The Critically Ill Stroke Patient: Why Neuro ICU Matters

Holly Hinson, MD
Division of Neurosciences Critical Care
Department of Neurology
Oregon Health and Science University
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Disclosures

- 2012 American Brain Foundation Practice Research Training Fellowship for *Quantifying Paroxysmal Sympathetic Hyperactivity*

- 2013 NHLBI K12/Oregon Multidisciplinary Training Program for Emergency Medicine Clinical Research
Outline

• The Dedicated Neuro ICU
• The art of the Neuro ICU
  – Cerebral edema/ICP management
  – Fever control
  – Seizure control
• Does it work?
Neuro ICU at OHSU

- Founded in 2005
- 17 bed unit
- 24 hour CT/MRI access
- 24 Hour access to EEG techs, Epilepsy faculty
- Proximity to OR and Angio suites
- 24-7 Neuro-Intensivist coverage with 7 faculty
Patient Population

- Severe ischemic stroke
- Ischemic stroke following thrombolysis with tPA or thrombectomy
- Cerebral venous thrombosis
Patient Population

- Intracerebral and intraventricular hemorrhage
- Subdural and epidural hematoma
Patient Population

- Subarachnoid hemorrhage
- Cerebral aneurysms
- Cerebral and spinal vascular malformations
- Brain tumors
Patient Population

- Status epilepticus
- Meningitis and encephalitis
- Neuromuscular disorders in crisis (myasthenia gravis, Guillain-Barre syndrome) and acute myelopathies
What Can We Offer?

• Cerebral resuscitation
  – “The Brain Code”
• Disease-specific management
• Full complement of subspecialists
• Cutting-edge technology
Cerebral Resuscitation: acute catastrophic neurologic injury

- Catastrophic neurologic injury: ↑ICP ➔ herniation
Cranial Vault Mechanics

- **Monroe and Kellie**
  - Skull is a rigid container
  - Cranial contents (brain, blood, CSF) are viscous gel and incompressible
  - Additional volume (pathologic or expansion of the 3 normal contents) will lead to the displacement of another content

Cranial vault mechanics

CPP = MAP - ICP

CBF = CPP/CVR

CD02 = CBF x CaO2

ICP<20, CPP>60 = mortality reduction by > 50% in TBI

Cerebral Resuscitation: herniation syndromes

**Subfalcine Herniation**
Cerebral cortex under falx
- Ipsi/contra leg weakness
- ↓ mental status

**Upward Herniation**
Brainstem up through tentorium
- ↓ mental status
- Dilated pupil (CNIII), ophthalmoplegia
- Ipsi paresis/posturing (contra cerebral crus)

**Central Herniation**
Brainstem down through tentorium
- ↓ mental status
- Dilated pupil (CNIII), ophthalmoplegia
- Ipsi paresis/posturing (contra cerebral crus)
- Basilar stroke

**Tonsillar Herniation**
Cerebellar tonsils in foramen magnum
- Awake, quadriparesis
- Arrhythmia/cardiac arrest
- Respiratory arrest

**Uncal Herniation**
- Uncus over tentorial notch
- Dilated pupil (CNIII), ophthalmoplegia
- Ipsi paresis/posturing (contra cerebral crus)
- PCA stroke
Medical Interventions

Reduce Cranial Contents:
- Blood – vasodilation to constriction
- Venous Return
- Hyperventilation
- Reduction of CMR02

Brain water
- Osmolar therapy for edema

Surgical Interventions

Drain CSF
- Surgical removal of mass
- Break the rigid skull - craniectomy

Brain Code

Medical Interventions

Airway: O2 sat>90%
Breathing: normal CO2
Circulation CPP> 60mmHg

Surgical Interventions

Head of Bed:
- 30 degree, midline

Hyperventilation:
- pCO2 30 +/- 2 mmHg

Hyperosmolar therapy
- Mannitol IV 1 gm/kg IV
- Hypertonic saline (CVL)
  - 3% NaCl or 23.4% NaCl

Normothermia/?Hypothermia
Pharmacologic Coma
Cerebral Resuscitation: compartment approach to ICP management

**Venous blood**
- HOB up
- Neck straight
- No IJ lines, do not lay flat for lines
- Do not use venodilating BP agents

**Arterial blood**
- Hyperventilate
- Avoid hyperemia: MAP target 60, PaO2 > 50
- Decrease metabolism: sedation, cooling

**Brain parenchyma**
- Osmotherapy (mannitol, hypertonic saline)
- Steroids only if appropriate (Vasogenic edema)

**Lesion**
- Blood, tumor, pus -> surgery
- Air -> 100% NRB, surgery

**CSF**
- Place IVC
- Change popoff
Cerebral Resuscitation: arterial compartment

Arterial blood
- Hypervent
- Avoid hyperemia: MAP target 60, PaO2 > 50
- Decrease metabolism: sedation, cooling

Cerebral Resuscitation: compartment approach to ICP management

**Venous blood**
- HOB up
- Neck straight
- No IJ lines, do not lay flat for lines
- Do no use venodilating BP agents

**Arterial blood**
- Hyperventilate
- Avoid hyperemia: MAP target 60, PaO2>50
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**CSF**
- Place IVC
- Change popoff

**Brain parenchyma**
- Osmotherapy (mannitol, hypertonic saline)
- Steroids only if appropriate (Vasogenic edema)

**Lesion**
- Blood, tumor, pus -> surgery
- Air -> 100% NRB, surgery
Cerebral Resuscitation: venous compartment

Venous blood
- HOB up
- Neck straight
- No IJ lines, do not lay flat for lines
- Do no use venodilating BP agents

If CVP exceeds ICP, CPP = MAP - CVP

Ropper: n=19. 52% had ↓ICP when HOB increased from 0->60°. 2% had ↑ICP.
Davenport: n=8. Median ↓ICP from 18->15 with 20° elevation, no ↓ in CPP until > 60°.
Lee: n=30. Trendelenburg positioning ↑ICP from 20->24, but ↓ICP in 20% of pts. (!)

Cerebral Resuscitation: compartment approach to ICP management

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- Neck straight
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- Osmotherapy (mannitol, hypertonic saline)
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Lesion
- Blood, tumor, pus -> surgery
- Air -> 100% NRB, surgery

CSF
- Place IVC
- Change popoff
Cerebral Resuscitation: CSF compartment

CSF
- Place IVC
- Change popoff
Cerebral Resuscitation: compartment approach to ICP management

Venous blood
- HOB up
- Neck straight
- No IJ lines, do not lay flat for lines
- Do not use venodilating BP agents

Arterial blood
- Hyperventilate
- Avoid hyperemia: MAP target 60, Pa02>50
- Decrease metabolism: sedation, cooling

Brain parenchyma
- Osmotherapy (mannitol, hypertonic saline)
- Steroids only if appropriate (Vasogenic edema)

CSF
- Place IVC
- Change popoff

Lesion
- Blood, tumor, pus -> surgery
- Air -> 100% NRB, surgery
Cerebral Resuscitation: Brain parenchyma

**Brain parenchyma**
- Osmotherapy (mannitol, hypertonic saline)
- Steroids only if vasogenic edema
- Surgery (hemicrani, SOC)

**Types of edema:**
- Cytotoxic
- Vasogenic
- Hydrostatic
Cerebral Resuscitation: Brain parenchyma

Reflection Coefficient

- Sodium = 1.0
- Mannitol = 0.90
- Glycerol = 0.54
- Urea = 0.60
### Osmotic Load

<table>
<thead>
<tr>
<th>Solution Concentration</th>
<th>Sodium Concentration (mEq/L)</th>
<th>Osmolarity (mOsm/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ringer's lactate</td>
<td>130</td>
<td>275</td>
</tr>
<tr>
<td>0.90%</td>
<td>154</td>
<td>308</td>
</tr>
<tr>
<td>2.00%</td>
<td>242</td>
<td>684</td>
</tr>
<tr>
<td>3.00%</td>
<td>513</td>
<td>1062</td>
</tr>
<tr>
<td>Mannitol 20%</td>
<td>n/a</td>
<td>1098</td>
</tr>
<tr>
<td>Mannitol 25%</td>
<td>n/a</td>
<td>1375</td>
</tr>
<tr>
<td>7.50%</td>
<td>1283</td>
<td>2566</td>
</tr>
<tr>
<td>23.40%</td>
<td>4004</td>
<td>8008</td>
</tr>
</tbody>
</table>

P.S. 1L of NS is 3.5g of Na⁺ in 1 liter of free water

Hinson et al, J Intensive Care Med (2011)
Cerebral Resuscitation: Brain parenchyma

• Both improve rheology of erythrocytes → increases deformability through small capillaries

• Mannitol easier to give: no central line

• HS increases vascular volume → improves CBF up to 23%

• HS reduces inflammatory response by reducing PMN adhesion to microvasculature


# Recent Trials

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Type of Prospective Trial</th>
<th>Agent</th>
<th>Condition(s) Treated</th>
<th>Number of Patients?</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ichai/2009</td>
<td>Randomized Controlled</td>
<td>3% sodium lactate v. 20% mannitol</td>
<td>TBI</td>
<td>34</td>
<td>HS&gt;Mannitol for ↓ICP, ↑GOS</td>
</tr>
<tr>
<td>Francony/2008</td>
<td>Randomized Controlled</td>
<td>7.5% HS v. 20% mannitol</td>
<td>TBI + Stroke</td>
<td>20</td>
<td>Both ↓ICP similarly</td>
</tr>
<tr>
<td>Battison/2005</td>
<td>Randomized Controlled</td>
<td>20mL 20% mannitol v. 100mL 7.5% HS dextran</td>
<td>TBI + SAH</td>
<td>9</td>
<td>HS&gt;mannitol for ↓ICP</td>
</tr>
<tr>
<td>Harutjunyan/2005</td>
<td>Randomized Controlled</td>
<td>7.2% HS + 6% HES v. 15% mannitol</td>
<td>Neurosurg patients</td>
<td>40</td>
<td>HS&gt;mannitol for ↓ICP</td>
</tr>
<tr>
<td>Viallet/2003</td>
<td>Randomized Controlled</td>
<td>7.5% HS v. 20% mannitol</td>
<td>TBI</td>
<td>20</td>
<td>HS&gt;Mannitol for reducing elevated ICP episodes</td>
</tr>
</tbody>
</table>

Hinson et al, J Intensive Care Med (2011)
## Adverse Effects

<table>
<thead>
<tr>
<th>Complication</th>
<th>Mannitol</th>
<th>Hypertonic Saline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renal Failure</td>
<td>Avoid continuous infusion, repeat high dosing</td>
<td>Avoid prolonged hypernatremia &gt;160mEq/L</td>
</tr>
<tr>
<td>Rebound</td>
<td>Allow clearance prior to repeat dosing</td>
<td>Allow clearance prior to repeat dosing</td>
</tr>
<tr>
<td>Metabolic Acidosis</td>
<td>n/a</td>
<td>Reduce chloride in admixture</td>
</tr>
<tr>
<td>Hypokalemia</td>
<td>n/a</td>
<td>Add potassium to fluids</td>
</tr>
<tr>
<td>Hypovolemia</td>
<td>Concurrent volume resuscitation</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Hinson et al, J Intensive Care Med (2011)
Cerebral Resuscitation: compartment approach to ICP management

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Cerebral Resuscitation: Lesion

• Surgical evacuation: STICH
  – Subjects with ICH (≥2cm) randomized to early (<24 hours) surgical evacuation v. medical management
  – No benefit to early surgery in general
  – Superficial lesions, large cerebellar lesions (≥3cm) may benefit
  – Summary: “Except for possibly those with superficial ICHs, craniotomy at 1 day or longer after onset is not better than initial conservative medical treatment with or without later craniotomy for patients who have deterioration.”

Cerebral Resuscitation: Lesion

• Hemicraniectomy in stroke: DECIMAL, DESTINY, HAMLET
  – All small trials showed non-significant trend toward benefit of hemicraniectomy
  – Meta-analysis suggests an absolute risk reduction of 13%
  – Patient selection?

Disease Specific Management: Subarachnoid Hemorrhage

- Feared Complications:
  - Hydrocephalus
  - Aneurysm re-rupture
  - Seizures
  - Vasospasm
  - Stressed myocardium
  - Neurogenic pulmonary edema
Disease Specific Management: Subarachnoid Hemorrhage

Blood pressure management
- Use of intermittent labetalol boluses or continuous infusion of nicardipine to maintain SBP less than 140 mmHg (unsecured) and less than 160 mmHg (secured)

Vasospasm prophylaxis
- Nimodipine 60 mg every 4 hours for 21 days

Vasospasm monitoring
- Daily transcranial doppler sonography for 14 days

Hydrocephalus treatment
- Extraventricular Drain (EVD) placement
Cardiac Support after SAH

- Reduced Ejection Fraction or Symptomatic Vasospasm
  - Fluids, vasopressors
  - Hemodynamic monitoring
Fever

• ~50% of stroke patients develop fever\(^1\)
• Body temp > 37.5°C significantly correlates with poor outcomes\(^2\)
• Fever in first 24 hours linked to infarct volume\(^3\)
• Induced normothermia may reduce metabolic stress\(^4\)

Fever and Hypothermia

• Fever treatment
  – Acetaminophen
  – Cooling blankets
  – Intravascular cooling devices

• Hypothermia
  – Not Standard of Care
  – No clinical evidence yet to support its use
  – National Acute Brain Injury Study: Hypothermia II terminated early for futility

1. GL Clifton, A Valadka, D Zygun *et al.* Lancet Neurol, 10 (2011), pp. 131–139
Seizures after Stroke

• Seizures occur in ~ 9% of patients\textsuperscript{1}
  – Greater risk after hemorrhagic stroke
  – ~2.5% have recurrent seizures
  – Stroke location modifies risk
• Routine prophylaxis not recommended\textsuperscript{2}
• Seizure always on differential in depressed mental status
  – Continuous EEG helpful in making diagnosis

\textsuperscript{1} Arch Neurol. 2000 Nov;57(11):1617-22. \textsuperscript{2} Stroke. 2010; 41: 2108-2129
Does Neurocritical Care matter?

- Improved Mortality for ICH patients

Does Neurocritical Care matter?

- Reduced Mortality
- Shorter LOS
- More discharges to home/rehab

Does Neurocritical Care matter?

- Reduction in mortality after Neurointensivist appointed

Cerebral Resuscitation: outcomes

Long-term outcome after medical reversal of transtentorial herniation in patients with supratentorial mass lesions
Qureshi,,Geocadin,Suarez, Ulatowski, CRITICAL CARE MEDICINE 2000;28:1556-1564

- 11/28 (40%) survived to discharge
- 7/11 (59%) survivors functionally independent
Does Neurocritical Care matter?

YES!
Thank you!

• Questions?