Pediatric Traumatic Brain Injury and Pediatric Ventilation

Kyle Lemley, MD
Pediatric Critical Care/Hospitalist
Springfield, MO
Objectives

• Discuss history of traumatic brain injury (TBI)
• Review the epidemiology of TBI
• Discuss the pathophysiology of TBI
• Discuss diagnosis and treatment of TBI
• Discuss ventilation in pediatrics
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History of TBI

• Treating TBI dates back to ancient Mesopotamians

• Evidence of trepanation in skulls found in graves

• Linked seizures, paralysis, and vision/hearing loss
History of TBI

- Edwin Smith Papyrus (1650-1550 BC)
  - Describes head injury symptoms
  - Classified based on presentation and tractability

- During Middle ages:
  - Trepanation continued
  - Symptoms further described
  - Concussion systematically described by Carpi (16th century)
History of TBI

• 18th century
  – Intracranial pressure most important pathology
  – Confirmed around end of 19th century

• 19th century
  – TBI related to psychosis
  – Phineas Gage
History of TBI—20th Century

- CT and MRI
- Intracranial pressure monitoring
- Improved mortality rate
- Dedicated facilities after WWI
- Increased research in the 1970s
- 1990s first set of standardized guidelines
- 1990s known as “Decade of the Brain”
History of TBI

• 21st century
  – Diffusion tensor imaging (DTI)

  – Continued push for
    • Research
    • Evidenced-based guidelines
    • Rehabilitation
    • Understanding of affect on psyche
Objectives

- Discuss history of traumatic brain injury (TBI)
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- Discuss the pathophysiology of TBI
- Discuss diagnosis and treatment of TBI
- Discuss ventilation in pediatrics
## Table 3. Median Proportions of Traumatic Brain Injury by Selected Cause.

<table>
<thead>
<tr>
<th>Age range</th>
<th>Motor vehicle or transport</th>
<th>Falls</th>
<th>Sports or recreation</th>
<th>Assault</th>
<th>Firearms</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Attended in hospital emergency departments or all medically attended&lt;sup&gt;11,15,30-32,34,36,39,42&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-4</td>
<td>7</td>
<td>69</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5-9</td>
<td>13</td>
<td>53</td>
<td>31</td>
<td>2</td>
<td></td>
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<tr>
<td>10-14</td>
<td>19</td>
<td>37</td>
<td>26</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>≥15</td>
<td>37</td>
<td>11</td>
<td>20</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Attended in hospital inpatient services&lt;sup&gt;17,20,22,24,37,38,40&lt;/sup&gt;</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0-4</td>
<td>15</td>
<td>59</td>
<td>2</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>5-9</td>
<td>29</td>
<td>50</td>
<td>4</td>
<td>2</td>
<td></td>
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<tr>
<td>10-14</td>
<td>54</td>
<td>23</td>
<td>8</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>≥15</td>
<td>56</td>
<td>12</td>
<td>9</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Fatal injuries only&lt;sup&gt;28,29&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-4</td>
<td>47</td>
<td>4</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5-9</td>
<td>71</td>
<td>2</td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>10-14</td>
<td>57</td>
<td>2</td>
<td></td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>≥15</td>
<td>54</td>
<td>1</td>
<td></td>
<td>38</td>
<td></td>
</tr>
</tbody>
</table>

The Epidemiology of Traumatic Brain Injury in Children and Youths: A Review of Research Since 1990

David J. Thurman, MD, MPH
## Table 4. Temporal Trends in Rates of Hospitalization and Death Associated With Traumatic Brain Injury.

<table>
<thead>
<tr>
<th>Study population</th>
<th>Interval</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hospitalizations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>United States, all ages</td>
<td>1980-1995</td>
<td>-51.0</td>
</tr>
<tr>
<td>Canada, children</td>
<td>1991-2005</td>
<td>-63.8</td>
</tr>
<tr>
<td><strong>Mortality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>United States, all ages</td>
<td>1980-1995</td>
<td>-17.0</td>
</tr>
<tr>
<td>United States, children</td>
<td>1991-2005</td>
<td>-20.0</td>
</tr>
<tr>
<td>United States, all ages</td>
<td>1998-2007</td>
<td>-17.2</td>
</tr>
</tbody>
</table>
Epidemiology

- Long-term disability in 40% of adult survivors
- Presumed to be large burden in pediatrics
- Danish study in 1979-1981 showed 20%
- With improved mortality, likely more with disability
- Mortality between 17-33%
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• Discuss ventilation in pediatrics and TBI
Pathophysiology

- **Brain physiology**
  - Consumes 20% of oxygen
  - Receives 15% of cardiac output
  - Oxygen delivery based on
    - Cerebral blood flow (CBF)
    - Cerebral perfusion pressure (CPP)
Pathophysiology

- **Intracranial pressure (ICP)**
  - Goal < 15 mmHg

- **Cerebral Perfusion Pressure**
  - Mean arterial pressure – Intracranial Pressure
  - Can substitute central venous pressure if larger
  - Age dependent but at least > 40 mmHg

- **Cerebral blood flow (CBF)**
Pathophysiology
Pathophysiology

- Direct injury
  - Blunt or penetrating trauma

- Indirect injury
  - Accelerating/decelerating shearing forces
Pathophysiology

- **Primary injury**
  - Direct result of initial insult
  - Usually irreversible

- **Secondary injury**
  - Occurs minutes to days after insult
  - Preventable
  - Consequence of primary injury
  - Cascade of cellular and biochemical events
  - Exacerbated by mismanagement of TBI patients
Direct Injury

http://schatz.sju.edu/neurosem/luria/mechanism.html
Pathophysiology

TBI → Stretching of cellular membranes → Neuronal depolarization → Increased extracellular glutamate → Calcium influx through glutamate receptors → Spreading of calcium through gap junctions

Reduced astrocytic glutamate uptake

Excitotoxicity
Indirect Injury

 Diffuse Axonal Injury

Sudden acceleration-deceleration forces cause injury to the brain.

The injury is greatest in where the density difference is greatest. Most tearing occurs at the gray-white matter junction.

Diffuse Axonal Injury

https://radiopaedia.org/cases/normal-brain-ct

Diffuse Axonal Injury

https://radiopaedia.org/images/15747778

Rainer Scheid et al. AJNR Am J Neuroradiol 2003;24:1049-1056

©2003 by American Society of Neuroradiology
Diffuse Axonal Injury

- Can take 1-2 years for recovery

- Poor prognosis
  - GCS ≤ 8 in immediate post-injury period with DAI
  - 90% with severe DAI remain in vegetative state
  - Those who don’t, remain severe disabled
  - Small percentage return to near-normal
Pathophysiology Nuances in Peds

• Infants open sutures allowing for pop-off valve
• Diffuse swelling elevates ICP more than adults
• Neuronal development continues into 2^{nd} decade
• Autoregulation limited if less than 2 years
• Brain cells tend toward apoptosis
• Unintended effects of neuroactive medicine
Objectives

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• Discuss the pathophysiology of TBI

• Discuss diagnosis and treatment of TBI

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Diagnosis of TBI

• History
  – Usually limited and via EMS and/or witnesses
  – Appearance of the scene
  – Vitals, mental status, Glasgow Coma Scale (GCS)
  – Glucose level
  – Developmental considerations
  – Past medical history
  – Social history for drug/alcohol abuse
Diagnosis of TBI

• Physical Exam
  – Airway
  – Breathing
  – Circulation
  – Disability
  – Exposure
# Glasgow Coma Scale

<table>
<thead>
<tr>
<th></th>
<th>Adult</th>
<th>Pediatric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eyes</strong></td>
<td>Spontaneously: 4</td>
<td>Spontaneously: 4</td>
</tr>
<tr>
<td></td>
<td>To verbal: 3</td>
<td>To verbal: 3</td>
</tr>
<tr>
<td></td>
<td>To painful: 2</td>
<td>To painful: 2</td>
</tr>
<tr>
<td></td>
<td>None: 1</td>
<td>None: 1</td>
</tr>
<tr>
<td><strong>Verbal</strong></td>
<td>Oriented: 5</td>
<td>Coos/Cries: 5</td>
</tr>
<tr>
<td></td>
<td>Confused: 4</td>
<td>Irritable Cry: 4</td>
</tr>
<tr>
<td></td>
<td>Inappropriate: 3</td>
<td>Inconsolable: 3</td>
</tr>
<tr>
<td></td>
<td>Nonsense: 2</td>
<td>Grunts: 2</td>
</tr>
<tr>
<td></td>
<td>None: 1</td>
<td>None: 1</td>
</tr>
<tr>
<td><strong>Motor</strong></td>
<td>Obeys: 6</td>
<td>Spontaneous: 6</td>
</tr>
<tr>
<td></td>
<td>Localizes pain: 5</td>
<td>Withdraws to touch: 5</td>
</tr>
<tr>
<td></td>
<td>Withdraws: 4</td>
<td>Withdraws to pain: 4</td>
</tr>
<tr>
<td></td>
<td>Decorticate: 3</td>
<td>Decorticate: 3</td>
</tr>
<tr>
<td></td>
<td>Decerebrate: 2</td>
<td>Decerebrate: 2</td>
</tr>
<tr>
<td></td>
<td>None: 1</td>
<td>None: 1</td>
</tr>
</tbody>
</table>
Specific Exam Findings

• Basilar skull fractures
  – Periauricular ecchymosis (Battle sign)
  – Periorbital ecchymosis (Raccoon eyes)
  – Nasal CSF leakage or Hemotympanus

• Cushing’s triad
  – Hypertension
  – Bradycardia
  – Irregular respirations
# Herniation Syndromes

<table>
<thead>
<tr>
<th></th>
<th>Eye Findings</th>
<th>Gross Motor</th>
<th>Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncal</td>
<td>Unilateral fixed dilated pupil with unilateral ptosis</td>
<td>Hemiparesis</td>
<td></td>
</tr>
<tr>
<td>Diencephalic</td>
<td>Small midpoint pupils, but reactive to light</td>
<td>Decorticate posturing, hypertonia</td>
<td>Cheyne-Stokes</td>
</tr>
<tr>
<td>Midbrain</td>
<td>Midpoint fixed pupils</td>
<td>Decerebrate posturing</td>
<td>Hyperventilation</td>
</tr>
<tr>
<td>Medullary</td>
<td>Dilated and fixed pupils</td>
<td>No response to pain</td>
<td>Irregular or gasping</td>
</tr>
</tbody>
</table>

[Source](https://www.ebmedicine.net/topics.php?paction=showTopicSeg&topic_id=135&seg_id=2708)
<table>
<thead>
<tr>
<th>Image Modality</th>
<th>Positives</th>
<th>Negatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT scan</td>
<td>Fast, easy to obtain</td>
<td>Low contrast, can miss early injury</td>
</tr>
<tr>
<td>MRI Scan</td>
<td>Better resolution, non-hemorrhagic injury, following injury</td>
<td>Long, requires sedation, difficult to obtain</td>
</tr>
<tr>
<td>Cranial US</td>
<td>No radiation, easy to obtain</td>
<td>Low sensitivity and specificity</td>
</tr>
<tr>
<td>Transcranial Doppler</td>
<td>Cerebral blood flow and/or vasospasms</td>
<td>Technician and reader dependent</td>
</tr>
<tr>
<td>MR spectroscopy</td>
<td>Information on cellular metabolism</td>
<td>Expensive and difficult to interpret</td>
</tr>
</tbody>
</table>
Upcoming Imaging Techniques

- MR with diffusion tensor imaging (DTI)
- Blood oxygen level-dependent (BOLD) fMRI
- Perfusion imaging
- PET/SPECT
- Magnetoencephalography
Management

Monroe-Kellie Doctrine

- Brain
- CSF
- Blood
Management
Equations

- Serum Osmolality = $2\text{Na} + \frac{\text{Glu}}{18} + \frac{\text{BUN}}{2.8}$
- CPP = MAP – ICP (or CVP)
- Oxygen Content = $1.34 \times \text{Sat} \times \text{Hg} + (0.003 \times \text{PaO2})$
- Oxygen delivery = $\text{CO} \times \text{Oxygen content}$
- CO dependent on preload, afterload and contractility and heart rate
# Management

<table>
<thead>
<tr>
<th>Physiologic</th>
<th>Medical Management</th>
<th>Surgical Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevate HOB</td>
<td>Avoid Fever</td>
<td>EVD</td>
</tr>
<tr>
<td>Head Midline</td>
<td>Avoid hypotension</td>
<td>Decompressive Craniectomy</td>
</tr>
<tr>
<td>Ensure C-collar fits</td>
<td>Normal PaCO2 and PaO2</td>
<td></td>
</tr>
<tr>
<td>Quiet environment</td>
<td>Sedation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analgesia</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paralysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hyperosmolar therapy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Avoid hyperglycemia</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seizure treatment/prophylaxis</td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing CBF, PaO2, PaCO2, and MAP as functions of blood pressure.](image)

**Brain**

**CSF**

**Blood**
Special Considerations

- Ketamine
- Hypothermia
- Hyperosmolar therapy
- ICP monitoring
Ketamine

- The Ketamine Effect on ICP in TBI (Zeiler et al)

- 2014 Review article in Neurocritical Care

- 7 prospective articles: 4 randomized trials, 2 single arm, 1 case-control
Ketamine

- 4 continuous infusions of Ketamine
- 3 bolus dosing
- No increase in ICP and bolus dosing led to non-sustained decrease
- Oxford 2b, Grade C evidence against elevation in ICP
## Grading System

<table>
<thead>
<tr>
<th>Level</th>
<th>Type of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Systematic review with homogeneity of randomized control trials</td>
</tr>
<tr>
<td>1b</td>
<td>Individual randomized control trial with a narrow confidence interval</td>
</tr>
<tr>
<td>1c</td>
<td>All or none related outcome</td>
</tr>
<tr>
<td>2a</td>
<td>Systematic review with homogeneity of cohort studies</td>
</tr>
<tr>
<td>2b</td>
<td>Individual cohort study (including low-quality randomized control trials, e.g., &lt;80% follow-up)</td>
</tr>
<tr>
<td>2c</td>
<td>“Outcomes” Research: Ecological studies</td>
</tr>
<tr>
<td>3a</td>
<td>Systematic review with homogeneity of case–control studies</td>
</tr>
<tr>
<td>3b</td>
<td>Individual case–control study</td>
</tr>
<tr>
<td>4</td>
<td>Case-series (and poor-quality cohort and case–control studies)</td>
</tr>
<tr>
<td>5</td>
<td>Expert opinion without explicit critical appraisal, or based on physiology, bench research or “first principles”</td>
</tr>
</tbody>
</table>

### Grades of recommendation

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>Consistent level 1 studies</td>
</tr>
<tr>
<td>B</td>
<td>Consistent level 2 or 3 studies or extrapolations from level 1 studies</td>
</tr>
<tr>
<td>C</td>
<td>Level 4 studies or extrapolations from level 2 or 3 studies</td>
</tr>
<tr>
<td>D</td>
<td>Level 5 evidence or troublingly inconsistent or inconclusive studies of any level</td>
</tr>
</tbody>
</table>
Hypothermia

Comparison of hypothermia and normothermia after severe traumatic brain injury in children (Cool Kids): a phase 3, randomised controlled trial

P David Adelson, Stephen R Wisniewski, John Beca, S Danielle Brown, Michael Bell, J Paul Muizelaar, Pamela Okada, Sue R Beers, Goundappa K Balasubramani, Deborah Hirtz, for the Paediatric Traumatic Brain Injury Consortium
Cool Kids

• Multicenter, multinational, phase 3 randomized control trial

• Aim: Assessed hypothermia effect on mortality

• Population: < 18 y/o with severe TBI presenting within 6 hours of injury

• Goal: 340 patients
Figure 2: Outcomes at 3 months after injury
Outcomes in terms of Glasgow outcome scale (GOS; A) and GOS-extended paediatrics (GOS-E Peds; B). A GOS of 5 and a GOS-E Peds of 8 corresponds to mortality; a score of 1 corresponds to normal functioning for both measures. p values are for comparison between therapeutic hypothermia and normothermia.
# Cool Kids

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Hypothermia</th>
<th>Normothermia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Glasgow outcome scale</strong>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good outcome (scores 1–2)</td>
<td>44/76 (59%)</td>
<td>22/38 (58%)</td>
<td>22/38 (58%)</td>
</tr>
<tr>
<td>Poor outcome (scores 3–5)</td>
<td>32/76 (41%)</td>
<td>16/38 (42%)</td>
<td>16/38 (42%)</td>
</tr>
<tr>
<td><strong>Glasgow outcome scale-extended pediatrics†</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good outcome (scores 1–4)</td>
<td>38/75 (51%)</td>
<td>20/38 (53%)</td>
<td>18/37 (49%)</td>
</tr>
<tr>
<td>Poor outcome (scores 5–8)</td>
<td>37/75 (49%)</td>
<td>18/38 (47%)</td>
<td>19/37 (51%)</td>
</tr>
</tbody>
</table>

Data are number of patients (%). *Between-group difference (p value=0.90). †Between-group difference (p value=0.73). Despite random assignment, there were missing data for two patients: one patient was lost to follow-up at 3 months, and Glasgow outcome scale-extended pediatrics data were missing for one patient in the normothermia group.

*Table 3: Secondary outcomes at 3 months after injury*
Cool Kids

• Interim data analysis on 77 patients

• No difference in between-group mortality

• Trial stopped due to futility
Hyperosmolar Therapy

• Mannitol or hypertonic saline (HTS) in the setting of traumatic brain injury: What we have learned? (Boone et al)

• Surgical neurology International 2015

• Review article
Mannitol vs. HTS

- 7 articles: 5 randomized trials, 1 prospective nonrandomized, 1 retrospective cohort

- Conclusion: Both effective but heterogeneity with regard to efficaciousness
Mannitol

- Early effect is reduced viscosity
- Leads to osmotic diuresis
Hypertonic Saline

- 3% Normal Saline

- Increases serum osmolality

- Hemodynamically stable
Mannitol vs. HTS

• Hemodynamic effects
  – Mannitol can lead to hypotension
  – HTS low volume hemodynamic resuscitation
  – HTS leads to centrally mediated increased CO

• Immunomodulatory effects
  – HTS leads to brain cell immune modulation
  – May lead to anti-inflammatory effect
  – No effect with mannitol
Mannitol vs. HTS

• Neurochemical effect
  – HTS reduces excitatory amino acid accumulation
  – Increased extracellular Na restores action potential

• Vasoregulatory and microcirculatory effects
  – HTS increases capillary diameter and plasma volume increasing CBF
  – Reduces RBC size improving oxygen delivery
ICP Monitoring

Intracranial Pressure Monitoring in Children With Severe Traumatic Brain Injury: National Trauma Data Bank-Based Review of Outcomes

Fuad Alkhoury, MD; Tassos C. Kyriakides, PhD

Published online April 30, 2014.
ICP Monitoring in Children

• Retrospective cohort

• Aim: Evaluate change in practice patterns and outcomes with ICP monitoring

• Population: < 17 with TBI, injury severity score > 9, GCS < 9

• Primary outcome: Mortality
ICP Monitoring in Children

• Brain Trauma Foundation Guidelines ICP monitoring
  – Level II:
    • Salvageable patients with GCS 3-8 after resuscitation
      AND
    • Abnormal CT scan
  – Level II (2 of 3)
    • > 40 years
    • Unilateral or bilateral posturing
    • Low blood pressure
# ICP Monitoring in Children

## Table 2. Hospital Outcomes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
<th>No ICP Monitoring</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICP</td>
<td>Monitoring</td>
<td></td>
</tr>
<tr>
<td>Ventilator days</td>
<td>9.2 (8.5)</td>
<td>4.7 (16.7)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>ICU LOS</td>
<td>12.6 (10.3)</td>
<td>6.3 (8.7)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Hospital LOS</td>
<td>21.0 (19.5)</td>
<td>10.4 (14.9)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Hospital charges, $</td>
<td>49 000 (34 000)</td>
<td>34 000 (25 000)</td>
<td>.001</td>
</tr>
</tbody>
</table>

Abbreviations: ICP, intracranial pressure; ICU, intensive care unit; LOS, length of stay.
ICP Monitoring in Children

Table 4. Stepwise Logistic Regression Results for Mortality Outcome of ICP Monitoring vs No ICP Monitoring\(^a\)

<table>
<thead>
<tr>
<th>GCS Score</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.64 (0.43-1.00)</td>
</tr>
<tr>
<td>4</td>
<td>1.09 (0.75-1.60)</td>
</tr>
<tr>
<td>5</td>
<td>0.59 (0.22-1.56)</td>
</tr>
<tr>
<td>6</td>
<td>0.31 (0.78-1.00)</td>
</tr>
<tr>
<td>7</td>
<td>0.41 (0.16-1.06)</td>
</tr>
<tr>
<td>8</td>
<td>0.20 (0.05-1.73)</td>
</tr>
</tbody>
</table>

Abbreviations: GCS, Glasgow Coma Scale; ICP, intracranial pressure; OR, odds ratio.

\(^a\) All variables were entered into all models: ICP, sex, age category, Revised Trauma Score category, and Injury Severity Score category; ICP was the only one that remained.
ICP Monitoring in Children

• ICP monitoring is used infrequently

• Small survival advantage with GCS 3

• Lengthens stay, increased cost, more vent days
Objectives

• Discuss history of traumatic brain injury (TBI)

• Review the epidemiology of TBI

• Discuss the pathophysiology of TBI

• Discuss diagnosis and treatment of TBI

• Discuss ventilation in pediatrics
Pediatric Mechanical Ventilation

• Provide adequate ventilation and oxygenation

• Minimize barotrauma and volutrauma

• Optimize work of breathing

• Optimize patient comfort
Pediatric Mechanical Ventilation

• Non-invasive

• Invasive
Non-Invasive Ventilation

• Benefits
  – Reduces ventilator associated pneumonia
  – Reduces sedation and subsequent dependence
  – Improves family involvement

• Difficulty
  – Patient-ventilator interface in pediatrics
  – Skin breakdown
Invasive Ventilation

• Typical Modes
  – Pressure control
  – Volume control
  – Pressure regulated volume control or adaptive pressure ventilation
  – Pressure support
Pediatric Mechanical Ventilation

• Ventilation
  – Minute ventilation
  – Inspiratory time to expiratory time ratio

• Oxygenation
  – Mean airway pressure
  – PEEP
  – FiO2
Pediatric Mechanical Ventilation

- Compliance = change in volume / change in pressure
- Depends on which mode is set
- Must follow to minimize trauma
Pediatric Mechanical Ventilation

• Triggering
  – Ineffective
  – Auto
  – Double
  – Delayed

• Delayed Cycling

• Premature Cycling
Pediatric Mechanical Ventilation

• How to improve synchrony
  – Change modes or adjust settings
    • Proportional assist ventilation
    • Neurally adjusted ventilatory assist (NAVA)
  – Sedate
  – Paralyze
Central nervous system

Phrenic nerve

Diaphragm excitation

Diaphragm contraction

Chest wall and lung expansion

Airway pressure, flow and volume

Flow trigger

Ventilator Unit

Assisted Breath

Adapted from Sinderby, Nature Med 1999
Central nervous system

Phrenic nerve

Diaphragm excitation

Nasogastric tube

Diaphragm contraction

Ventilator Unit

Chest wall and lung expansion

Assisted Breath

Airway pressure, flow and volume

Adapted from Sinderby, Nature Med 1999
NAVA Benefits

• Improved synchrony

• Improved comfort

• Improved non-invasive support due to trigger mechanism
NAVA

Trigger Delay in milliseconds; $p=0.019^*$

Number of ineffective trigger events; $p=0.076$
NeuroSync Index

NIV PS: Trigger error p=0.039*, Cycle off error p=0.007*, Avg error p=0.02*

NIV NAVA: Trigger error p=0.039*, Cycle off error p=0.007*, Avg error p=0.02*
High Frequency Percussive Ventilation (HFPV)

- Volumetric Diffusive Ventilator (VDR)
  - Subtidal volumes with cycled, pressure control ventilation
  - Improves oxygenation
  - Improves ventilation
  - Lowers airway pressures
  - Improves secretion removal
  - Often used in regional burn centers
HFPV

- HFPV improves oxygenation and ventilation in pediatric patients with acute respiratory failure (Rizkalla et al)

- Observational study from CHOP

- Aim: Describe effectiveness and safety in noninhalational pediatric respiratory failure
HFPV

• Results:
  – Improved oxygenation index and PaO2/FiO2 (p<0.05)
  – No increase in mean airway pressure
  – Reduced PCO2 (p<0.01)
  – Reduced peak pressure (p<0.01)

• Conclusion
  – HFPV improves ventilation and oxygenation in a lung protective manner
High-Frequency Percussive Ventilation and Bronchoscopy During Extracorporeal Life Support in Children

Nadir Yehya,* Cheryl L. Dominick,† James T. Connelly,‡ Daniela H. Davis,* Peter C. Minneci,§ Katherine J. Deans,§ John J. McCloskey,* and Todd J. Kilbaugh*
HFPV and ECMO

• Prospective cohort with historic controls

• Aim: Compare outcomes with HFPV and bronchoscopies

• Population: Respiratory ECMO patients at CHOP

• Outcome: ECLS free days
### Table 2. Effects of HFPV on Clinical Outcomes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre-HFPV (n = 22)</th>
<th>HFPV (n = 14)</th>
<th>p Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days of HFPV</td>
<td>—</td>
<td>6 [5, 9]</td>
<td>—</td>
</tr>
<tr>
<td>Bronchoscopies per patient</td>
<td>1 [0, 2]</td>
<td>2 [1, 3]</td>
<td>0.019</td>
</tr>
<tr>
<td>Frequency of bronchoscopies (days on ECLS)</td>
<td>11.8 [5.5, 13.5]</td>
<td>6 [4.3, 8.4]</td>
<td>0.060</td>
</tr>
<tr>
<td>Frequency of bronchoscopies (days between bronchoscopies)</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Vasopressor score 24 hr post-ECLS</td>
<td>3.5 [0.5]</td>
<td>0 [0, 5]</td>
<td>0.428</td>
</tr>
<tr>
<td>Developed air leak on ECLS</td>
<td>7 (32%)</td>
<td>3 (21%)</td>
<td>0.706</td>
</tr>
<tr>
<td>ECLS-free days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 days</td>
<td>7 [0, 17]</td>
<td>19.5 [13, 22]</td>
<td>0.042</td>
</tr>
<tr>
<td>60 days</td>
<td>18.5 [0, 47]</td>
<td>49.5 [43, 52]</td>
<td>0.035</td>
</tr>
<tr>
<td>Ventilator-free days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 days</td>
<td>0 [0, 0]</td>
<td>0 [0, 5]</td>
<td>0.518</td>
</tr>
<tr>
<td>60 days</td>
<td>0 [0, 24]</td>
<td>21 [0, 35]</td>
<td>0.092</td>
</tr>
<tr>
<td>Days on ECLS (all patients)</td>
<td>13 [11, 19]</td>
<td>10.5 [8, 16]</td>
<td>0.389</td>
</tr>
<tr>
<td>Survival to decannulation</td>
<td>14 (64%)</td>
<td>12 (86%)</td>
<td>0.255</td>
</tr>
<tr>
<td>Days on ECLS</td>
<td>13 [11, 19] (n = 14)</td>
<td>9 [7, 14] (n = 12)</td>
<td>0.315</td>
</tr>
<tr>
<td>Survival to hospital discharge</td>
<td>11 (50%)</td>
<td>11 (79%)</td>
<td>0.160</td>
</tr>
</tbody>
</table>

*Continuous data are in the form of median [interquartile range], and categorical are in the form of n (%).
†Medians are compared using the Wilcoxon rank sum test, and categorical variables are compared using a Fisher’s exact test.
HFPV, high frequency percussive ventilation; ECLS, extracorporeal life support; —, not applicable.
HFPV and ECMO

- HFPV and bronchoscopies improved survival and days free of ECLS
- HFPV independently associated with ECLS-free days
Summary—TBI

- TBI continues to affect numerous pediatric patients each year.
- The pathophysiology affected by type of injury and subsequent biochemical response.
- The diagnostic strategies continue to evolve with increased technology.
- The management remains without clear, high grade evidence to support decisions.
Summary—Ventilation

- Achieving goals of ventilation is fraught with difficulties overcoming asynchronies.
- Newer modes are available but need specific ventilators.
- NIV ventilation is difficult in children due to interface issues.
- VDR is promising not only for burn patients but general respiratory failure as well.
Guidelines

- Management of Severe TBI Pediatrics in Pediatric Critical Care 2012
- Updated on the guidelines—information for Anesthesia in Paediatric Anesthesia 2012
Guidelines

- CPP 40-50 may be considered with potential age-specific thresholds (infants at lower end)

- HTS should be considered for increased ICP (dosing: Bolus 6.5-10 ml/kg, Continuous 0.1 to 1 ml/kg/hr, Serum osmolarity < 360)

- Avoid hypothermia. However, if was initiated, do not warm faster than 0.5°C
Guidelines

• Avoid severe hyperventilation (PaCO2 < 30)

• If need for refractory increased ICP, use neuromonitoring

• Don’t use steroids
Guidelines

• Thiopental may be considered for increased ICP

• Don’t use immune-modulating diet

• Prophylactic seizure management with phenytoin may be considered
Anesthesia Guidelines

- Use appropriate cervical spine precautions
- May perform chin lift and jaw thrust (if performed correctly)
- No nasal airway in facial fracture
- Gentle cricoid pressure
Anesthesia Guidelines

- **Etomidate**
  - Reduces ICP and improves CPP with stable MAP

- **Barbiturates**
  - Reduces ICP without affect CPP but may reduce MAP

- **Propofol**
  - Avoid due to Propofol infusion syndrome
Anesthesia Guidelines

• Ketamine
  – Mitigates increased ICP with procedures
  – Useful in refractory intracranial hypertension

• Fentanyl and Midazolam
  – Limited data but would avoid midazolam due to hypotension
Anesthesia Guidelines

• Succinylcholine
  – Hyperkalemia and arrest
  – Fasciculations increasing ICP
  – May be mitigating with risk of aspiration
Anesthesia Guidelines

• Hyperglycemia
  – Age < 4, GCS ≥ 8, and multiple lesions
  – Associated with poor outcome
  – Insufficient data to suggest glycemic control