Traumatic Brain and Cervical Spine Injuries in Children

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I have no disclosures.
• Gap: Pediatric trauma patients represent a unique population. Assessment and management of TBI and C-spine injuries among pediatric patients is often extrapolated from guidelines for adults. This can lead to such issues as over-utilization of advanced imaging or failure to initiate appropriate interventions promptly.

• Need: Education and/or review of the tenants of pediatric trauma care, specifically related to TBI and C-spine injuries.
Objectives

• Understand the basic biomechanics of head and c-spine injury in pediatric trauma patients and the resultant injury patterns.
• Describe the important factors in assessing children with suspected TBI and C-spine injury, particularly with respect to the utilization of advanced imaging
• Describe the most important factors in the initial treatment of TBI, including when intracranial hypertension is suspected.
• Identify when abusive head trauma or non-accidental trauma should be suspected
• Understand how and when a c-spine can be clinically cleared and what steps to taken when it cannot.
Expected Outcome

• Learner will understand when to use advanced imaging in assessment of TBI and C-spine injuries.
• Learner will gain improved awareness of risk factors for abusive head trauma or non-accidental trauma.
• Learner will be able to carry out appropriate initial management algorithms for traumatic brain injury and intracranial hypertension.
• Learner will understand the tenants for cervical spine immobilization and clearance.
Part 1.

Traumatic Brain Injuries
Traumatic Brain Injury (TBI) is leading cause of morbidity and mortality in pediatric patients.

While many consider TBI outcomes as better in children than adults, TBIs in those <4yo result in worse long term prognosis.
Predisposition of children to TBI

- Large size of head in relation to rest of body
- Weaker neck muscles
- Incomplete myelinization – increased susceptibility to TBI in unmyelinated regions
Scenario #1

- Infant arrives in ED after MVC in which restraint status is unknown
- Airway appears to be intact, as he is crying
- Bilateral breath sounds
- Mildly tachycardic, good peripheral perfusion
- Small bruise to forehead, eyes are open
- Inconsolably crying but spontaneously moving

What is this infant’s GCS?
**Pediatric GCS**

### Pediatric Glasgow Coma Scale (PGCS)

<table>
<thead>
<tr>
<th>Section</th>
<th>&gt; 1 Year</th>
<th>&lt; 1 Year</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eye Opening</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spontaneously</td>
<td>Spontaneously</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>To verbal command</td>
<td>To shout</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>To pain</td>
<td>To pain</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>No response</td>
<td>No response</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Motor Response</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obeys</td>
<td>Spontaneous</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Localizes pain</td>
<td>Localizes pain</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Flexion-withdrawal</td>
<td>Flexion-withdrawal</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Flexion-abnormal (decorticate rigidity)</td>
<td>Flexion-abnormal (decorticate rigidity)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Extension (decerebrate rigidity)</td>
<td>Extension (decerebrate rigidity)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>No response</td>
<td>No response</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Verbal Response</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oriented</td>
<td>Appropriate words/phrases</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Disoriented/confused</td>
<td>Inappropriate words</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Inappropriate words</td>
<td>Persistent cries and screams</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Incomprehensible sounds</td>
<td>Grunts</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>No response</td>
<td>No response</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL PEDIATRIC GLASGOW COMA SCORE (3-15):**

Our Patient:
- Eye: 4
- Verbal: 3
- Motor: 6
- GCS: 13

**Differences from adults**
Scenario #1

- Infant arrives in ED after MVC in which restraint status is unknown
- Airway appears to be intact, as he is crying
- Bilateral breath sounds
- Mildly tachycardic, good peripheral perfusion
- Small bruise to forehead, eyes are open
- Moving spontaneously
- Crying but consolable

Should you get a CT scan?
Imaging in TBI

- Multiple “rules” have been devised to guide imaging decisions
  - PECARN (2 rules: <2yr and 2-18yr)
  - CATCH (< 17 yr)
  - CHALICE (<16 yr)
- Rules are aimed to identify CLINICALLY SIGNIFICANT TBI (defined differently in each study)
  - PECARN – death, neurosurgical intervention, intubation >24 hours or admission 2+ nights for TBI
  - CATCH – death, neurosurgical intervention or intubation from TBI within 7 days
  - CHALICE – death or neurosurgical intervention for TBI, or marked HCT abnormality
- On several validation studies, all perform well
- PECARN has highest sensitivity but tends to have lower specificity
## PECARN Rule

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Risk cTBI</th>
<th>Rec</th>
<th>Predictor</th>
<th>Risk cTBI</th>
<th>Rec</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2 years old</td>
<td></td>
<td></td>
<td>2-18 years old</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCS $\leq$ 14</td>
<td>4.4%</td>
<td>Non-contrast HCT</td>
<td>GCS $\leq$ 14</td>
<td>4.3%</td>
<td>Non-contrast HCT</td>
</tr>
<tr>
<td>AMS</td>
<td></td>
<td></td>
<td>AMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palpable Skull fracture</td>
<td></td>
<td></td>
<td>Signs of basilar skull fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-frontal Scalp Hematoma</td>
<td>0.9%</td>
<td>Consider non-contrast HCT</td>
<td>History of vomiting</td>
<td>0.9%</td>
<td>Consider non-contrast HCT</td>
</tr>
<tr>
<td>Severe mechanism</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Pedestrian/cyclist without helmet struck by car</td>
<td></td>
<td></td>
<td>• Pedestrian/cyclist without helmet struck by car</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Fall $&gt;1m$ or $3ft$</td>
<td></td>
<td></td>
<td>• Fall $&gt;2m$ or $5ft$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Head struck by high impact object</td>
<td></td>
<td></td>
<td>• Head struck by high impact object</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOC $\geq$ 5 sec</td>
<td></td>
<td></td>
<td>LOC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abnormal behavior per parents</td>
<td></td>
<td></td>
<td>Severe headache</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None of above</td>
<td>&lt;0.02%</td>
<td>No HCT</td>
<td>None of above</td>
<td>&lt;0.05%</td>
<td>No HCT</td>
</tr>
</tbody>
</table>

- **LOC**: Loss of Consciousness
- **AMS**: Acute Neuropsychiatric Symptoms

- None of above <0.02% No HCT
## CHALICE Predictors of Clinically Significant Head Injury

### History
- Witnessed LOC > 5 min
- History of Amnesia > 5 min duration
- Abnormal drowsiness
- ≥ 3 vomits after head injury
- Suspicion of non-accidental injury
- Seizure after head injury in a patient with no history of epilepsy

### Exam
- GCS < 14 or GCS < 15 in a patient under 1 year of age
- Suspicion for penetrating or depressed skull injury or tense fontanelle
- Signs of Basal skull fracture
- Presence of a bruise, swelling, or laceration > 5 cm if <1 year old

### Mechanism
- High speed accident (> 40 mph) as either a pedestrian, cyclist, or occupant
- Fall > 3 m
- High speed injury from projectile or object

- <16yr
- HCT if any of these are present
- 98% sensitivity to detect death or neurosurgical intervention for TBI, or marked HCT abnormality
CATCH

CATCH Predictors for Clinically Significant TBI

- GCS Less than 15 at 2 hours post trauma
- Suspected open or depressed skull fracture
- History of worsening headache
- Irritability on exam

- Any Sign of Basal Skull Fracture
- Large, boggy scalp hematoma
- Dangerous mechanism of injury defined as MVC, fall from > 3 ft or 5 stairs, fall from bicycle with no helmet

1+ present → 100% sensitivity for neuro intervention

1+ present → 98% sensitivity for presence of brain injury on CT scan

<17 years old
Scenario #1

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- Airway appears to be intact, as he is crying
- Bilateral breath sounds
- Mildly tachycardic, good peripheral perfusion
- Small bruise to forehead, eyes are open
- Moving spontaneously
- Crying but consolable

GCS 13, <1yo ➔ GET A SCAN
Linear fractures
- Parietal > occipital > frontal > temporal

- Imaging
  - Distinguish from suture lines by anatomic configuration, presence of complex serrations
  - Associated extracranial subcutaneous swelling

- In those <2yr, concurrent intracranial injury in 15-30%

- Time necessary for epidural hematoma to present on CT scan = 4-6hrs

- Consider non-accidental trauma, particularly in those <2yo
CT Scan Findings: Fractures (cont)

- Depressed
  - Increased risk of dural tear and cortical laceration

- Diastatic
  - Fracture line transverses one or more sutures, causing a widening of the suture

- Basilar skull fracture
  - Rare in children
  - Independent predictor of mortality

HealthCare
KENTUCKY CHILDREN'S HOSPITAL
<table>
<thead>
<tr>
<th>Types of Intracranial Injury</th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Focal</strong></td>
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<tr>
<td><img src="image1.png" alt="Image" /></td>
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<tr>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Non-Focal</strong></td>
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<tr>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
<tr>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
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</tbody>
</table>
Epidural Hematoma (EDH)

- Relatively uncommon in young infants b/c dura mater is strongly adherent to inner surface of skull,
- When does occur in infants, is usually d/t injuries over the dural venous sinus
- In older children, usually d/t meningeal artery tear; less likely to have lucid interval than adults
Types of Intracranial Injury

Focal

Non- Focal
Subdural Hematoma (SDH)

- More common than EDH
- Wider subdural space – bridging veins susceptible to traction and rupture
- Higher rate of underlying brain contusion than EDH → worse prognosis
- Very commonly seen in abusive head trauma (AHT) in those <2yo
Types of Intracranial Injury

Focal

Non-Focal
Subarachnoid Hemorrhage (SAH)

- Commonly associated with severe TBI in children
- **Vasospasm** common sequelae
- Blood can flow back into ventricular system → May often lead to hydrocephalus and need for shunt
Types of Intracranial Injury

Focal

Non- Focal
Intraventricular Hemorrhage

• Often caused by rupture of intracerebral hematomas located next to ventricles or SAH flowing back into ventricular system
• Associated with post-traumatic hydrocephalus
Types of Intracranial Injury

Focal

Non- Focal
Cerebral Contusions

- Relatively common in pediatric TBI
- Usually seen in gray matter just below site of impact
- Often quickly leads to swelling, hypoxia and increase in focal cerebral pressures in limited middle or posterior fossa
Types of Intracranial Injury

Focal

Non-Focal
Cerebral Edema

- Develops more readily in children because of relative lack of CSF available for displacement.
- Children have under-developed auto-regulatory mechanism for cerebral blood flow so are particularly vulnerable to intracranial hypertension.
Types of Intracranial Injury

Focal

Non-Focal
Diffuse Axonal Injury

- Due to shearing forces with rotational acceleration-deceleration injuries
- Secondary injury happens over hours-days due to biochemical cascades that directly injure axons
- Unmyelinated white matter in developing pediatric brains are particularly vulnerable
- Often difficult to see on CT scan, MRI more accurate
- MC seen with MVC and abusive head trauma (AHT)
Types of Intracranial Injury

Focal

Non-Focal
• Mild TBI without intraparenchymal injury

• Symptoms often non-specific
  • Difficulty concentrating or remembering new information
  • Headaches, blurry vision, nausea, light and sound sensitivity, balance issues
  • Irritability, sadness, emotional lability, anxiousness
  • Increased or decreased sleep

• Treatment: Supportive care
Scenario #1 (Cont)

- Child becomes non-responsive and requires intubation…
- VS: T:38 C, SBP 70, HR 120, O2: 90% (after intubation)

- Any Interventions?
- What labs should you check?
- Repeat Imaging?
TBI Management

• Mainstay of initial management is prevention of secondary injury
  • Maintain oxygenation (O2 sat > 93%)
  • Maintain normal blood pressure (SBP > 75th % for age)
  • Na > 135
  • Glucose 100-180
  • Maintain core body temp 36-37 C°
  • Evaluate and correct coagulopathy
  • If intubated: pCO2 ~ 35mmHg
  • Treatment and prevention of seizures

• Repeat imaging indicated for neurologic decline

<table>
<thead>
<tr>
<th>Age</th>
<th>Systolic BP in mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Term Neonates (0-28 days)</td>
<td>&lt;60</td>
</tr>
<tr>
<td>Infants (1-12 months)</td>
<td>&lt;70</td>
</tr>
<tr>
<td>Children 1-10 years</td>
<td>&lt; 70 + (age in years x 2)</td>
</tr>
<tr>
<td>Children &gt;10 years</td>
<td>&lt;90</td>
</tr>
</tbody>
</table>
• Children (especially infants) have lower seizure threshold
• Recommend immediate prophylactic administration when severe TBI, particularly
  • <2yo
  • History of AHT
  • GCS <= 8
  • Hypotension
• Little evidence regarding appropriate anticonvulsant
You increase FiO2 and PEEP, administer Tylenol and place cooling blanket
  • O2 sat improves to 98%, temp comes down to 37 C

You check labs
  • Glucose: 120, Na: 136, pCO2:40, INR: 1.0

You note he is no longer breathing over the set respiratory rate.
• His HR begins to intermittently drop and his BP is high.
Elevated Intracranial Pressure

• Signs of Elevated ICP
  • Bradycardia
  • Hypoventilation, Apnea
  • Hypertension
  • Bulging fontanelles
  • Headache
  • Confusion, lethargy

Cushings Triad

• Hypertension
• Bradycardia
• Hypoventilation, apnea

IMPENDING HERNIATION
Elevated ICP: Treatment

• Elevate Head of Bed
• Ensure C-collar not too tight
• Sedate and paralyze
  • Combination of opioids and benzodiazepines
  • Neuromuscular blockade – improves compliance with mechanical ventilation, reduces metabolic demand, eliminates shivering
• **Hypertonic Saline** 3-5 mL per kg (goal Na 150-170)
  • Mannitol can cause intravascular depletion and electrolyte abnormalities
• pCO2~30-35
  • pCO2 <30 → too much vasoconstriction → decreased perfusion
• Continue to maintain SBP, O2 sats, temperature, glucose
Scenario #2

- 6 month old male brought to ED by mother due to seizures.
- On evaluation, he is unresponsive and apneic.
- She reports that she thinks he may have rolled off the bed earlier today.
- You intubate him and obtain a CT scan, which reveals a small SDH.
Abusive Head Trauma

• Most common cause of TBI in children <2yo
• Consider carefully in young children in whom mechanism is unclear
• HCT Findings
  • 77-89% have SDH
  • SAH, ICH and contusions also common
• Associated findings
  • Rib fractures & retinal hemorrhage – highest independent predictors of AHT
  • Apnea, seizures, head & neck bruising and long bone fractures also increase likelihood of AHT
Additional Note on Non-Accidental Trauma

Concerning Bruises for Abuse
“TEN 4”

T = Torso
E = Ears
N = Neck
4 = In children <4 yrs. and
Any Bruise in infant <4 mos.

• If concern for abuse, likely need evaluation at pediatric trauma center
Part 2.
Cervical Spine Injuries
Biomechanics of CSI

- Relatively large head compared to neck → angular momentum forces to neck are greater
- Ligaments and joint capsules more flexible
- More likely to have ligamentous injuries and cord injuries without bony fractures
CSI Injury Patterns by age

- Fulcrum of spine changes with age and affects location of injuries
  - <14yo → more likely to have C1-C4 injury
  - >14yo → more likely to have C5-C7 injury

- Skeletal maturity and cord mobility alter types of CSI
  - <10yo → more likely to have dislocations and cord injury without fractures
  - >10yo → more likely to have fractures

- Note: C-spine injury should raise suspicion for blunt cerebrovascular trauma
Scenario #3

- EMS arrives to assess a 2yo who flipped over the handlebars of his bike.
- He reports LOC and is somewhat confused (GCS 14).
- His airway is intact and he is HDS.
- He has bruising to his abdomen and complains of abdominal pain

Does he need a C-collar placed?
Indications for C-spine immobilization

- Must have HIGH index of suspicion for CSI
- When in doubt, should immobilize

**High risk mechanisms**
- Pedestrian or cyclist hit by vehicle >30mph
- MVC passenger >60mph or with ejection
- Fall >3meters
- Kicked by or fall from horse
- Thrown over handlebars of bike
- Being backed over by car

**Concerning symptoms**
- Neck pain
- Neurologic deficits
- Neck TTP
- Acute torticollis
- Unexplained hypotension or bradycardia
How to Immobilize

- Fitting rigid C-collar (or sandbags) and fixation to spinal board
- D/T large head, fixation to spinal board can cause head to flex
- To keep C-spine in neutral position, place padding under torso or place occiput through recess in board
- Off backboard within 2 hours to prevent pressure ulcers
Types of C-collars

- Extraction collars
  - Used by EMS for ease of use and low cost
  - Not intended for longer term use
  - Quickly lead to skin breakdown

- Longer term collars
  - If cannot clear c-collar prior to transfer to another hospital or admission, change to more properly fitted and padded collar
6 Year Old male brought to your ED from the scene after an MVC.
He was appropriately restrained with no loss of consciousness.
His ABCs are intact.
His GCS if 15 and he is cooperative.
His neurologic exam is intact. He denies neck pain and has no tenderness to palpation. He has no other obvious injuries.
NEXUS Criteria used to removal C-collars in adults without imaging:
1. No neurologic defect
2. No cervical spine tenderness to palpation
3. No intoxication
4. No altered mental status
5. No distracting injuries

Canadian Cervical Spine Rules corroborated and began applying this to cooperative children.
Scenario #5

- 2yo after presents to ED after MVC.
- His airway is intact and he is HDS.
- GCS is 13.

Can you clear his C-Spine clinically?
Clinical Clearance of the Cervical Spine in Blunt Trauma Patients Younger Than 3 Years: A Multi-Center Study of the AAST
J Trauma. 2009;67: 543–550

- Neck pain or splinting
- Facial fractures
- Skull fracture
- Loss of consciousness
- Long Bone Fracture

Weighted Score
GCS < 14 = 3
GCS_{EYE} = 1 = 2
MVC = 2
Age > 2yr = 1

0-1: No imaging
2-4: Imaging at discretion of physician
5-8: Imaging Recommended

A score of <2 had a negative predictive value of 99.93% in ruling out CSI.
A total of 8,707 patients (69.5% of all patients) had a score of <2 and were eligible for cervical spine clearance without imaging.
There were no missed CSI in this study.
Cervical Spine Imaging: Proposed Algorithm

- Cincinnati Children’s C-Spine Clearance Algorithm
- Assess ability to clear with NEXUS or CCS
- If cannot clear, follow algorithm
- Note: CT scan nowhere on algorithm
Cervical Spine Imaging Options

- Plain Films – AP, lateral, odontoid
- CT scan – Sensitive for fractures but less so for ligamentous and cord injury
- MRI – More sensitive for cord and ligamentous injury

Note: If fracture seen at one vertebral level, entire spine should be imaged
  - 10-16% chance of injuries at other vertebral levels

Because children more likely to have ligamentous injuries, CT scan often does not answer the question and thus exposes child to unnecessary radiation.
Cincinnati Children’s C-Spine Clearance Algorithm

- If cannot clear clinically, NO CT SCAN…. Plain films instead
  - If plain films abnormal, go straight to neurosurgical consult.
  - If plain films normal, you can admit and repeat exam the next day. Often pain will resolve and you can clear clinically at that time.
Imaging: Normal Pediatric Variants

- Pseudo-subluxation of C2 on C3
- Absence of cervical lordosis
- Ossification centers can appear like fractures
- Anterior wedging of vertebral bodies can be a developmental finding
Spinal cord injury without radiographic abnormality

- Laxity of ligaments and cord mobility allow stretching with return to alignment without fracture but with underlying spinal cord damage
- MRI is more sensitive for cord injuries so incidence of SCIWORA is decreased
  - Still possible to have normal MRI with neurologic defects attributed to SCI
Scenario #6

- 3 yo presents to ED after MVC.
- He is obtunded and requires intubation.
- His HR and BP begin to drop precipitously and does not respond to volume. MTP begun but pressures remain low.
- CXR, PXR and FAST are normal.
- He is not stable enough to move to CT scanner.

Lateral C-spine film in trauma bay can add information
## Neurogenic vs Spinal Shock

<table>
<thead>
<tr>
<th>Neurogenic Shock</th>
<th>Spinal Shock</th>
</tr>
</thead>
<tbody>
<tr>
<td>• High injuries (T6 and above)</td>
<td>• Loss of sensation and motor function, loss of reflexes</td>
</tr>
<tr>
<td>• Hypotension + Bradycardia</td>
<td>• If cremasteric and cavernous bulbous reflexes return, no longer spinal shock → permanent defects</td>
</tr>
<tr>
<td>• Due to loss of sympathetic tone</td>
<td></td>
</tr>
<tr>
<td>• Treatment: Volume first, then vasopressors and inotropes</td>
<td></td>
</tr>
<tr>
<td>• Phenylephrine often used but there is no single recommended agent</td>
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</table>
Take Away Points

• TBI is leading cause of morbidity and in pediatric patients and patterns of injury differ from that of adults
• PECARN is helpful to guide imaging decisions, with the lowest risk of missed injury.
• Have a high index of suspicion for AHT in children <2yo with associated rib fractures or retinal hemorrhages.
• C-spine injuries are relatively uncommon in pediatric population but one should maintain high index of suspicion
• NEXUS and CCS rules can assist in clearing collars without imaging
• When imaging is needed, start with plain films. CT scans have limited utility.
Questions?