Head Injury Management in the Pediatric Population

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Epidemiology
- Most common cause of head injury classified by age
  - Neonates and infants:
    - non-accidental trauma and MVA
  - Children:
    - MVA and falls
  - Adolescents:
    - MVA, sports related accidents
  - Teens:
    - MVA, sports and penetrating trauma

Types of injury
- Scalp Lacerations and Skull Fractures
- Diffuse Axonal injury
- Subarachnoid hemorrhage
- Epidural hematoma
- Subdural hematoma
- Intraparenchymal hemorrhage

Scalp Lacerations
- General Management
  - Hemostasis
  - Examination
  - Debridment
  - Skin closure
  - Antibiotics
  - Tetanus Prophylaxis

Scalp Nerve and Blood Supply
- Anterior portion of scalp and forehead supplied by supraorbital and suprafrontal nerves-terminal branches of the opthalmic division of the trigeminal nerve.
- Posterior portion supplied by the greater and lesser occipital nerves-from dorsal rami of C2-C4.
- 20%of cardiac output supplied to scalp
- Can lead to rapid potentially fatal blood loss
- Most vessels originate from external carotid system

Skull Fractures
- Incidence
  - 40-60% of head injured children
- 3 types
  - Linear-most common: approx 73%
  - Depressed fractures: approx 7-10%
  - Basilar skull fractures: approx 14%
Skull Fractures
- Linear fractures
  - Most common
  - In infants heal in 1-2 months
  - Rare: growing fracture/leptomeningeal cyst
    - 0.05-1%
    - Mechanism felt to be due to dural tear and CSF pulsations
    - Surgical correction
  - Repeat skull films 1-2 months after injury

Skull Fractures
- Depressed Skull Fractures
  - Mechanisms
    - Fall 40%
    - Traffic accidents 22%
    - Birth injury 16%
    - Others 22%: golf clubs, baseball bats, lawn darts, shot put.
Skull Fractures
- Basilar skull fractures
  - Many are linear
  - May be associated with dural tear and CSF leak
  - Most frequent site is petrous temporal bone: 80-90%; Facial nerve injury in 15% of cases; more likely in a transverse fracture.

Skull Fractures
- Battle’s sign: ecchymosis over the mastoid
- Raccoon sign: periorbital ecchymosis
- CSF otorrhea, rhinorhea

Closed Head Injury
- 200 per 100,000 for children <15yrs old
- 340 per 100,000 for adolescents/young adults

Closed Head Injury
- Diffuse Injury I
  - No visible pathology seen on CT (patient in coma)
- Diffuse Injury II
  - Cisterns present, midline shift less than 5mm, with or without parenchymal hemorrhage less than 25ml
Closed Head Injury

• Diffuse Injury III
  – Swelling, cisterns compressed or absent, midline shift less than 5mm, with or without parenchymal hemorrhage less than 25ml

• Diffuse Injury IV
  – Shift, midline shift > 5mm, with or without parenchymal hemorrhage less than 25ml

Closed Head Injury

• Primary Injury
  – Immediate, irreversible effects
  – Neuronal and glial disruption
  – Vascular injuries
  – Shear injury
  – Dependent on the mechanism and the amount of energy transferred

Closed Head Injury

• Secondary Injury
  – External factors: hypoxia, hypotension
  – Metabolic alterations
  – Fluid/electrolyte imbalances
  – Cellular level: toxic biochemical reactions

Diffuse Axonal Injury

Normal T2 MRI

T1 MRI with DAI

Subarachnoid Hemorrhage

Closed Head Injury

• Treatment Goals
  – Prevention of brain ischemia
  – Control intracranial pressure
  – Provide physiologic substances for cellular energy/maintenance (glucose, oxygen)
  – Prevent secondary complications: infections, metabolic disruptions
**Parameters to compare**

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<thead>
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<th></th>
<th>Child</th>
<th>Adult</th>
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<tbody>
<tr>
<td>ICP</td>
<td>&lt;40mmHg</td>
<td>&lt;20mmHg</td>
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<td>(?) 10?15?</td>
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<td>CPP</td>
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<td>GCS</td>
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**Definitions**

- ICP = intracranial pressure
- CPP = cerebral perfusion = MAP - ICP
- CBF = cerebral blood flow
- CBV = cerebral blood volume

**Closed Head Injury**

- ICP
  - Intracranial compartment is fixed volume.
  - 3 incompressible constituents:
    - blood
    - cerebrospinal fluids (CSF)
    - brain parenchyma

**ICP issues**

- ICP in adults: no prospective study was done, but poor outcome is associated with ICP > 20mmHg.
- ICP in children: 20-60mmHg with good outcome
- General lack of data to monitor ICP in children
- Treatment protocols
  - Infants > 15mmHg
  - Young children > 17-18mmHg
  - Others treat > 20mmHg

**ICP control and pathway**

ICP > 20mmHg for 10 minutes or greater without stimulation. Pain controlled. Keep euvolemic.

Drain CSF to get ICP less than 20mmHg. No research has shown that it needs to be 10, 11, 12, 13mmHg. Just < 20mmHg!!!

Don't leave ventriculostomy open to drain. It may lead to drain clogging. It gives a feeling that we are doing something despite an elevated pressure.
ICP control and pathway

Mannitol 0.5-1gm/kg IV pm ICP >20mmHg not responding to drainage or pain medication. Maintain serum osm <320
Isotonic 3% NS. Maintain serum osm <360.
• Hypotension increases mortality by four-fold in children after head injury.
• Their response to diuretics shows a significant decrease in cardiac index 10 minutes after administration.
• Dehydration from mannitol can precipitate renal failure

Attempt to keep PCO2 35+2 mmHg.
Literature suggests anything from 30-35mmHg and it is based on the SjVO2 monitoring.
• In adults: 31-32mmHg is consistent with an adequate SjVO2, ADO2 and xenon cerebral blood flow. Adult trauma NS use 35 ± 2 mmHg for protection.
• 26-27mmHg: jugular desats, decreased CSF and widen AVDO2.

Closed Head Injury

• CPP is the mean arterial pressure (MAP) minus the intracranial pressure (ICP).
  • CPP is increased or decreased within this range by changes in vascular tone.
  • This restores CBF to resting levels.
  • This is called auto regulation.

CPP issues

• No clear agreement, but a past study showed that children with CPP <40mmHg died and suggest a threshold of 45 mmHg.
• Others suggest 40-50mmHg in infants and toddlers and 50-60mmHg in children
• In adult literature dopamine or phenylephrine can be used

CBF

• Fiction: children have a hyperemic stage
• Fact: Data on children was compared to mean CBF in adults which is 50ml/100g/min.
• Fact: CBF varies at different ages. Children have their lowest CBF at birth which is 40ml/100g/min. It peaks at 3-5yrs (108ml/100g/min) and remains high until 9 years (71ml/100g/min). CBF returns to adult levels by the age of 19 years

Closed Head Injury

• Hypotension is the most deadly insult.
• In patients with TBI, one episode of hypotension has been reported to increase mortality from 27-50%.
• Remember ABC's
Closed Head Injury

Perfuse it... Lose it...

Hematomas
- Neonates
  - Posterior Fossa hemorrhage
  - Supratentorial
- Infant
  - Acute Subdural Hematoma
  - Chronic Subdural Hematoma

Hematomas
- Toddler/Child
  - Epidural hematoma
- Adolescent
  - Intraparenchymal hematoma
  - Acute subdural hematoma
  - Epidural hematoma

Epidural hematoma
Subdural Hematoma

Hematomas
Hematomas

Nonaccidental Injury
- Est. 15 per 1000 children per year
- Approx 1000 deaths per year
- Usually brought to ER for lethargy, irritability, to apnea/unresponsiveness
- "the baby was found in the crib breathing funny."

Nonaccidental Injury
- Seizure activity may be seen in 40-70% of children
- Skeletal fractures seen in 30-70%
- Retinal hemorrhages seen in 65-95%
  - Seen in 40% of newborns after vaginal delivery, but resolve after 1 month.

Nonaccidental Injury
- Work up
  - Child abuse team
  - Social Work
  - Skeletal survey
  - Ophthalmology
  - Neurosurgery
  - CT/MRI

Nonaccidental Injury

Decrease body temp to 36 degrees.
- Literature suggests anything from 30-36 degrees. In adults, current hypothermia study in children is evaluating 32 degrees for 24 and 48 hrs. No increase signs of DIC, infectious problems, cardiac arrhythmias or deaths.
- Mechanisms: Decreases cerebral edema in rats after MCA stroke model, abolishes glutamate release in cerebral microdialysis, improves integrity of BBB, decreases inflammatory response cells.
Conclusions for ICP, CBF, CBV

- Absolutely no data that correlates ICP to CBF or CBV.
- No definite hyperemic CBF phase in children.
- No rights or wrongs!!!
- Need more data!!!

CBF

- Adelson 1997: Evaluated CBF in 23 severely head injured children. Values are not different from the normal ranges in children, but hyperemic when compared to adults. There was an increase in the CBF measurements from initial measurements. Which is the normal value for that patient?
- Sharples 1995: 21 injured children (ages 2-16yrs). Only 6% of the CBF done showed hyperemia when compared to normal child values

CBF/CBV

- Fiction: Children have diffuse brain swelling from vascular engorgement
- Fact: Absolutely no well organized study documents this. In fact, most studies are now refuting this. MRI may or may not be showing vasogenic edema.

CBV

  - Compared the Housfield units in 12 of these patients during acute swelling and when it resolved. The increase in these units were increased suggestive of "vascular engorgement rather than edema". However, when comparing the Housfield units to control, they were not different.

Poiseuille equation

- \[ \text{CBF} = \frac{k(CPP \times d^4)}{8 \times L \times V} \]
- Using calculation done by Muizelaar and Maramarou concerning ICP and PVI differences:
  - if ICP increased from 5 to 10 to 15 mmHg the CBF and CBV would have to increase by 250% and 150%, respectively (which is unheard of).
*Traumatic Brain Injury
2013

*Adapted from Cincinnati Children's Hospital Major Head Injury 2004

GCS < 8
No neurologic improvement post resuscitation

Surgery as indicated

Treat ICP sustained >10min
1. 0-12 mo: >10 mmHg
2. 1-12 yrs: >10 mmHg
3. Adol: >15 mmHg

Age Appropriate CPP:
1. 0-1mo: >40 mmHg
2. 2mo-1yr: >45 mmHg
3. 2-8yrs: >50 mmHg
4. >7yrs: >60 mmHg

General Measures to Optimize CPP
1. Maintain normal body temperature (36.5-37.5°C)
2. Reverse Trendelenburg: HOB elevated 30°
3. Head midline; avoid jugular venous outflow obstruction
4. Adequate sedation
5. Keep PaCO2 about 35-45torr
6. Adequate MAP + isotropic support
7. Seizure prophylaxis
8. Neuromuscular blockade, if needed
9. Suction: Use lidocaine - 1 mg/kg IV 3 minutes before suctioning

Insertion ICP Monitor and/or Ventricular Drainage

ICP elevated

Consider enteral feedings

Consider weaning ICP treatments

Isotonic to 3% saline bolus (4 mL/kg)
Maintain serum osmolality ≤360 and serum NA 145-155

Mannitol 0.25 to 1 g/kg as needed to optimize CPP
Maintain osmolality ≤320

Add 3% saline infusion
(0.1 - 2 mL/kg/hr) titrate q30min by 0.1 mL/kg/hr to optimize ICP and CPP
Maintain serum osmolality ≤360 and serum NA 145-155
Stop mannitol if ICP still > 20 and osmolality > 320

Moderate hyperventilation
PaCO2 30 – 35 torr

Pentobarbital therapy
Load 10 mg/kg over 30min
Initial Infusion rate: 1 mg/kg/hr
Continuous EEG titrate to burst suppression

MD discussion for ICP refractory to treatment
Consider:
- Hypothermia (33-34 °C)
- Surgical decompression
- Hypertensive therapy

Age Appropriate SBP
1. Term neo >60 mm Hg
2. 1-12 mo >70 mm Hg
3. 1-10 yrs >70 mm Hg + (2xage in yrs)
4. >10 yrs >80 mm Hg

Age Appropriate MAP
1. 0-12 mo: 35-60 mmHg
2. 1-10 yrs: 50-65 mmHg
3. >12yrs: 60 mmHg