Stepwise Management of ICP
Modern Thoughts on an Ancient Problem

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ICP: Basic Concepts

- **Monroe-Kellie doctrine:**
  skull = fixed volume

- **3 components of intracranial volume**

- **Normal ICP**
  - $\leq 20$ cm H2O
  - $\leq 15$ mm Hg
<table>
<thead>
<tr>
<th>Causes of Increased ICP:</th>
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<tbody>
<tr>
<td><strong>Space Occupying Lesion</strong></td>
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<tr>
<td>Hematoma, Tumor, Abscess</td>
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<tr>
<td><strong>Increased CSF</strong></td>
</tr>
<tr>
<td>Hydrocephalus</td>
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<tr>
<td><strong>Inc. Blood Volume</strong></td>
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<tr>
<td>(Vasogenic edema)</td>
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<tr>
<td>Trauma, Tumor, Abscess,</td>
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<tr>
<td>Hypertensive encephalopathy</td>
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<tr>
<td><strong>Inc. Brain Volume</strong></td>
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<tr>
<td>(Cytotoxic edema)</td>
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<tr>
<td>Infarction, Ischemia</td>
</tr>
<tr>
<td>Methods to Reduce Elevated ICP</td>
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<tr>
<td>-------------------------------</td>
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<tr>
<td><strong>• Remove Mass Lesion</strong></td>
</tr>
<tr>
<td><strong>• Reduce CSF Volume</strong></td>
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<tr>
<td><strong>• Reduce Cerebral Blood Volume</strong></td>
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<tr>
<td><strong>• Reduce Parenchymal Volume</strong></td>
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</table>
ICP/CPP Management

Cerebral Perfusion Pressure (mm Hg)

Cerebral Blood Flow (ml/100 g/min)

Passive Collapse

Maximum Dilatation

Zone of Normal Autoregulation

Maximum Constriction

Stephan A. Mayer, MD
Reduced Intracranial Compliance: Extremes of BP Can Drive Elevated ICP

Vasodilatory Cascade Zone

Zone of Normal Autoregulation

Maximum Constriction

Passive Collapse

Autoregulation Breakthrough Zone

Cerebral Blood Flow (ml/100 g/min)

Cerebral Perfusion Pressure (mm Hg)

ICP (mm Hg)

GOAL

Stephan A. Mayer, MD
Figure 5-5. Two classic A waves are shown (open arrows). Note that when the ICP falls after the A wave (closed arrow), it does not return to the baseline preceding the first wave.
CPP OPTIMIZATION:
Dopamine infusion resulting in increased MAP and CPP, and decreased ICP
Clinical Signs

- **Increased ICP**
  - Depressed level of consciousness
  - Pressor response
  - Projectile vomiting
  - CN 6 palsies

- **Symptomatic Intracranial Mass Effect**
  - CN 3 palsey
  - Motor posturing
  - Lower extremity rigidity
  - Loss of lateral EOMs
  - Hyperventilation
Intracranial Hypotension

• Post-Craniotomy “Brain Sagging”
  – Large amount of intracranial air
  – Clinical signs of herniation
  – Improvement with Trendelenberg

• Spontaneous intracranial hypotension
  – Postural headache
  – Dizziness, vertigo, lower cranial nerve deficits
  – Improvement with epidural blood patch
Dural Enhancement in spontaneous intracranial hypotension
Post-craniotomy brain sagging
Indications for ICP Monitoring

• Coma (Glasgow Coma Scale score ≤8)
• CT evidence of intracranial mass effect
  – Extra-axial mass lesion
  – Midline shift
  – Effacement of basal cisterns
  – Exception: severe TBI with motor posturing
• Prognosis is such that aggressive ICU care is warranted
Emergency Treatment of Increased ICP

• Un-monitored patient with clinical signs of herniation
  – Elevate head of bed 30°
  – Normal saline 100 ml/hr
  – Intubate and hyperventilate (pCO2 26-30)
  – Mannitol 20% 1.0 to 1.5 g/kg rapid IV infusion
  – Foley catheter
  – CT scan and neurosurgical evaluation
ICP: General Care Issues

• Elevate head of bed 30°
• Use only isotonic fluids (0.9% saline)
  – Option: 3% saline or mannitol 1 g/kg Q6H for target osmolality of 300-320 mOsm/L
• Control fevers aggressively
• Seizure prophylaxis
• Reserve steroids only for patients with mass lesions related to abscess or tumor
Critical Pathway for Treatment of Intracranial Hypertension in the Severe Head Injury Patient (Treatment Option)

- **Insert ICP Monitor**
- **Maintain CPP ≈ 70 mmHg**
  - YES: Intracranial Hypertension?
  - NO: Ventricular Drainage (if available)
  - YES: Intracranial Hypertension?
    - YES: Intracranial Hypertension?* (Mannitol 0.25 - 1.0 g/kg IV)
    - NO: May Repeat Mannitol if Serum Osmolarity < 320 mOsm/L & Pt euvolemic
  - NO: Carefully Withdraw ICP Treatment

Consider Repeating CT Scan

- YES: Intracranial Hypertension?
  - YES: Intracranial Hypertension?
    - YES: Hyperventilation to PaCO2 30 - 35 mmHg
      - YES: Intracranial Hypertension? (Hyperventilation to PaCO2 < 30 mmHg)
        - YES: Monitoring SjO2, AVDO2, and/or CBF Recommended
      - NO: Other Second Tier Therapies
    - NO: High Dose Barbiturate therapy
  - NO: Other Second Tier Therapies
Columbia Stepwise ICP Protocol

1. SURGICAL DECOMPRESSION
2. SEDATION
3. CPP OPTIMIZATION
4. OSMOTHERAPY
5. HYPERVENTILATION
6. PENTOBARBITAL
7. HYPOTHERMIA
Revised Columbia Stepwise ICP Protocol

1. SURGICAL DECOMPRESSION
2. SEDATION
3. CPP OPTIMIZATION
4. OSMOTHERAPY
5. HYPERVENTILATION
6. HYPOTHERMIA
7. PENTOBARBITAL
Aneurysmal SAH with associated subdural hematoma and bilateral motor posturing
ICU Intravenous sedation

• Goal is reversibility to allow repeated neurologic assessment
• Alternatives (in intubated pts):
  – *Fentanyl* or *Remifentanil*
  – *Midazolam*
  – *Propofol*
    » Ultrashort acting
    » Allows “wake-up” in 5-15 mins
    » Reduces ICP, CMRO$_2$
    » Drawbacks: hypotension, infection
ICP/CPP Treatment Thresholds

Guideline

- ICP treatment should be initiated at an upper threshold of 20 mm Hg.

Option

- Cerebral Perfusion Pressure should be maintained at a minimum of 50 mm Hg.
MMM: “Imaging” Vasodilatory Cascade Physiology

MMM: “Imaging” Perfusion Pressure breakthrough Physiology

Osmotherapy

- **Mannitol**
  - 0.25 to 1.5 g/kg IV wide open
  - Dose up to Q1H on an as-needed basis
  - Mechanisms:
    » Acute dehydrating effect (osmotic gradient across BBB)
    » Secondary hyperosmolality (diuretic effect)
    » Reflex vasoconstriction (viscosity effect)

- **Hypertonic Saline**
  - Varying concentrations: 3%, 7.5%, 10%, and 23.4%
  - Optimal dosing not known
7.2% Hypertonic Saline vs 15% Mannitol Solution for Treating ICP in Neurosurgical Patients

Critical Care 2005;9:R530
30 ml 23.4% Bullets
Effect of Hypertonic Saline in CBF in SAH patients

TSENG M-Y, Stroke 2003;34:1389.)

- **10 poor grade SAH patients**
- **2 mL/kg of 23.5% saline**
- **ICP fell 74%**
- **CPP rose 27%**
- **CBF rose 23%**
- **Peak effect @ 20-60 minutes**
Evidence: 3% Saline Infusion

  - 3% saline reduced ICP and CT midline shift in patients with TBI or neoplasm
  - Effect not seen with ICH or infarction

  - 3% saline infusion reduced ICP in pediatric TBI patients
  - Effect modest: 4 mm Hg over 2 hours
### Poor Grade SAH: In-Hospital Complications

<table>
<thead>
<tr>
<th></th>
<th>HTS Cases (N= 36)</th>
<th>Controls (N= 57)</th>
<th>P</th>
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<tbody>
<tr>
<td><strong>Neurological</strong></td>
<td></td>
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<tr>
<td>Herniation</td>
<td>8 (23%)</td>
<td>10 (18%)</td>
<td>0.56</td>
</tr>
<tr>
<td>Infarction secondary to vasospasm</td>
<td>6 (17%)</td>
<td>13 (23%)</td>
<td>0.45</td>
</tr>
<tr>
<td>Seizures</td>
<td>10 (28%)</td>
<td>8 (14%)</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>Medical</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pneumonia</td>
<td>21 (58%)</td>
<td>14 (25%)</td>
<td>0.001</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>10 (28%)</td>
<td>3 (5%)</td>
<td>0.002</td>
</tr>
<tr>
<td>Pulmonary Edema</td>
<td>17 (47%)</td>
<td>10 (18%)</td>
<td>0.003</td>
</tr>
<tr>
<td>Congestive Heart Failure</td>
<td>7 (19%)</td>
<td>4 (7%)</td>
<td>0.07</td>
</tr>
<tr>
<td>Fever (Temp. &gt;101.5 F)</td>
<td>31 (86%)</td>
<td>47 (83%)</td>
<td>0.64</td>
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</table>
HYPERVENTILATION IS THE MOST RAPID WAY TO REDUCE ICP
EXCESSIVE HYPERVENTILATION CAN WORSEN CEREBRAL ISCHEMIA

MECHANISM OF ACTION:
- HYPOCARBIA INDUCES SERUM AND CSF ALKALOSIS
- ALKALOSIS INDUCES CEREBRAL VASOCONSTRICTION
- VASOCONSTRICTION REDUCES CEREBRAL BLOOD VOLUME

TIME COURSE:
- ICP IS REDUCED ALMOST IMMEDIATELY
- PEAK REDUCTION IN UP TO 20 MINUTES
- CAN HAVE SUSTAINED EFFECTS IN PATIENTS WITH VASODILATORY VASOGeneric CEREBRAL EDEMA
Hypothermia

MECHANISM OF ACTION:
PROFOUNDLY REDUCES CEREBRAL METABOLISM, AND HENCE CEREBRAL BLOOD VOLUME

TARGET
32-33°C

INDICATION
PENTOBARBITAL-REFRACTORY ICP

COMPLICATIONS:
ARRHYTHMIA AND CARDIOVASCULAR DEPRESSION
IMMUNOSUPPRESSION
COAGULOPATHY
METABOLIC: SHIVERING AND REWARMING
Contemporary Management of Traumatic Intracranial Hypertension: Is There a Role for Therapeutic Hypothermia?

Matthew Schreckinger · Donald W. Marion

Table 3 Comparison of contemporary therapies for intracranial hypertension

<table>
<thead>
<tr>
<th>Therapy</th>
<th>Total number of patients</th>
<th>Average decrease in ICP</th>
<th>Standard deviation</th>
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<tbody>
<tr>
<td>Hyperventilation</td>
<td>126</td>
<td>6.08</td>
<td>4.22</td>
</tr>
<tr>
<td>Mannitol</td>
<td>140</td>
<td>7.93</td>
<td>5.34</td>
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<tr>
<td>Barbiturates</td>
<td>167</td>
<td>8.47</td>
<td>6.71</td>
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<tr>
<td>Hypothermia</td>
<td>367</td>
<td>9.97</td>
<td>6.66</td>
</tr>
<tr>
<td>Hypertonic saline</td>
<td>133</td>
<td>15.06</td>
<td>7.34</td>
</tr>
<tr>
<td>CSF drainage</td>
<td>72</td>
<td>15.45</td>
<td>4.67</td>
</tr>
<tr>
<td>Decompressive craniectomy</td>
<td>192</td>
<td>19.15</td>
<td>7.70</td>
</tr>
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Hypothermia for Barbiturate Refractory ICP in TBI: *TITRATION of Cooling*

- **Tateshi (Neurosurgery 1998)**
  - Titrated the depth of cooling between 33-36 °C to keep ICP <20 mm Hg in 9 patients refractory to thiopental.
  - All patients responded:
    - Mean brain reduction of temperature of 2° C
    - Mean reduction of ICP from 24 → 15 mm Hg.
  - The frequency of infectious and hematologic complications in this relatively small series was still high.
High-Dose Barbituates

MECHANISM OF ACTION:
PROFOUNDLY REDUCES CEREBRAL METABOLISM, AND HENCE CEREBRAL BLOOD VOLUME

PENTOBARBITAL:
LOADING DOSE = 5-20 mg/kg IV OVER 1 mg/kg/min
MAINTAINANCE DRIP = 1-4 mg/kg/hr
GOAL: NORMAL ICP, BURST SUPPRESSION ON EEG

COMPLICATIONS:
MYOCARDIAL DEPRESSION AND HYPOTENSION
NEUROLOGICAL EXAM IS OBSCURED
ILEUS
BLOOD STREAM INFECTION