Traumatic Brain Injury

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San Francisco General Hospital
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Goals & Overview

- Guidelines traumatic brain injury management?
- Indications for ICP monitoring?
- Isn’t ICP monitoring enough?
  Anything more is just for academic interest!
- Advanced monitoring -
  - What’s involved? How much work is it?
  - How do we use the information?
Guidelines - Central Concept

- Secondary Injury

Primary Injury
- Mechanical
- Vascular

Not all neurological damage from TBI occurs at the moment of impact
Current TBI Guidelines

“Guidelines for the management of traumatic brain injury”
Journal of Neurotrauma 24(S), May 2007
<table>
<thead>
<tr>
<th>Topic</th>
<th>Level I</th>
<th>Level II</th>
<th>Level III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood pressure and oxygenation</td>
<td>-</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Hyperosmolar therapy</td>
<td>-</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Prophylactic hypothermia</td>
<td>-</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Infection prophylaxis</td>
<td>-</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>DVT prophylaxis</td>
<td>-</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Indications for ICP monitoring</td>
<td>-</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>ICP monitoring technology</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>ICP thresholds</td>
<td>-</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>CPP thresholds</td>
<td>-</td>
<td>√</td>
<td>√</td>
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<tr>
<td>Brain oxygen monitoring and thresholds</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Anesthetics, analgesics, and sedatives</td>
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<tr>
<td>Nutrition</td>
<td>-</td>
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<tr>
<td>Anti-seizure prophylaxis</td>
<td>-</td>
<td>√</td>
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<tr>
<td>Hyperventilation</td>
<td>-</td>
<td>√</td>
<td>√</td>
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<tr>
<td>Steroids</td>
<td>√</td>
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</tbody>
</table>
TBI Guidelines

1. Raised intracranial pressure
2. Brain metabolism - oxygen & glucose
3. Cerebral perfusion
Intracranial Pressure (ICP)

ICP = Brain + CSF + Blood vascular volume + Mass Lesion

Pressure Volume Curve
Raised intracranial pressure

Pre-hospital Guidelines

Signs of raised ICP requiring emergency intervention
1. Dilated pupil
2. Decerebrate posturing
Hyperosmolar Therapy Revised

Mannitol

• Level II
  - Mannitol (0.25-1.0 gm/Kg) for ICP control ;
  - avoid arterial hypotension

• Level III
  - Prior to ICP monitoring, Restrict mannitol use to patients with signs of impending cerebral herniation
Treatment Raised ICP

**Mannitol**
- Osmotic diuresis
- Reduces blood viscosity
- 1-1.4gm/kg, bolus
When to hyperventilate?

Hyperventilation

- CO2 causes relaxation of vascular smooth muscles of arterioles and decreased vascular resistance

Goal in herniation
pCO2 32-35
Not <30

<table>
<thead>
<tr>
<th></th>
<th>Normal (breaths/min)</th>
<th>Hyperventilation (breaths/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>children</td>
<td>20</td>
<td>30</td>
</tr>
</tbody>
</table>
When is it OK to Hyperventilate?

Options

- Brief hyperventilation for acute deterioration secondary to raised ICP

- Avoid prophylactic hyperventilation ($\text{PaCO}_2 \leq 35 \text{ mmHg}$) during first 24 hours
  
  - can compromise cerebral perfusion during a time when cerebral blood flow (CBF) is reduced

- Prolonged hyperventilation — use $\text{SjVO}_2$, $\text{AVDO}_2$, or CBF monitoring if $\text{PaCO}_2 < 30 \text{ mmHg}$ needed
Steroids are NOT recommended for improving outcome or reducing ICP in patients with moderate or severe TBI.

High dose methylprednisolone is associated with increased mortality and is contraindicated.

<table>
<thead>
<tr>
<th>Outcome @6mo</th>
<th>Steroid</th>
<th>Placebo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead</td>
<td>1248</td>
<td>1075</td>
</tr>
<tr>
<td>(26%)</td>
<td>(22%)</td>
<td></td>
</tr>
</tbody>
</table>

CRASH Trial

Lancet 364: 1321 (2004);
Brain Metabolism: Importance of Aerobic Metabolism

- ATP synthesized in the mitochondria by the process of oxidative phosphorylation coupled to electron transport

**Anaerobic:** 2 mol ATP/mol glucose

**Aerobic:** 34 mol ATP/mol glucose
Cerebral Metabolism: Hypoxia

- 50 TBI patients rescued by helicopter
- SaO2 measured by pulse oximeter

<table>
<thead>
<tr>
<th>O2 Sat</th>
<th>Mortality</th>
<th>Severe Disability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;90%</td>
<td>14%</td>
<td>5%</td>
</tr>
<tr>
<td>60-90%</td>
<td>27%</td>
<td>27%</td>
</tr>
<tr>
<td>&lt;60%</td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
</table>

Cerebral Metabolism: Hypoxia

Pre-hospital Guidelines

1. Measure SaO2 with pulse oximeter continuously
2. Provide supplemental O2
3. Keep SaO2 > 90%
Cerebral Metabolism : Hypoxia

Pre-hospital Guidelines

Intubate patients with:

1. Persistent hypoxemia (sat <90%) not corrected by supplemental O2
2. Inability to maintain an adequate airway
   - Apnea
   - Airway compromise
   - Unconsciousness or unresponsiveness with GCS< 8

- Cough & gag reflexes can raise ICP
- Orotracheal > nasotracheal
Cerebral Autoregulation

- The concept: CBF remains constant at mean arterial pressures of 60-140 mmHg
- CPP is the primary stimulus for autoregulation
Cerebral Dysautoregulation in TBI

CPP = mean arterial BP – ICP

Severe TBI
- Cerebral autoregulation more likely to be lost or impaired
- CBF may become pressure dependent

Brain perfusion becomes completely dependent on systemic BP
Cerebral Perfusion: Hypotension

<table>
<thead>
<tr>
<th>Secondary insult</th>
<th>No of patients</th>
<th>GOS 4-5 % good</th>
<th>GOS 2-3 % poor</th>
<th>GOS 1 % death</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neither</td>
<td>456</td>
<td>51</td>
<td>22</td>
<td>27</td>
</tr>
<tr>
<td>Hypoxia</td>
<td>78 (11%)</td>
<td>45</td>
<td>22</td>
<td>33</td>
</tr>
<tr>
<td>Hypotension</td>
<td>113(16%)</td>
<td>26</td>
<td>14</td>
<td>60</td>
</tr>
<tr>
<td>Both</td>
<td>52 (7%)</td>
<td>6</td>
<td>19</td>
<td>75</td>
</tr>
</tbody>
</table>

- Dominant role of hypotension in poor / dead outcome
- Hypoxia and hypotension synergistic effect

Chesnut *J Trauma* 34: 216 (1993)
Guidelines Blood Pressure - Level II

Blood Pressure

- Avoid hypotension
  sBP < 90 mmHg
- Isotonic saline
- Fluid resuscitation a balance:
  ▪ Maintain cerebral perfusion ⇔ avoid fluid overload, osmotic shifts, brain edema

Hyperventilation

- Prophylactic
  (PaCO₂ < 25 mmHg)
  not recommended
Who Needs ICP Monitoring?

Primary indication for ICP monitoring
- absence of a neurological exam that can be followed

Guidelines Level II

GCS < 8 and
Abnormal CT scan

Or Normal CT scan with
- age > 40
- unilateral or bilateral posturing
- systolic pressure < 90 mmHg
ICP Treat for threshold > 20 mmHg

CPP = mean arterial BP – ICP

Cerebral Perfusion Thresholds Level II

- Avoid aggressive attempts to maintain CPP > 70 mmHg with fluids and pressors; increased risk of ARDS
Advanced TBI Monitoring
Pathophysiological Complexity

Why isn't ICP monitoring enough?

ICP = Brain + CSF + Blood Vol + Mass Lesion

Pressure Volume Curve

CBF - Metabolic coupling

Glucose → Glycolysis → Pyruvate → Lactate

Acetyl CoA

TCA

NADH

FADH2

E-Transport

CPP Guided Therapy

ICP Guided Therapy

Autoregulating

Pressure Passive

Mean BP

Mean BP

CMRO2

GCS
Patient-Specific targeted therapy: What do you REALLY want to know?

- ICP
- Compliance
- Cerebral Blood flow
- Autoregulation
- Oxygenation
- Metabolism
- Function
  - EVD, Camino Bolt
- Jugular venous sat’n
- Licox Brain Tissue O2
- CBF probe
- Reactivity challenges
- Ornim non-invasive
- Microdialysis
Jugular Venous Saturation

Measures total venous brain tissue extraction of oxygen

Placement:
- Ipsilateral to side of brain injury
- Right jugular vein > Left
- Trendelenburg position for placement
- Target above C1
- Lodging against vessel wall and malfunction
- Calibration
Jugular Venous Oxygen Saturation

Woodman, et al., 1994
Jugular Venous Saturation

### New Guideline

**SjvO2 Treatment Threshold** < 50%

<table>
<thead>
<tr>
<th>SjvO2 Normal values</th>
<th>50-75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical values</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>Hypoxia</td>
<td>Decreased</td>
</tr>
<tr>
<td>Increased O2 demand (seizures, fever, agitation)</td>
<td>Decrease due to increased extraction</td>
</tr>
<tr>
<td>Global Decrease CBF (hypotension, hypovolemia, ischemia)</td>
<td>Decreased</td>
</tr>
<tr>
<td>Hyperemia</td>
<td>Increase</td>
</tr>
</tbody>
</table>
Brain Tissue Oxygen Monitor $\text{PBtO}_2$

A closed polarographic probe with reversible electrochemical reactions
Brain Tissue Oxygen

• Brain O2 probes placed in white matter
• Normal values for white matter 20-30mmHg
• Equilibrate 2h
• 100% O2 challenge

• Contralateral to burden of lesion
• Placement in contusions, infarcts, injured brain may cause low values refractory to treatment
Brain Tissue Oxygen

\[ P_{brO_2} = CBF \ (P_{aO_2} - P_{vO_2}) \]

Not an ischemia monitor

Rosenthal et al. CCM, 2008
### Brain Tissue Oxygen

#### Abnormal PBrO2

1. Check arterial blood gas
2. 100% FiO2 challenge - Check probe functioning
3. Consider CT scan
4. Challenge CPP

#### New Guideline

**PBrO2 Treatment Threshold** < 15 mmHg

#### Table

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal values (white matter)</td>
<td>20-30 mmHg</td>
</tr>
<tr>
<td>Critical values</td>
<td>&lt; 15</td>
</tr>
<tr>
<td>Hypoxia</td>
<td>Decreased</td>
</tr>
<tr>
<td>Increased O2 demand (seizures, fever, agitation)</td>
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</tr>
<tr>
<td>Global Decrease CBF (hypotension, hypovolemia, ischemia)</td>
<td>Decreased</td>
</tr>
<tr>
<td>Hyperemia, hyperoxia</td>
<td>Increase (&gt;40 mmHg)</td>
</tr>
</tbody>
</table>
Cerebral Blood Flow

- Less than 1 mm diameter flexible probe
Cerebral Microdialysis

Blood capillary

Microdialysis catheter

Extracellular fluid

Cell

Glucose metabolism

Lactate metabolism

Pyruvate metabolism

Glycerol metabolism

Glutamate metabolism

Urea metabolism

Glucose

Lactate

Pyruvate

Glycerol

Glutamate

Urea

Metabolic -- blood flow coupling

Membrane damage
SFGH Goals of Severe TBI management

- Maintain PO2 of 100 mmHg
- Maintain PaCO2 of 40 mmHg
- Maintain Hb of 10
- EVD / ICP monitor
- PBrO2:
  - Triggers PBrO2 <15 mmHg
  - >50% change in PBrO2
- SjVO2
- CBF probe
- Pressure challenge & FIO2 challenge daily
Reactivity Testing

**Autoregulation challenge**

*Goal Map:* 10-15 mmHg above baseline

- **ABG and VBG** at baseline FiO2
- **Iv pressure** 10ug/min iv and increased by 20ug/min q 5min until goal MAP; endpoints ICP, CPP and CBF

**PBrO2**

- Evaluate probe function
- **Magnitude & time course**
- **FiO2 100% x 20 min**
- **PBrO2 allowed to stabilize; repeat ABG & VBG**
## Outcomes from Multi-Modal Therapy

<table>
<thead>
<tr>
<th>Monitoring</th>
<th>No of cases</th>
<th>Good (%)</th>
<th>Moderate/Poor (%)</th>
<th>Death (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-modal</td>
<td>17</td>
<td>53</td>
<td>Moderate 42</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Poor 5</td>
<td></td>
</tr>
<tr>
<td>ICP Unimodal</td>
<td>31</td>
<td>68</td>
<td>7</td>
<td>26</td>
</tr>
<tr>
<td>None</td>
<td>44</td>
<td>62</td>
<td>12</td>
<td>27</td>
</tr>
</tbody>
</table>

*Isa et al Neurosurg Focus 2003*
Case Studies
Case

- 49 year old male
- Fall from scaffolding ~ 8 feet
- GCS 8 field, 11 ED
- (E3,V3,M5)
- OR decompressive hemicraniectomy
## Case

<table>
<thead>
<tr>
<th>Time</th>
<th>ICP</th>
<th>EVD</th>
<th>MAP</th>
<th>CPP</th>
<th>FiO2</th>
<th>PO2</th>
<th>PBrO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2300 (2hours postop)</td>
<td>13</td>
<td>0</td>
<td>85</td>
<td>72</td>
<td>60%</td>
<td>319</td>
<td>18</td>
</tr>
<tr>
<td>0700</td>
<td>20</td>
<td>1x/h</td>
<td>96</td>
<td>76</td>
<td>30%</td>
<td>138</td>
<td>19</td>
</tr>
<tr>
<td>1200</td>
<td>19</td>
<td>1x/h</td>
<td>95</td>
<td>76</td>
<td>30%</td>
<td>138</td>
<td>17</td>
</tr>
<tr>
<td>1900</td>
<td>18</td>
<td>2x/h</td>
<td>84</td>
<td>66</td>
<td>30%</td>
<td>132</td>
<td>15</td>
</tr>
<tr>
<td>2200</td>
<td>19</td>
<td>2x/h</td>
<td>80</td>
<td>61</td>
<td>30%</td>
<td></td>
<td>13</td>
</tr>
</tbody>
</table>
Contusion expansion: Brain Tissue Oxygen desaturation

ICP still < 20 mmHg

<table>
<thead>
<tr>
<th>Time</th>
<th>ICP</th>
<th>EVD</th>
<th>MAP</th>
<th>CPP</th>
<th>FiO2</th>
<th>PBrO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>20</td>
<td>5x/h</td>
<td>80</td>
<td>60</td>
<td>30%</td>
<td>8</td>
</tr>
</tbody>
</table>
Conclusions

ICP Unimodal Therapy

- Mannitol for impending herniation
- Monitoring GCS ≤ 8 and abnormal CT
- Maintain < 20mmHg
- No Steroids, avoid hypotension and hypoxia, and hyperventilation

Multimodal Patient-Specific Therapy

- Cerebral Perfusion, Brain Metabolism, Injury heterogeneity
- SjVO2, PBtO2, CBF, microdialysis, reactivity challenges
Thank you
Case

- 25 yo female peds vs auto
- BIBA, apnea in field
- GCS 3 Field, 3 ED
- BP 62/palp, intubated
- Pupils reactive, corneal √
- Multiple injuries:
  - liver laceration,
  - hemothorax - non-operative Rx
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ICP</td>
<td>12-13</td>
</tr>
<tr>
<td>MAP</td>
<td>85</td>
</tr>
<tr>
<td>CPP</td>
<td>72</td>
</tr>
<tr>
<td>FiO2</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>7.4/35/141</td>
</tr>
<tr>
<td>PBrO2</td>
<td>16</td>
</tr>
<tr>
<td>SjVO2</td>
<td>83-95</td>
</tr>
</tbody>
</table>

Case

![Brain CT scan](image)
Case

- 25 yo female
- Right EDH, Left SAH & SDH
- Decompressive crani
- Post-op Day 8:
  - PBrO2 decreased to 8
  - FiO2 challenge --> probe responded, functioning
  - Systemic hypoxic causes r/o’d
  - CBF increased - no improvement in PBrO2
Traumatic Vasospasm

Pre-treatment

Post-treatment

Shahlaie 2008
Case

- 42 yo female s/p GSW to head
- GCS 12 Field, declined to 6 in ED
- CT diffuse swelling; wound debrided
Case

- ICP controlled with intermittent CSF drainage and sedation for 48 hours

- ... ICP 28-38 mmHg
- 2 doses of mannitol --> no response
- 23% NaCL --> no response
## Case

<table>
<thead>
<tr>
<th></th>
<th>Case</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICP</td>
<td>28-38 mmHg</td>
<td></td>
</tr>
<tr>
<td>PBrO2</td>
<td>26 mmHg</td>
<td>20-30 mmHg</td>
</tr>
<tr>
<td>CBF</td>
<td>24 cc/100g/min</td>
<td>25 cc/100g/min</td>
</tr>
<tr>
<td>CPP</td>
<td>87 mmHg</td>
<td></td>
</tr>
<tr>
<td>SjVO2</td>
<td>82%</td>
<td></td>
</tr>
</tbody>
</table>

What do you want to do?

A Mannitol
B Increase ventilation rate
C decrease CPP
D Repeat CT scan
<table>
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What do you want to do?
A Mannitol
B Increase ventilation rate
C decrease CPP
D Repeat CT scan
Seizures

- Anticonvulsants recommended to decrease the incidence of early seizures, < 7 days (early seizures not associated with worse outcome)
- Prophylactic use of dilantin or valproate to prevent onset of Late post-traumatic seizures is NOT recommended
Why isn’t ICP monitoring enough?

- CSF obstruction
- Mass lesion
- Consider repeating CT scan
- Ventricular Drainage (if available)
  - ICP > 20 mmHg
  - Hyperventilation
    - ICP > 20 mmHg
    - Mannitol
      - Hyperemia
      - Edema
Case

Hypoxic Ischemic Injury
Withdrew supportive care, patient died
Ornim Non-Invasive Oxygen Levels
Pulse Ox in Brain

- Non-invasive laser based sensor for direct monitoring of oxygen levels within the brain
- Pulse oximetry: differences in absorption of different wavelengths of light by oxygenated and deoxygenated blood
CBF Probe based on Thermal diffusion

![Graph showing temperature and power over time.](image)

- **Temperature [°C]**
- **Power [mW]**

- **Blue line**: Distal Temperature
- **Red dashed line**: Measured Power

**X-axis**: Time [seconds]
**Y-axis**: Temperature
**Y-axis**: Power

Time points:
- 0 seconds
- 5 seconds
- 10 seconds
- 15 seconds
- 20 seconds
- 25 seconds
Brain Tissue Oxygen desaturation

ICP still < 20 mmHg

<table>
<thead>
<tr>
<th>Time</th>
<th>ICP</th>
<th>EVD</th>
<th>MAP</th>
<th>CPP</th>
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<th>PBrO2</th>
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<tbody>
<tr>
<td>0000</td>
<td>20</td>
<td>5x/h</td>
<td>80</td>
<td>60</td>
<td>30%</td>
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</tr>
</tbody>
</table>
Secondary Injury Mechanisms

Why isn’t ICP monitoring enough?

Not all neurological damage from TBI occurs at the moment of impact.