Pediatric Head Injury:  
Part I – Basic Principles

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Introduction

- Second most common neoplasm
- Most common solid malignancy
- Derive from intrinsic/parenchymal elements of CNS
- Majority are in midline
- Classify by site or histology
Introduction

- Trauma leading cause of death in children.
- More deaths than all other diseases combined!
- Often occurs after-hours, requires intense and immediate interventions.
Introduction

- 500,000 admissions per year
- 3000 - 4000 deaths per year
- 20,000 prolonged hospitalization
- Decreased M/M in recent decades.
- Better understanding of pathophysiology
**Introduction**

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Introduction

*Fatalities are Just the Tip of the Iceberg...*

- Deaths
- Hospitalized
- Require medical care

For each death, 19 persons are hospitalized and 300 have injuries requiring medical care.
Algorithm

Derivation of the children’s head injury algorithm for the prediction of important clinical events decision rule for head injury in children

Dunning J, Daly JP, Lomas J-P, et al on behalf of the children’s head injury algorithm for the prediction of important clinical events (CHALICE) study group

Sensitivity 98%. Scan rate 14%

Arch Dis Child 2006; 91:885-891
Etiology

- Falls < 10 y.o.
- MVA > 10 y.o.
- NAT < 2 y.o.
- Sports > 4 y.o.
- 50% with associated injuries
- GCS correlates with outcomes
- 80% mild, 10% mod., 10% severe
Pathophysiology

- Brain 15% at birth, 3% as adult
- Skull / brain relationships vary
- Increased water content in children
- Diffuse injury more common
- Less operative trauma
- Plasticity of neurologic return
Monro-Kellie Doctrine

- \( V_{\text{blood}} + V_{\text{CSF}} + V_{\text{brain}} = V_{\text{total}} \)
- Intracranial space is limited!
- Hypothesis proposed in 1783
- Cushing popularized concept in 1902
- \( \text{CPP} = \text{MAP} - \text{ICP} \)
- \( \sim 50 \text{ mm Hg} \) adequate in children
- Ultimate goal = adequate CPP
Cerebral Blood Flow

- Adult human brain weighs 1500gm
- 2% body wt. & receives 15% C.O.
- Measured by xenon and TCD
- Need continuous O₂ & glucose supply
- Cerebral edema causes CBF
- Increased with loss of autoregulation
Cerebral Blood Flow

Effect of reduced cerebral blood flow on cerebral function and cellular homeostasis

- Function Impaired
- Electrical Function Lost
- Potassium Release
- Cell Death

Pediatric Head Injury
## Glasgow Coma Scale

<table>
<thead>
<tr>
<th>Glasgow Coma Scale</th>
<th>Modified Coma Scale for Infants</th>
<th>Point Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye opening</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spontaneous</td>
<td>Spontaneous</td>
<td>4</td>
</tr>
<tr>
<td>To speech</td>
<td>To speech</td>
<td>3</td>
</tr>
<tr>
<td>To pain</td>
<td>To pain</td>
<td>2</td>
</tr>
<tr>
<td>None</td>
<td>None</td>
<td>1</td>
</tr>
<tr>
<td>Verbal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oriented</td>
<td>Coos, babbles</td>
<td>5</td>
</tr>
<tr>
<td>Confused</td>
<td>Irritable</td>
<td>4</td>
</tr>
<tr>
<td>Inappropriate words</td>
<td>Cries to pain</td>
<td>3</td>
</tr>
<tr>
<td>Grunting</td>
<td>Moans to pain</td>
<td>2</td>
</tr>
<tr>
<td>None</td>
<td>None</td>
<td>1</td>
</tr>
<tr>
<td>Motor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follows commands</td>
<td>Normal spontaneous movements</td>
<td>6</td>
</tr>
<tr>
<td>Localizes pain</td>
<td>Withdraws to touch</td>
<td>5</td>
</tr>
<tr>
<td>Withdraws to pain</td>
<td>Withdraws to pain</td>
<td>4</td>
</tr>
<tr>
<td>Abnormal flexion</td>
<td>Abnormal flexion</td>
<td>3</td>
</tr>
<tr>
<td>Abnormal extension</td>
<td>Abnormal extension</td>
<td>2</td>
</tr>
<tr>
<td>Flaccid</td>
<td>Flaccid</td>
<td>1</td>
</tr>
</tbody>
</table>
Associated Injuries

- 50% BTAT
- 3-5% spine
- 15-20% ortho
- Increase severity
Skull Fractures

• 5 - 15% of mild head injuries
• 30 - 70% in child abuse cases
• History usually reliable
• Often with focal scalp injury
• Increases suspicion of brain inv.
• Usually require observation
Skull Fractures

...takes much force to fracture a skull!
Epidural Hematoma
Subdural Hematoma
Non-accidental Trauma

- Interhemispheric falx hemorrhage
- Sub-dural hemorrhage
- Large, non-acute extra-axial fluid collection
- Basal ganglia edema

p<0.05 for above per Hymel et al, Pediatr Radiol; (1997 Sep) v27 n9 p743-7.
Cerebral Concussion

- Most frequent head injury
- Loss of neurologic function
- Temporary paralysis of function
- Altered cerebral blood flow
- No structural abnormality
- Outcome uniformly excellent
Cerebral Concussion

- Variable level of consciousness
- Loss of tone, reflexes, resp. control
- Pupil abn., cortical blindness
- Pallor, heart rate abn., vomiting
- Lethargy, slurred speech
- Confusion, amnesia of events
Admission Criteria

- Decreasing consciousness
- Persistent confusion / lethargy
- Excessive headache / vomiting
- Uncertain history of trauma
- Focal neurologic signs
- Seizures / skull fracture
OCTOPUS – observation or computed tomography of mild head injury in Sweden: a randomized clinical trial concerning effects and costs

### Observation

**Table 3** Death and complications according to final evaluation by blinded external and internal reviewers

<table>
<thead>
<tr>
<th></th>
<th>Computed tomography (n=1316)</th>
<th>Observation in hospital (n=1286)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaths:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caused by head injury</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Possibly related to head injury</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Other causes</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>4</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Admission to ICU/neurosurgical ward during acute phase</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Neurosurgical operations:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-During acute phase</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-During three month follow-up</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Readmissions:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Readmission due to symptoms of head injury</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

ICU=intensive care unit.

### Table 5: Cost per patient (€) for computed tomography vs observation in hospital (€)

<table>
<thead>
<tr>
<th></th>
<th>Computed tomography</th>
<th>Observation in hospital</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean cost during acute stage and complications (1st and 3rd quartile)</td>
<td>461 (354-490)</td>
<td>677 (543-688)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mean cost during follow-up</td>
<td>257</td>
<td>237</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>718</td>
<td>914</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Infants - recommendations

• **High Risk:** CT scan
  Skull fracture, seizure, bulging fontanel, LOC > 1 min, decreased mental status, focal neurologic deficit

• **Intermediate Risk:** CT scan
  LOC < 1 min, nonacute skull fx, vomiting, caretaker concern, High energy mechanism, large scalp hematoma, unwitnessed injury

• **Low Risk:** Observe and Discharge
  Low energy mechanism, (fall < 3 ft), asymptomatic, Over 2 hours from injury, older age (> 12 mo)

Post-concussive Syndrome

- Persistent headaches
- Dizziness / lightheadedness
- Difficulty with concentration
- Irritability, stress intolerance
- Often in intelligent patients
- Normal neurologic exam
Cerebral Contusion
Seizures

• Increase CBF and ICP
• Higher incidence with GCS
• \(~20\%\) if cerebral contusion
• Immediate seizures not recurrent
• ? Prophylactic anticonvulsant use
• Treat for 2-4 weeks??
Diffuse Axonal Injury
Diffuse Axonal Injury

Some evidence that axons are not initially disrupted only swollen
Diffuse Axonal Injury

Diffuse cerebral swelling in 2-5 X more common in children than in adults, possibly due to ischemia

- Zwienenburg Muizelaar J Neurotrauma 16(10):937-43

In severe head injury, autoregulation is intact 59% of the time, and dysfunctional 41%

- Muizelaar, et al J Neurosurg 71:72-76

If autoregulation is intact, ICP varies inversely with MAP, directly if autoregulation is not intact

- Bouma et al J Neurosurg 77:15-19
Pediatric Head Injury:
Part II - Current management

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Hyperventilation

- Immediate increase in CSF pH
- 1 torr PCO₂ decreases CBF by ~ 3%
- May try mild hyperventilation in kids
- Prophylactic use ineffective
- Recent data do not support use
- Appropriate in severe cases of impending herniation
Head Position

- Great controversy!
- Modest ICP improvement
- Improves jugular return
- 30 - 45 degrees optimal
- Avoid during hypotension
- ? A-line transducer position
Osmotic Agents

- Immediate ↓ in blood viscosity
- Improves blood flow
- 1-3 ml/Kg 3% NaCl
- 0.25 - 2 gm/kg dose mannitol
- Hypertonic saline effective
- Primary effect by dehydration
- BBB must be intact
- Monitor serum osmolality (~300)
Hypothermia

- Initially suggested by Phelps in 1897
- Mild hypothermia to 32 - 34°C
- 5 - 10% CMRO₂ change per °C
- Hyperthermia injures BBB
- 2 randomized trials in adults
- No consistent data in children
Hypothermia

- Reduces cerebral metabolism (7% / °C heat)
- Currently under trial for refractory ICP control
- Moderate cooling 32-34 degrees can decrease the severity of increased ICP, but not the average ICP in head injured children without coagulopathy
- There was no difference in outcome
- CoolKids trial underway
- ? Inc. mortality w/ rapid rewarming
  (Hutchinson, et al, NEJM 2008)
Barbiturate Coma

Cardiovascular depressant (watch your BP!)
Lowers cerebral metabolic rate and possibly vasoconstricts
Burst suppression goal on EEG
Barbiturates

- No controlled trials in children
- Decrease CMRO$_2$
- ↓ CNS lactate & glutamate
- EEG burst suppression or levels
- ? ↑ Survival, but poor outcome
- Arterial hypotension common
- Recent success in small series
Barbiturates

- Suppress brain metabolism, up to 50%
  - Piatt, Schiff Neurosurgery 1984 15:427-44
- Alters cerebral vascular tone
- Associated reduction of coupled CBF, reduces cerebral blood volume and therefore ICP
  - Bolus iv delivery 10mg/kg, over 30 min
  - Then 5mg/kg/hr for 3 hours
  - Hourly delivery 1-5mg/kg
  - Usually dosed to burst suppression on EEG
  - May also dose by levels, but not recommended
    - Kassell et al Neurosurgery 1980 7:598-603
Barbiturate Coma

- Prophylactic use is unsupported
- May develop decreased jugular venous saturation of <45%, associated with poor outcome
  - Cruz J Neurosurg 1996 85:758-61

- Myocardial suppression and hypotension requiring inotropie infusion

- Role in refractory ICP elevation unclear
Decompressive Craniectomy

- Initially described by Cushing -1905
- Some studies suggested edema
- Increased use recently (selective)
- Better outcomes in young patients
- Second tier therapy with barbiturate coma
Decompressive Craniectomy

Some recent studies: improved functional outcomes, less mortality
(JNS Jaganathan 2007; Cochrane Database, 2006)
Decompressive Craniectomy

- Bifrontal craniectomy was effective in resolving refractory intracranial hypertension in 44% of patients.
- Pilot study showed efficacy in all 6 patients with refractory elevated ICP.
  - (Ruf et al Crit Care 2003 7(6):R133-8)
- Craniectomy, primary or delayed, showed positive influence on outcome and survival on pediatric subpopulation (16).
  - (Messing-Junger et al Zentralbl Neurochir 2003 64:171-7)
Decompressive Craniectomy

- **COMPLICATIONS ---**
- Brain shift form overdrainage
- Bone flap storage in children is challenging
  - Frozen flap
  - Subcutaneous space is small
  - Demineralization?
- Bone resorption in children could be as high as 50% (Grant, Ellenbogen, *et al* JNS:Spine 2004)
Lumbar Drainage

- Controversial technique to treat refractory high ICP when ventriculostomy and medical management is ineffective

- Can lead to tonsillar herniation
  - 2 patients, Munch et al. *Crit Care Med* 2001 29(5):976-81
Controversies in Management

- Steroids
- Hemodilution
- Hypoglycemia
- Prophylactic anticonvulsants
- Controlled arterial hypertension
- Liquid ventilation / ECMO
Cell Damage
Prevention

- Almost always forgotten!!!
- Simple common sense
- Use available resources
- Child seat enforcement
- Occupant Protection Program
- ThinkFirst program
- Safe Kids programs
Outcomes

- Good = 75%
- Moderate = 10%
- Severe = 5-10%
- Death = 1-5%
- Where do we send our HI patients?
- Be an eternal, pragmatic optimist!
Mortality Rates

Outcomes

<table>
<thead>
<tr>
<th>Mortality</th>
<th>Early 1980's</th>
<th>Early 1990's</th>
<th>Late 1980's</th>
<th>Late 1990's</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>35</td>
<td>32</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>28</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
</tr>
</tbody>
</table>
Discussion

- Marked increase in diagnosis
- Some improvement in outcome
- Better understanding of pathophysiology and brain injury
- Future looks somewhat better
- Cautious optimism appropriate
“…patients at greatest risk for inadequate diagnosis and treatment [are] those who are predicted to be at relatively low risk of dying…”

Discussion

Incidents that lead to injuries may not be intentional - BUT, they are **PREVENTABLE**
Conclusion

Be an EXPERT
-- Make the same mistakes for at least 20 years.
Conclusion

Optimal care of the child with traumatic brain injury requires timely intervention by a highly specialized group of dedicated individuals.
Thank You!

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