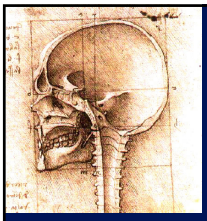

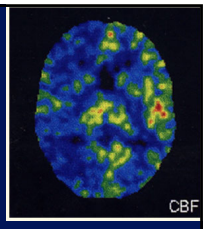

Evaluation and Treatment of Severe Brain Injury in Children

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- I have no disclosures.

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Objectives

- Review pathophysiology of traumatic brain injury in children
- Discuss current recommendations for management of traumatic brain injury in children
- Review goals of treatment

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How patients present

- **Obvious**--motor vehicle accident, car vs pedestrian, fall from height, etc
- **Less obvious**--sports injuries (football), delayed deterioration (epidural)
- **Hidden**--shaken baby syndrome, older child maltreatment

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Mechanisms of injury-Primary

- **Impact**: epidural, subdural, contusion, intracerebral hemorrhage, skull fractures
- **Inertial**: concussion, diffuse axonal injury
- **Hypoxic\Ischemic**

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Mechanisms of injury-Secondary

- Hypoxia of brain tissue
- Ischemia of brain tissue
- Impairment of cerebral blood flow
  - Increased intracranial pressure
  - Localized pressure – SDH, EDH
  - Foreign Body

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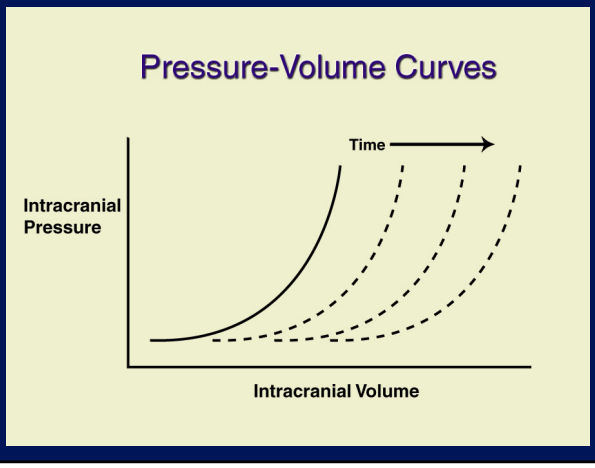
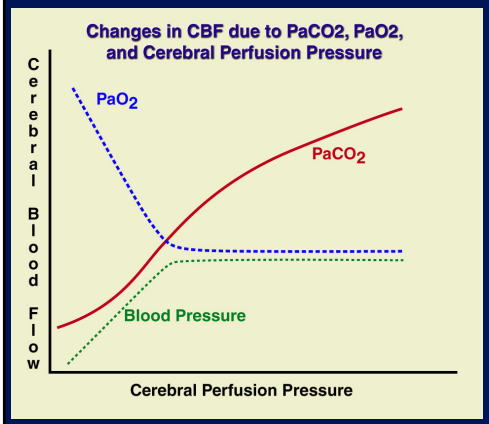
Monro-Kellie Doctrine

$$V_{intracranial\ vault} = V_{brain} + V_{blood} + V_{csf}$$



Blood: Cerebral Blood Flow



- The brain has the ability to control its blood supply by autoregulation
- With severe brain injury the body loses the ability to autoregulate and CBF will follow MAP

Management of TBI

Guidelines for the Acute Medical Management of Severe Traumatic Brain Injury in Infants, Children and Adolescents

Pediatric Critical Care Medicine 2012
Volume 13 No. 1 (Supplement)

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- Guidelines for the Management of Pediatric Severe Traumatic Brain, Third Edition: Update of the Brain Trauma Foundation Guidelines.
  - Pediatric Critical Care Medicine 2019; 20: S1-S82.

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TOPICS COVERED

- MONITORING
  - ICP
  - Advanced Neuromonitoring
  - Neuroimaging

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TOPICS COVERED

- THRESHOLDS
  - ICP
  - CPP

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TOPICS COVERED

- TREATMENTS
  - Hyperosmolar Therapy
  - Analgesics, sedatives and neuromuscular blockade
  - CSF Drainage
  - Seizure Prophylaxis

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TOPICS COVERED

- TREATMENTS
  - Ventilation
  - Temperature
  - Barbiturates
  - Decompressive Craniectomy
  - Nutrition
  - Corticosteroids

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GCS and Traumatic Brain Injury

- 13-15 mild TBI
- 9-12 moderate TBI
- ≤ 8 severe TBI

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- THRESHOLDS
  - ICP
  - CPP

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Threshold for Treatment of Intracranial Pressure

- Young children have less autoregulatory reserve than older patients
- Strong predictor of mortality is refractory elevated ICP

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Threshold for Treatment of Intracranial Pressure

- Goal of PICU Management
  - Control ICP
  - Preserve CPP

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Threshold for Treatment of Intracranial Pressure

- Per 2019 Guideline update
- "Treatment of intracranial pressure may be considered at a level of 20 mm Hg"

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Threshold for Treatment of Intracranial Pressure

- Miller Ferguson et al. Pediatric Crit Care Med. 2016
  - N = 85, Children's Hospital in Pittsburg
  - Outcome by threshold >14, >20, >30
  - No difference
  - Selection bias per neurosurgery

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Threshold for Treatment of Intracranial Pressure

- Mehta et al. Pediatric Crit Care Med. 2010
  - Pediatric Neuro Trauma Registry
  - Outcome by threshold with mean ICP <15 and <20
  - No difference in outcome in first 7 days

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Threshold for Treatment of Intracranial Pressure

- Adelson et al. J of Neurosurgery
  - Multicenter Study
  - Children with good outcome spent > 80% of time with ICP < 20
  - ICP was most sensitive predictor of poor outcome

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Threshold for Treatment of Intracranial Pressure

- ICP THRESHOLD – 20 mmHg
- > 20 for > 5 minutes – sustained elevation associated with poor outcome

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Cerebral Perfusion Pressure

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Cerebral Perfusion Pressure

CPP = MAP – ICP

- Pressure gradient driving cerebral blood flow

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Cerebral Perfusion Pressure Thresholds

- Autoregulation:
  - Changes in the cerebral vascular resistance for CBF to be maintained with changes in CPP, i.e. blood pressure lability, etc.
  - Severe TBI >> lose autoregulation >> poor outcome

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Cerebral Perfusion Pressure Thresholds

- "A minimum CPP threshold of 40 mm Hg may be considered in children with TBI"
- "Recommended CPP range of 40 – 50 mm Hg is age-specific with infants in the lower end and adolescents in the upper end of the range."

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Cerebral Perfusion Pressure Thresholds

- Allen, et al. Peds Crit Care Med. 2014
  - Class 2 Study
  - Predictors of mortality at 14 days post-injury
    Elevated ICP, lower CPP, hypotension
  - Identified Thresholds
    - ➢50 for > 6 years
    - ➢40 for 0-6 years
  - kdk

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Cerebral Perfusion Pressure Threshold

- What is the magic number?

- 6 – 17 years > 50 mm Hg
- 0 – 5 years > 44 mm Hg

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Cerebral Perfusion Pressure Threshold

- ICP was a more important factor than systemic hypotension in low CPP associated mortality

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Treatments

- **Hyperosmolar Therapy**
- Analgesics, sedatives and neuromuscular blockade
- CSF Drainage
- Seizure Prophylaxis

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Hyperosmolar Therapy

- 3% Hypertonic Saline
- Initial bolus of 2 – 5 ml / kg
- Continuous infusion of 0.1-1 cc/kg/hour

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Hyperosmolar Therapy

- Goal Directed
  - ICP < 20 mm Hg
  - Serum Osmolarity < 360 mOsm/L
  - Sodium level < 160 mmol/L

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Hyperosmolar Therapy

- Euvolemia not dehydration
- Foley catheter to avoid bladder rupture
- Avoid sustained serum Na over 170

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Hyperosmolar Therapy

- Side-effects of hyperosmolar therapy with hypertonic (3%) saline:
  - Rebound ICP with rapid wean
  - Central pontine myelinolysis
  - Renal impairment
  - SAH
  - Hyperchloremic acidosis
  - Masking development of Diabetes Insipidus

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Hyperosmolar Therapy

- No studies using Mannitol met criteria for inclusion into guidelines.

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Treatments

- Hyperosmolar Therapy
- **Analgesics, sedatives and neuromuscular blockade**
- CSF Drainage
- Seizure Prophylaxis

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Analgesics, Sedatives and NMBA

- "In the absence of robust outcome data, choice of analgesics, sedatives and NMBA should be left to the treating physician"

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Analgesics, Sedatives and NMBA

Benefits of Analgesics and Sedatives

- Anticonvulsant
- Antiemetic
- Prevent Shivering
- Decrease Pain and Stress
  - -Decrease CNS Metabolism
  - -Decreased CNS Oxygen Requirement

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Analgesics, Sedatives and NMBA

- Risk of analgesics and sedatives:
  - In bolus form they can decrease blood pressure >> decreased MAP >> decreased CPP >>> Poor outcome

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Analgesics, Sedatives and NMBA

Benefits of Neuromuscular Blocking Agents

-Reduce ICP by reducing intrathoracic pressure

-Prevention of shivering

-Optimize patient/ventilator interactions

-Decreased skeletal muscle metabolic demands

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Analgesics, Sedatives and NMBA

Risks of NMBA

- Mask seizure activity
- Increased risk of nosocomial pneumonia
- Immobilization stress
- Increased length of ICU stay
- Development of myopathy
- Exacerbate ICP's due to undersedation

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Analgesics, Sedatives and NMBA

- Sedative (versed) and narcotic (fentanyl) goal:
  - Sedation and pain control
  - NOT ICP MANAGEMENT

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Analgesics, Sedatives and NMBA

- Ketamine
  - Single dose for intubation
  - Watch for catecholamine depletion and rebound hypotension

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Analgesics, Sedatives and NMBA

- Some words about propofol:
  - Avoid in the prehospital setting
  - If already started, can continue, however HYPOTENSION AND CEREBRAL ISCHEMIA IS A REAL RISK!
  - PIS occurs with prolonged infusion < 12 hours.

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Treatments

- Hyperosmolar Therapy
- Analgesics, sedatives and neuromuscular blockade
- CSF Drainage
- **Seizure Prophylaxis**

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Seizure Prophylaxis

- Risk factors for post-traumatic seizures
  - Cerebral contusion
  - Retained bone or metal fragments
  - Depressed skull fracture
  - Focal neurologic defects
  - Loss of consciousness
  - GCS < 10
  - SDH or EDH
  - Penetrating injury
  - **Age – infants and children have lower seizure thresholds**

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Seizure Prophylaxis

- Infants and children have lower seizure thresholds than adults
- Incidence of post-traumatic seizures higher in pediatric severe TBI vs adult TBI
  - 70%

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Seizure Prophylaxis

- Phenytoin >> reduces the incidence of early (< 7 days) post-traumatic seizures in pediatric TBI
- NO DATA to encourage Keppra over phenytoin
- Bottom line – use either if available.

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Treatments

- **Ventilation**
- Temperature
- Barbiturates
- Decompressive Craniectomy
- Nutrition
- Corticosteroids

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Ventilation Strategies

- Prophylactic severe hyperventilation ($PaCO_2 < 30$ mmHg) should be avoided in the initial 48 hours after injury.

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Ventilation Strategies

- Hyperventilation >>>> decreased cerebral blood flow
- Prolonged or severe hyperventilation
  - $PaCO_2 < 27$
  - Associated with poor outcomes in pediatric TBI

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Ventilation Strategies

HOWEVER

- In the setting of active herniation:
  - i.e. Cushings triad

Hyperventilation can be considered while preparing other life saving treatments

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Treatments

- Ventilation
- **Temperature**
- Barbiturates
- Decompressive Craniectomy
- Nutrition
- Corticosteroids

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Temperature Control

- Level 2 Recommendation

  "Prophylactic moderate hypothermia (32-33 C) is not recommended over normothermia to **improve overall outcomes**"

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Temperature Control

- Level 3 Recommendation

  "Moderate hypothermia is recommended for **ICP control**"

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Temperature Control

AVOID HYPERTHERMIA

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Treatments

- Ventilation
- Temperature
- **Barbiturates**
- Decompressive Craniectomy
- Nutrition
- Corticosteroids

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Barbiturates

- Reduction in cerebral metabolism
- Higher brain oxygenation
- Lower CBF

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Barbiturates

- Risk of Barbiturate Therapy
  - Hypotension
  - Hypoxemia
  - Ventilator associated pneumonia

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Summary of Recommendations

- Maintain ICP < 20
- Maintain CPP 40 – 50 mm Hg, or 50 – 60 mm Hg
- Hyperosmolar Therapy
  - Hypertonic Saline 0.1 – 1 cc/kg/hour
    Serum Osm < 360 and Na 160 -165
  - Mannitol – 0.25 - 1 grams/kg as rescue ONLY
- Temperature Control
  - Normothermia
  - Avoid hyperthermia

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Summary of Recommendations

- Hyperventilation
  - PaCO2 < 30 associated with poor outcome
- Analgesia, Sedatives, NMBA
  - No true studies
  - Common sense of avoiding hypotension while providing adequate sedation and analgesia
- Antiseizure Prophylaxis
  - Phenytoin or Fosphenytoin

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Goals of TBI Management

- Good
  - PaCO2/ETCO2 32 - 40
  - O2 Sat > 90%
  - SBP > 90 (adjust for age)
  - MAP > 60
  - BG > 70

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Goals of TBI Management

- BAD
  - Hyperventilation
  - Hypoxia
  - Hypotension
  - Hypoglycemia

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Thank You