Intracranial Hypertension from Traumatic Brain Injury

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Outline

ICP: Vital Sign in Brain Injury

Brain Trauma and Herniation Syndromes

=> Central Herniation

=> Lateral Brain Herniation

Treatment Options
Intracranial Pressure

• Normal ICP: 5-10 mm Hg

• Intracranial Hypertension: Sustained > 15 mm Hg

• Basic Concepts....
Intracranial Contents

**Content**
- Brain Parenchyma
- Cerebrospinal Fluid & Interstitial Fluid
- Blood: Arterial, Capillary, Venous

**Abnormality**
- => Tumor, ICH
- => Hydrocephalus & Cerebral Edema
- => Venous Sinus Thrombosis
Pressure-Volume Curve

Compliance: Δ in volume/pressure

Increasing intracranial volumes

A0: Normal ICP

A1: IPC high normal

B: ICP rapidly increases

First CSF, second CBV translocation

Raised ICP

⇒ ↓ CBF and ischemia

⇒ Pressure gradients: herniation

(compartmental alterations)

1: Optimal – 2: Spatial compensation – 3: Spatial decompensation
ICP Waveform

P1: Percussion wave => choroid pulsations

P2: Dicrotic wave => pulsations of major arteries

Tidal wave => blood perfusion ‘wave’

Increased ICP

↑P2 > P1

↑ P1 and tidal wave (waveform ‘rounded’)

Simultaneous EKG

Systemic Arterial Pressure (torr)

Intracranial Pressure (torr)
Measuring ICP
‘Bedside’ Camino
Bedside Monitoring
Ventricular Catheters
Insertion

A. Right Frontal Incision on Scalp

B. Drilling of Twist Drill Hole

C. Placement of Small Opening Through Dura

D. 8/2/99, Post-Operative Color Enhanced CT Scan of the Head, Lateral View

Ventricle

Cannula

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Ventricular Drainage Systems

Leveling to EAC
Cerebral Perfusion Pressure

• CPP = Cerebral Perfusion Pressure
• CPP = MAP – ICP
• Goal CPP = 70 – 100 mm Hg

Depressed Consciousness and Raised ICP

• ↑ ICP => ↓ CPP => Cerebral Ischemia
• Decreased LOC from ↑ ICP => ischemic encephalopathy
CSF Displacement

First

**CSF** displacement compensates for ICP

Dynamic equilibrium: absorption = production

CSF total 90 to 150 ml; 20ml/h or 500ml/d

Production: steady despite ↑ ICP!
Second

CBV Δ (displacement) with ↑ICP

=> Only 10% of the IC volume but dynamic CBV changes

=> Compensatory decreases in venous CBV with ↑ ICP

Examples ↑CBV: * Head down * Pain, arousal * Valsalva * Seizures

CBV is affected by CBF

Acidosis (hypoxia, hypercapnia, ischemia):

dilatation => ↑CBF => CBV => ↑ICP

In contrast: reduction in brain metabolism and hypothermia: ↓CBV
Auto(dys)regulation

Decrease in MAP

↓

Cerebral Vasodilatation (intact autoregulation)

↓

Vasoparalysis (dysregulation)

↓ ↓

Increase Decrease
in cerebral blood volume flow

↓

Further increase in ICP

↓

Compromise of CPP => Ischemia
Herniation Syndromes

Differentiate two commonly observed herniation syndromes:

- Central herniation
- Lateral displacement/herniation

Initial therapy similar: “stabilize the ICP”
Subsequent therapy: different!
Central and Lateral Herniation

Figure 7. Schematic representation of central herniation.
Gradual inflation of right frontal balloon in porcine model

Multiple measurements throughout intracranium

Regionalization of ICP noted

ICP Differentials and Tissue Shifts

Ventricular Drainage / ICP Values
ALGORITHM FOR TREATMENT OF INTRACRANIAL HYPERTENSION IN ADULTS AND CHILDREN

A) ICP Identification and Stabilization Phase

STEP 1: Recognizing Intracranial Hypertension

High risk conditions (see Table 7): coma, i.e., TBI, infection, unexplained etc.
Suggestive on examination (see Tables 4 and 5): herniation signs, i.e., unreactive pupil, posturing, etc.
Imaging evidence (see Table 4): diffuse brain edema; mass lesion with brain shift, hydrocephalus, etc.

↓

ICP Likely Elevated
Suspected clinically and/or on imaging
ICP monitoring not yet available

↓
STEP 2: Stabilization Phase => ABCD

Airway/Breathing:
- Stabilize airway, oxygenate and maintain O2 sat >90%
- Cervical spine precaution if needed
- Rapid screening neurological examination
- Intubate if needed; minimize hypoxemia, hypoventilation and flat-on-bed time periods
- Induction medication (example):
  o Propofol 1.5-2.5 mg/kg => drip
  o Fentanyl 0.35-1.5 ug/kg => drip
  o If needed, Vecuronium 0.1 mg/kg IV
- Hyperventilate if with herniation signs and target PaCO2 28-30 mmHg (<20 mins)
- Minimize coughing, asynchrony, Valsalva, and etc.

Circulation:
- Initiate volume resuscitation (normal saline/colloids/blood products)
- Stabilize blood pressure to MAP >80 mmHg (fluids/pressors)

Decompression (Brain):
- Head elevated at 30-45° and straight; neck without tight wrapping
- Mannitol 1 gm/kg IV bolus (or 23.4% saline 30 ml IV bolus)
- Focused serial neurological examinations
- Preparation for immediate head CT (often also CTA and neck CT)

STEP 3: Head CT Obtained

1. Neurosurgical lesion => OR
2. Indication for CSF drainage => EVD
3. Indication for ICP/brain monitoring => EVD or intraparenchymal probe
4. NeuroICU admission

Neurosurgical Intervention - OR

Surgical decompression, examples:
- Focal hematoma
- Hydrocephalus
- Sub-/epidural hematoma
- Decompressive craniectomy (uni- or bilateral)
CT 20 hrs post IA t-PA
Rapid ↓ LOC

Protrusion of uncus
Open ambient cisterns
Distorted midbrain
Aqueduct open

AS Shift: 12mm
P Shift: 6mm
Hemicraniectomy
*(decompressing focal mass lesions)*

Decompressive hemicraniectomy with durotomy and dural grafting
Post-Hemicraniectomy Scans
S/P Bone Flap Replacement

(About 2 ms later)
### STEP 4: Brain Monitoring Obtained

1. ICP and/or EVD
2. Brain temperature
3. PbtO₂, transcranial oxymetry, jugular vein oxymetry
4. Cerebral blood flow
5. Microdialysis

### STEP 5: Neurocritical Care Approach

| A | Airways | Protect and secure airways  
 | Spine precautions in trauma patients  
 | Avoid | No prophylactic steroids and antibiotics |
|---|---|---|
| B | Breathing | Avoid hypoxia  
 | Goal PaO₂ >80 mmHg  
 | Goal O₂ sat >90%  
 | Keep PaCO₂ (35-38 mmHg), use end tidal CO₂ |
| Bedside exam | Hourly charted |
| C | Circulation | Avoid cerebral hypotension (CPP <80 mmHg)  
 | Head elevated 30-45°  
 | Keep neck straight; avoid tight neck wrapping |
| CPP=(MAP-ICP) | Stabilize CPP at 60-70 mmHg  
 | If no ICP monitoring: MAP ~80-90 mmHg |
| Cervical spine | Clearance |
| Calm | Minimize noxious stimuli |
| Sedation =⇒ propofol drip titrate to RASS-2  
 | Exam patient off sedation if ICP stable |
| Analgesia =⇒ morphine IV or fentanyl infusion  
 | Paralytics if indicated =⇒ Vecuronium |
| Coagulation /Platelets | Normalize parameters; platelet count >100 k/mL |
| D | Drugs | Avoid drugs that increases ICP (see Table 15)  
 | Dehydrate brain  
 | DVT prophylaxis |
| E | Electrolytes | Normalize |
| Epilepsy | Detect, prevent and treat seizures |
| Enteral feeding | Early feeding (within 24 hours) |
| F | Fever | Brain temperature ~37°C  
 | Sample CSF, if suspicion |
| Fluids | Normo- to mild hepervolemia  
 | No hypotonic or dextrose fluids |
| G | Glucose | Maintain 120-160 mg/dl |
| H | Herniation | Monitor for herniation signs (see Table 4 and 5) |
| Hyperventilation | No prolonged hyperventilation  
 | May use for ICP crises or pending herniation |
| Hypoventilation | Avoid hypercapnia (vasodilation) |
| Hemodynamics | Maintain intravascular hydration |
| I | Imaging | Repeat head CT, if:  
 | * Clinical deterioration, i.e. herniation, GCS change  
 | * Within less than 48 hours after injury  
 | * ICP rising or remains elevated |
| ICP monitor | Check for malfunction, drift, artifacts, etc.  
<p>| Correlate ICP, exam and imaging results |
| Intervention | Neurosurgery service stand-by |</p>
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICP</td>
<td>&lt;20 mmHg</td>
</tr>
<tr>
<td>CPP</td>
<td>60-70 mmHg</td>
</tr>
<tr>
<td>CVP</td>
<td>10-12 mmHg</td>
</tr>
<tr>
<td>PaO₂</td>
<td>&gt;80 mmHg</td>
</tr>
<tr>
<td>Brain Temp</td>
<td>&lt;37°C</td>
</tr>
<tr>
<td>PbtO₂</td>
<td>&gt;20 mmHg</td>
</tr>
</tbody>
</table>
B) Advanced ICP Treatment Approach

Level 1: Temporary ICP Elevation and Crisis

Check above A-I
- Check EVD (waveform, level, drainage); drain 3-5 ml of CSF
- Temporary increase in sedation
- 20% mannitol 1 gm/kg IV bolus x1 over 15-30 minutes OR 23.4% saline solution 30 ml IVP x1 over 5 minutes
- Short-term paralysis

Level 2: Recurrent or Persistent ICP Elevation

Carefully re-check above A-I; use Level 1 recommendations
- Repeat head CT
- Deepen sedation; switch to midazolam 0.5-0.1 mg/kg/hr
- IV bolus of 20% mannitol 1 g/kg x1 than 0.5 g/kg x 4-6 hrs; Adjust serum osmolality to target 320 mOsm/L
- Neuromuscular paralysis => vecuronium 0.8-1.4mg/kg/min IV infusion rate
cvEEG, i.e., r/o non-convulsive seizures
- If PbtO₂ below target of >20 mmHg consider: Increase CPP in 5 mmHg increments; Increase FiO₂ by 10% to reach goal; Transfusion for Hgb >10 mg/dL
- Mild brain hypothermia ~35°C; treat shivering
- Adjust serum Na level to 150 to 155 range:
  - 3% Hypertonic saline infusion at 150 ml every 4 hours
  - Na and serum osmolality checks every 4 hours
- Moderate Hyperventilation => PaCO₂ 30-32 mmHg; monitor PbtO₂
- Consider craniectomy
Level 3: Refractory ICP Elevations

Carefully re-check above A-I; use Level 1 and 2 recommendations
Repeat head CT

Decompressive craniectomy and durotomy (unilateral or bilateral)
If not a candidate => proceed with below

Pentobarbital (PB) coma => burst suppression x48 hours:
  o PB loading 20 mg/kg over 60 mins followed by 1 mg/kg/hr, may reload with 5 mg/kg and titrate drip
    up to 3 mg/kg/hr  Goal: 4-8 bursts per minute on cvEEG
  o Cautions:
    MAP may drop: may use smaller loading aliquots if hypotensive
    Pressors at bedside to maintain CPP
    Stop other sedatives; may not need neuromuscular paralysis

Increase hypothermia x48 hours:
  o Target brain cooling temperature 32°C (see Table 15)
  o Rewarm slowly (rebound ICP likely), if tolerated 0.3°C/hour or as slow as 1°C every 24 hours
Summary

TRAUMATIC BRAIN INJURY ALGORITHM INCLUDES

• Acute recognition and empiric Tx of increased ICP
• Neurosurgical removal of acute mass lesions
• Measuring ICP and monitoring CPP
• Stabilizing ICP crisis
• Repeated CT scanning if needed
Thank you for your attention!