      | • Not recommended for ICP control or outcome benefit                         
                                 | • High dose methylprednisolone is contraindicated due to increased mortality |
| Infection prophylaxis         | • Early tracheostomy can be considered                                      |
| DVT prophylaxis               | • Pharmacologic prophylaxis may be used but there is increased risk of ICH expansion, especially if benefit>risk  
                                 | • No recommendation of preferred agent or timing of initiation              |
| Seizure prophylaxis           | • PHT or VPA not recommended for LATE (<7 days) PTS                          
                                 | • PHT recommended for early PTS when benefit>risk, though seizures not shown to be associated with worse outcomes |
| ICP monitoring and threshold  | • Monitor salvageable patients (GCS3-8 after resuscitation) + abnormal CT*   
                                 | • Monitor with normal CT + ≥2 of the following: age>40, unilateral/bilateral posturing, SBP<90 mmHg*  
                                 | • ICP values + CT findings may be used to make decisions regarding treatment |
| Advanced monitoring and       | • Jugular bulb monitoring of AVDO₂ may be considered                         
                                 | threshold                                                                  |
                                 | • AVDO₂ <50% may be a threshold to avoid                                     |
| CPP threshold                 | • Avoid fluids and vasopressors to maintain CPP>70, given risk of respiratory failure |
## Secondary Injury

<table>
<thead>
<tr>
<th>Topic</th>
<th>Recommendation</th>
</tr>
</thead>
</table>
| Decompressive craniectomy     | • Bifrontal craniectomy is not recommended without a mass lesion, ICP>20 for more than 15 min within 1 hour, refractory to medical therapy*.  
• A large frontotemporoparietal DC >small frontotemporoparietal DC |
| Prophylactic hypothermia       | • Early (within 2.5 hours) short term (48 hours) prophylactic hypothermia is not recommended               |
| Cerebrospinal fluid drainage  | • Continuous EVD drainage may be more effective at lowering ICP burden than intermittent use  
• Consider CSF drainage to lower ICP in patients with initial GCS≤6 within first 12 hours of injury          |
| Nutrition                     | • Feed patients by the 5th and at most the 7th day                                                         |
| Infection prophylaxis         | • PI oral care is not recommended to reduce VAP  
• Consider an antimicrobial impregnated EVD                                                                |
| Seizure prophylaxis           | • Cannot recommend levetiracetam over PHT for early PTS ppx                                              |
| ICP monitoring and threshold  | • Management using information from ICP monitor is recommended  
• Treat ICP≥22 mmHg                                                                                     |
| CPP monitoring and threshold  | • Management using information from CPP monitor is recommended  
• Target CPP is 60-70 mmHg, but minimum CPP is unclear and may depend on autoregulation status             |
| Blood Pressure Threshold      | • Maintain SBP ≥100mmHg for patients 50-69 years old or ≥110mmHg for patients 15-49 or >70 years old       |
Outcomes

**IMPACT** ([www.tbi-impact.org](http://www.tbi-impact.org))
**CRASH** ([www.crash.lshtm.ac.uk](http://www.crash.lshtm.ac.uk))

### Prediction models for 6 month outcome after TBI

<table>
<thead>
<tr>
<th>Admission Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td></td>
</tr>
<tr>
<td>Age (14-99 years)</td>
<td></td>
</tr>
<tr>
<td>Motor Score</td>
<td>[Select]</td>
</tr>
<tr>
<td>Pupils</td>
<td>[Select]</td>
</tr>
<tr>
<td>Core+CT</td>
<td></td>
</tr>
<tr>
<td>Hypoxia</td>
<td>[Select]</td>
</tr>
<tr>
<td>Hypotension</td>
<td>[Select]</td>
</tr>
<tr>
<td>CT Classification</td>
<td>[Select]</td>
</tr>
<tr>
<td>tSAH on CT</td>
<td>[Select]</td>
</tr>
<tr>
<td>Epidural mass on CT</td>
<td>[Select]</td>
</tr>
<tr>
<td>Core+CT+Lab</td>
<td></td>
</tr>
<tr>
<td>Glucose (3-20 mmol/L)</td>
<td></td>
</tr>
<tr>
<td>Hb (6-17 g/dL)</td>
<td></td>
</tr>
</tbody>
</table>

### Head injury prognosis

These prognostic models may be used as an aid to estimate mortality at 14 days and death and severe disability at six months in patients with traumatic brain injury (TBI). The predictions are based on the average outcome in adult patients with Glasgow coma score (GCS) of 14 or less, within 8 hours of injury, and can only support - not replace - clinical judgment. Although individual names of countries can be selected in the models, the estimates are based on two alternative sets of models (high income countries or low & middle income countries).

- **Country**: Choose...
- **Age, years**: Choose...
- **Glasgow coma score**: Choose...
- **Pupils react to light**: Choose...
- **Major extra-cranial injury?**: Choose...
- **CT scan available?**: Choose...
- **Presence of petechial haemorrhages**: Choose...
- **Obliteration of the third ventricle or basal cisterns**: Choose...
- **Subarachnoid bleeding**: Choose...
- **Midline shift**: Choose...
- **Non-evacuated haematoma**: Choose...
Outcomes

Diffusion Tensor Imaging (DTI)
Outcomes