Management of Intracranial Pressure

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Disclosures

- No conflicts of interest.

Outline

- Intracranial physiology and autoregulation
- Signs and symptoms of elevated ICP
- Initial evaluation and management
- ICP monitoring
- Medical management
- Decompressive craniectomy
Monro-Kellie Doctrine

- The cranial vault is a fixed space of ~1400-1700 ml in average sized adults.
  - Blood 10% (~150 ml)
  - CSF 10% (~150 ml)
  - Brain 80% (~1400 ml)

Normal ICP

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Normal range (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults and older children</td>
<td>10-20</td>
</tr>
<tr>
<td>Young children</td>
<td>3-7</td>
</tr>
<tr>
<td>Term infants</td>
<td>1.5-6</td>
</tr>
</tbody>
</table>

The Compliance Curve

- Nonlinear
- As mechanisms are exhausted, compliance falls and even small increases in volume can dramatically increase ICP.
Cerebral Perfusion Pressure (CPP)

- The critical parameter for brain function and survival is not actually ICP.
- Is there adequate cerebral blood flow to meet oxygen demands?
- Cerebral blood flow depends on CPP, which depends on ICP (which is easily measured)
- CPP = MAP - ICP
- Normal >50 mmHg

Autoregulation

- Cerebral vasculature can vasoconstrict and vasodilate in response to various stimuli
- Changes in systemic blood pressure produce only small changes in CBF.

Causes of Elevated ICP

<table>
<thead>
<tr>
<th>Intracranial (primary)</th>
<th>Extracranial (primary)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traumatic brain injury (cerebral contusions, epidural and subdural hemorrhage)</td>
<td>Hyoxemia</td>
</tr>
<tr>
<td>Brain tumor</td>
<td>Hypertension</td>
</tr>
<tr>
<td>Intracranial hemorrhage (traumatic)</td>
<td>Hypernatremia</td>
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<tr>
<td>Sickle cell disease</td>
<td>Hypothermia</td>
</tr>
<tr>
<td>Hydrocephalus</td>
<td>Diabetes</td>
</tr>
<tr>
<td>Metabolic</td>
<td>Seizures</td>
</tr>
<tr>
<td>Status epilepticus</td>
<td>Hepato failure</td>
</tr>
<tr>
<td>Medications</td>
<td>Drug and toxins</td>
</tr>
<tr>
<td>Postoperative (hemorraghe, edema, CIVD disruptions)</td>
<td>Acutespan onto obstruction</td>
</tr>
<tr>
<td>High altitude cerebral edema</td>
<td>Asphyxiation</td>
</tr>
</tbody>
</table>
Signs and Symptoms of Elevated ICP

- Headache
- Nausea/vomiting
- Blurred vision
- Uneven or dilated pupils
- Diplopia
- Papilledema
- Altered level of consciousness
- Cushing triad: Hypertension, bradycardia, respiratory irregularity

Herniation

1. Subfalcial Herniation
2. Uncal Herniation
3. Downward Herniation
Uncal Herniation

- Generally from pathology in the frontotemporal region.
- Uncus is pushed over the tentorial edge compressing the third nerve and posterior cerebral artery.
  - Unilateral dilated pupil
  - Occipital lobe infarct

Uncal Herniation

**EARLY SIGNS:**
- Earliest consistent sign is unilaterally dilated pupil
  - Not to be confused with anisocoria.
  - Often accompanied by confusion, agitation or somnolence.

Uncal Herniation

**LATE SIGNS**
- Brainstem involvement
- Contralateral weakness
- Kernohan's phenomenon
- Followed by decerebrate posturing
- Sustained hypernea
- Cheyne-Stokes respirations are rare.
Kernohan’s Notch

- Ipsilateral weakness

Uncal Herniation

Initial Measures

- Elevate head of bed to 30-45°
  - ↓ ICP by enhancing venous outflow
- Keep neck straight and avoid neck constrictions (tight trach tape, tight cervical collar)
  - Constriction of jugular venous outflow causes ↑ ICP
- Avoid arterial hypotension (SBP <90 mmHg)
  - Hypotension reduces CBF
  - Normalize intravascular volume (isotonic fluids)
  - Pressors if needed
Initial Measures

- Avoid hypoxia
  - May cause further ischemic brain injury
  - Intubate if GCS <8.
- Ventilate to normocarbia (avoid prophylactic hyperventilation)
- CT head without contrast to rule out surgical pathology

Indications for ICP Monitoring

- No level I evidence.
- Level II evidence:
  - GCS <8 and abnormal CT head
- Level III evidence:
  - Also indicated in severe TBI patients with normal CT if two of the following criteria are met:
    - Age >40
    - SBP <90 mmHg
    - Decerebrate or decorticate posturing on motor exam
- Contraindications: awake patients, coagulopathy
Potential Monitoring Sites

External Ventricular Drain (EVD)
- Gold standard
- Can monitor ICP and drain CSF to lower pressure as needed.
- 10% risk of infection
- 1-2% risk of hemorrhage
- Frequently become clogged and require flushing or replacement.

Subarachnoid Bolt
- Quick and easy to put in.
- Low infection risk.
- May still need to place EVD if CSF drainage is necessary.
Remove Space Occupying Lesions

Posterior Fossa Pathology

- Smaller space
- Patients can rapidly decline

Freeman, 2015
Medical Management
Mannitol

- Mannitol has been used for ICP reduction for nearly 100 years.
- Large molecule (similar to starch)
- Causes increase in serum osmolality leading to an osmotic gradient between the serum and intracranial compartment
  - Net effect is the removal of brain water to ICP
- Rheologic properties
  - Decreases blood viscosity potentially improving cerebral perfusion

Medical Management
Mannitol

- Dosage
  - Acute setting: 1.5g/kg IV bolus
  - Less acute settings: 0.25g/kg IV bolus
  - Interval dosing: 25g q6h
- Simplify especially in the emergency setting with absolute doses 25g, 50g, 75g, or 100g.

Medical Management
Mannitol

- Cautions
  - Osmotic diuretic: must monitor for volume loss and prevent hypotension.
  - May require electrolyte replacement
    - E.g. Hypokalemia, hypophosphatemia
  - Renal injury (serum osmolarity <320 mOsm/k)
    - Especially for q6h dosing.
  - Precipitates when cold, may need IV filter.
  - Mannitol opens the blood brain barrier, and mannitol that’s crosses the BBB may draw fluid into the CNS (minimized with bolus dosing)
  - Must taper scheduled mannitol to prevent ICP rebound.
Medical Management
Hypertonic Saline

• 1.5%, 3%, or 23.4% solutions
• Provides hyperosmolar state and increased circulating blood volume compared to mannitol.
• May be preferable in patient populations where volume depletion may compromise cerebral perfusion.
  o Subarachnoid hemorrhage
• Goal Na 145-155.

Medical Management
Hypertonic Saline

• Cautions
  o Risk of thrombophlebitis if ran through a peripheral IV.
  o Need for central access if administration required for >24h.
  o Overshoot causes hypernatremia and hyperchloremic acidosis
    o Q6h Na monitoring.

Medical Management
Sedation

• Propofol, midazolam, fentanyl infusions
• Requires intubation if not already done.
• Reduces ICP by reducing Valsalva maneuver and jugular venous pressure elevation
Medical Management
Neuromuscular Paralysis

- Prevents coughing, which may cause ICP spikes.
- Requires intubation if not already done.
- Disadvantage:
  - Loss of neurologic exam aside from pupillary reflexes.

Medical Management
Barbituates

- Reduces brain metabolism and therefore oxygen demands leading to CBF.
- Anti-epileptic benefit.
- Cautions
  - Requires intubation and EEG monitoring to titrating to burst-suppression pattern.
  - Reduces cardiac output and may require vasopressor support
  - Contraindicated in patients with heart history.

Decompressive Craniectomy
Decompressive Craniectomy

- Most commonly used in large MCA or ICA infarcts.
- Mortality rate in large MCA infarcts approaches 80%
  - Decompressive craniectomy may reduce mortality to as low as 32% in nondominant hemisphere strokes (37% in all comers)

Decompressive Craniectomy

- Meta-analysis of 3 randomized controlled trials found that hemicraniectomy within 48 hrs after stroke onset:
  - Decreased mortality
  - Increased the number of patients with favorable functional outcomes.

Vahedi et al. 2007

Decompressive Craniectomy

- Indications
  - Age <70
  - Usually more strongly considered in nondominant hemisphere infarcts
  - Clinical and CT evidence of acute, complete ICA or MCA infarcts and direct signs of impending swelling or herniation.
Decompressive Craniectomy

• Technical Notes
  - GO BIG! Bone flap should be >12cm
  - Dura should also be opened, ± duraplasty
  - Bone flap can be stored in the abdomen or bone freezer.

• Potential Complications
  - Bleeding
  - Herniation of the brain through the bone opening (can cause local ischemia, minimized by making a big craniectomy)
  - Post-op fluid collections (subdural hygromas)
  - Hydrocephalus

Suboccipital Craniectomy

• Patients can decline quickly from posterior fossa infarcts
  - Swelling
  - Obstructive hydrocephalus
  - Brainstem compression
  - Duraplasty
  - Removal of infarcted tissue
  - Caution with aggressive EVD drainage prior to decompression
  - Risk of upward herniation
68 year old male

- Presented to the ER with severe headache, nausea and dizziness
- PMH: afib, hypertension, CAD, on Xarelto, ASA, and Plavix
- ICH score 1, NIH stroke score 4

68 year old male

Admission 6 hrs later

68 year old male
68 year old male

- 9 months post-op
  - Ambulating with a cane
  - No headaches

38 year old male

- Presented to outside ER with slurred speech and right sided weakness. CTA showed left common carotid thrombosis as well as left MCA occlusion
  - Given tPA at outside hospital
- PMH: smoker
- Exam: lethargic, right hemiparesis, withdraws left side to pain.

38 year old male

[Brain images]
38 year old male

- Taken to OR for decompressive craniectomy and ICP monitor placement on stroke day 2.

- Outcome (6 weeks out)
  - Bone flap replaced
  - Required shunt placement for extra-axial hygroma
  - Able to speak but still has considerable word finding difficulties, able to follow commands on the right.
22 yo male

- Presented to the ER with new right sided weakness and a couple week history of worsening headache.
- Exam: Answering some questions appropriately and intermittently following commands, right hemiparesis.

22 year old male

CTA on admission

CT head on day 2

22 year old male

- Heparin gtt
- Mental status improved significantly on 3% and mannitol.
- Held off on mechanical thrombectomy

CT head on day 2
22 year old male
- Patient no longer responding
- Left pupil nonreactive
- Patient intubated.

Day 4

22 year old male
- Emergent EVD placement
- Decompressive craniectomy

22 yo male
- Outcome (almost 6 months out)
  - Trapped left ventricle, underwent shunt placement
  - LUE DVT
  - Shunt malfunction with post-op seizures
  - Bone flap replaced last month
  - Exam: can carry on a conversation, able to stand, RUE plegic.
References


