

Cerebral Resuscitation and Increased Intracranial Pressure

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I. Introduction

There is a delicate balance between the volume of the intracranial vault (closed compartment) and the volume of its contents: blood, brain, and CSF. Because it is a closed space, if one compartment enlarges, the others must compress, and after spatial compensation is exhausted, with relatively small increases in volume, the intracranial pressure will rise. With increased intracranial pressure, blood flow and oxygen delivery may be compromised, and secondary injury occurs.

II. Etiology of Increased Intracranial Pressure--it is often helpful prognostically to understand the etiology of the increased ICP, and the differences in pathophysiology between the different entities. It is also essential in formulating a rational treatment plan.

A. Generalized brain injury

1. Hypoxic-ischemic injury
2. Diffuse head injury
3. Osmolar injury (hypo-osmolality, hyperosmolality, DKA?)
4. Encephalopathies: Reye's syndrome, hepatic encephalopathy
5. Infection: meningitis, encephalitis
6. Toxins

B. Focal intracranial lesion

1. Vascular: subdural, epidural, intraparenchymal hemorrhage, AVM
2. Focal traumatic lesion, focal edema w/o bleeding
3. Tumor
4. Abscess

C. CSF obstruction

III. Classification of brain edema

A. **Vasogenic**--characterized by increased permeability of brain capillary endothelial cells, as in tumor, abscess, hemorrhage, infarction, contusion, lead intoxication, and meningitis. The neurons and glia are relatively normal in appearance. This form of edema can respond to therapies intended to reduce it.

B. **Cytotoxic**--characterized by failure of the normal homeostatic mechanisms that maintain cell size: neurons, glia, and endothelial cells swell. This form of edema primarily represents cellular energy (ATP) failure, and is prominent in hypoxic-ischemic injury, osmolar injury, some toxins, and as part of the secondary injury sequence following head trauma. This form of edema does not respond well to therapies.

C. **Interstitial**--characterized by an increase in the water content of the periventricular white matter due to obstruction of CSF flow.

IV. Clinical presentation of patient with increased intracranial pressure--One may frequently encounter patients who have increased ICP and who do not yet have an ICP monitor in place--hence it is important to have an idea of clinical signs and symptoms which suggest increased ICP.

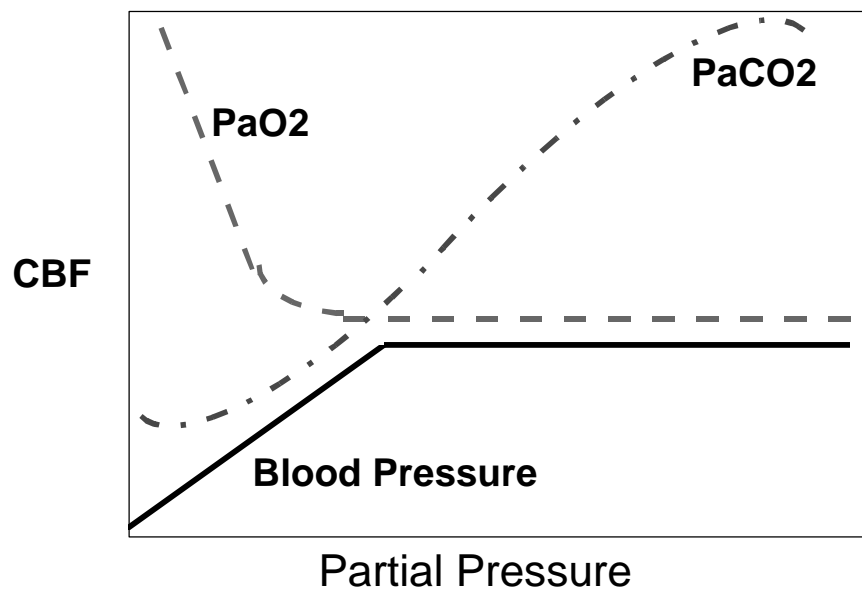
A. Headache

- B. Vomiting
- C. Depressed level of consciousness: confusion, restlessness, obtundation, progressive unresponsiveness.
- D. Abnormal posturing
- E. Abnormal breathing pattern: hyper or hypoventilation
- F. Abnormal cranial nerves findings: pupillary reaction (poor response to light, any size)
- G. Papilledema-not present early in course
- H. Hypertension with bradycardia or tachycardia. Cushing's triad: increased intracranial pressure, hypertension, bradycardia or tachycardia (bradycardia is late sign). Cushing's triad is a LATE SIGN. Do NOT assume the brain is OK because you do not see hypertension and bradycardia.
- I. Bulging fontanelle

A few basic concepts relative to the pathophysiology of the Intracranial Vault.

The intracranial vault is composed of three components--brain (cells and intercellular fluid), blood, and CSF. Increases in the size of any of the three compartments can lead to increased ICP. Therapeutic manoeuvres are designed to reduce the volume of one or more of the three compartments. It is important to realize that the injured brain may react differently to these manoeuvres than the normal brain. It is also important to remember that the brain is not a homogeneous structure, and that regional forces may be important.

Effect of Blood Gases on Cerebral Perfusion



As you can see, with increased pCO₂, cerebral blood flow increases, and hence the volume of the

blood in the brain increases, and the intracranial pressure increases. Similarly, with LOW pO₂ (less than 50mmHg), CBF will increase, and this can lead to increased ICP. Also note that with hypocapnia (ie, hyperventilation), CBF decreases--if this is severe or prolonged, ischemia may ensue. Autoregulation may or may not be intact in the injured brain (blood gases or blood pressure). Actually, autoregulation of cerebral blood flow in response to changes in blood gases is a complex phenomenon, and is in part a function of local **pH** (which is a function of pCO₂), possibly mediated by nitric oxide. Thus, patients who are chronically hypercapneic should not be corrected quickly, as this will lead to alkalosis and cerebral ischemia. Similarly, hyperventilation, and its induced alkalosis, will only reduce CBF for a short time (24-36 hours), until CSF pH normalizes.

Primary vs Secondary injury

The concept of primary vs secondary injury is an essential component of cerebral resuscitation strategies. Neurons do not regenerate--once damaged and killed, they are gone. When they are damaged or die, they release excitatory amino acids, free radicals, leukotrienes, etc (LONG LIST), and these substances damage surrounding neurons and glia, and alter the integrity of the blood brain barrier, which can lead to vasogenic edema. In addition, local or generalized swelling/increased ICP can interfere with cerebral blood flow and cause ischemic damage.

There is virtually nothing that can be done to reverse the primary injury. Our focus during resuscitation and ongoing management is to prevent, as much as possible, secondary injury.

V. Emergency Management

Patients who are suspected of having intracranial pathology must be managed in a careful, well-orchestrated manner, strictly adhering to the basic tenet of airway-breathing-circulation. Secondary injury must be prevented, and the patient stabilized before more thorough diagnostic investigations ensue. During the emergency stabilization, no ICP monitoring is possible, and evaluation is ongoing.

A. Airway

1. Quickly establish the adequacy of the airway. Is the patient breathing spontaneously with a normal rate and pattern? Is there any evidence of airway obstruction? What is the level of consciousness?
2. As a rough guide, a child with a GCS<8 should be intubated to protect his airway.
3. In the presence of trauma, avoid manipulation of the neck (potential C-spine injury).
4. In the presence of coexisting pulmonary or cardiovascular compromise (ie, sepsis, multi-system trauma), consider intubation with lesser apparent degree of head injury, in order to assure adequate delivery of oxygen and adequate ventilation.
5. Intubation **MUST** be done carefully, preferably by someone knowledgeable about the use of medications to reduce the ICP response to intubation. A rapid sequence intubation (pre-oxygenation, use of cricoid pressure) is warranted, and

the use of lidocaine (1.5 mg/kg) prior to intubation will help blunt the ICP response to intubation. If there is evidence of trauma, the neck should not be extended, and a second person should hold the head in-line. Choice of drugs and doses must take volume status into consideration--remember that trauma patients, as well as septic patients, are often hypovolemic. Thiopental, a great drug for intubation of patients with increased ICP due to its tendency to reduce ICP, will also cause systemic vasodilation and hypotension. Doses should be reduced accordingly.

B. Breathing

1. In the head injured patient, hypercapnia must be avoided, since it is a powerful cerebral vasodilator.
2. Adequate oxygenation is essential, regardless of the need for intubation. Provide supplemental oxygen while initially evaluating the patient.
3. CO₂ monitoring is especially useful in these patients. Until the extent of pathology is evaluated, mild hyperventilation and adequate oxygenation should be provided.

C. Circulation

1. Provision of adequate cardiac output and blood pressure is essential in management of the brain injured patient.
2. Assuring adequate circulating blood volume takes precedence over concerns regarding cerebral edema--fluid restriction is contraindicated in the hypovolemic or poorly perfused patient with brain pathology. Actually, provision of isosmotic fluid will NOT lead to development of cerebral edema, but care must be taken to AVOID lowering the osmolarity of blood--ie, NO hypotonic fluid should be administered initially. Normal saline or LR is good, as is albumin. (colloid vs crystalloid controversy is long).
3. The injured brain is extremely intolerant of further insult such as hypoxia, poor perfusion due to inadequate volume replacement, or hypercapnia.
4. The MOST important thing you can do in the initial stabilization of a brain injured child is provision of adequate oxygen delivery--adequate cardiac output, blood pressure, and oxygenation. This will help minimize the degree of secondary injury.

D. Initial Assessment

1. Initial Neurologic Assessment--the initial assessment provides important prognostic information, and allows for those caring for the patient after the initial stabilization to follow trends in the exam.
 - a. Assess level of consciousness, global status--Glasgow Coma Scale
 - b. Assess for presence of focal deficit, asymmetry to exam
 - c. ?Seizures
 - d. Focused neurologic exam, including attention to cranial nerve findings, motor tone and reflexes, response to stimuli.
 - e. The absence of papilledema does not rule out increased intracranial pressure (need prolonged increases in ICP to get papilledema).
2. Etiology of brain injury will dictate much of further evaluation and management.

- a. Trauma: mechanism of injury, estimation of degree of force applied to the patient (speed of the car, height of fall, etc.) Associated injuries need to be evaluated and treated.
- b. Infectious: detailed history of exposure, length of illness, past medical history, current medications.
- c. Toxin exposure: duration, amount of exposure.
- d. Unknown: Detailed history, including past medical history and social history. Absence of history of trauma does not rule out trauma (shaken baby syndrome) or the need for neurosurgical intervention (spontaneous intracranial hemorrhage, tumor). Look for signs of occult trauma or unknown disease (eg, signs of chronic liver disease).

E. Laboratory Evaluation--may be modified according to likely diagnosis

- 1. Blood gas
- 2. Electrolytes, Ca, Mg, Phos, Osmolality
- 3. Dextrostix (bedside) and blood glucose
- 4. LFTs, ammonia
- 5. CBC, Coagulation profile
- 6. Toxicology screen
- 7. Clot to blood bank
- 8. Blood, urine, sputum culture

F. CT scan, without contrast. Assess for evidence of intracranial blood, mass effect, edema, size of ventricles and basilar cisterns, effacement of cortical sulci, skull fracture. If the preliminary diagnosis on the unenhanced scan could be more precisely defined (ie, abscess or tumor), or the unenhanced scan is normal but the clinical presentation is compelling, a contrast scan can be done. In general, contrast should be avoided in the presence of bleeding (osmotic agent). It is important to remember that a CT scan is a poor way of determining the presence or absence of increased intracranial pressure. It provides anatomic information, and combined with clinical assessment, can be used to estimate the probability of increased intracranial pressure, and allow one to judge which patients should be monitored invasively.

VI. Management of the brain injured patient--beyond the initial resuscitation.

A. General measures--there is relatively little we can do specifically to address the brain injury, aside from surgical removal of blood/tumor. The bulk of most therapy revolves around general supportive care and prevention of secondary injury (brain), and complications associated with intensive care.

- 1. Pulmonary management--assure oxygenation and ventilation
- 2. Cardiovascular management--assure adequate cardiac output, volume status, blood pressure. This usually will necessitate an arterial line and central venous pressure monitoring.
- 3. Avoid hyperthermia--greatly increases brain metabolic need. Tylenol, cooling blankets, ibuprofen. Avoid shivering.
- 4. Avoid hypo or hyperglycemia
- 5. Avoid seizures--treat aggressively if they occur. Prophylactic treatment is controversial.
- 6. Analgesia and sedation--Patients whose ICP is monitored can and should be

adequately sedated, and paralysed if necessary to control ICP or manage pulmonary concerns. Patients who are not monitored should not be sedated, if possible, in order to preserve the neuro exam (its all you got!)

a. Narcotics (morphine or fentanyl) and benzodiazepines (ativan or midazolam) **titrated** to effect.

b. If the patient has documented increased ICP, pain and agitation should be treated aggressively.

c. Some patients who are mechanically ventilated, with significant intracranial hypertension, will require pharmacologic paralysis as part of the regiment to control ICP. Be certain to monitor the degree of paralysis (train of four with continuous infusion or intermittent dosing, prn movement.)

d. If you elect to “watch” the mental status, be aware of the possibility of deterioration.

7. GI prophylaxis--patients with head injury are at significant risk of stress ulceration. Sucralfate or H2 blocker should be ordered until enteral feeds are instituted.

8. Positioning--HOB elevated with head midline to avoid impeding venous return.

B. Surgical management--drainage of blood: epidural, subdural, intraparenchymal or intraventricular blood, removal of tumor, drainage of CSF or shunt revision. **Acute medical management of the patient may precede surgical intervention if the patient is at risk of significant deterioration prior to availability of the operating room.**

C. Medical management of increased intracranial pressure--the general idea is to reduce the ICP in order to allow for adequate cerebral blood flow so as to prevent further damage. Sometime this entails attempting to “shrink” the brain, often the normal brain, in order to allow the damaged brain to swell. While not desired, this may be necessary to prevent herniation. Other facets of medical management include provision of adequate substrate for the brain (glucose), and reduction in cerebral metabolic rate (temperature, seizures, agitation all increase CMRO₂, and in the injured brain which is relatively or regionally ischemic, may place neurons at risk.)

1. Intracranial pressure monitoring

a. Indications: GCS<8, need for non-neurosurgical surgical procedure after significant head trauma, need for prolonged paralysis or with significant cardiopulmonary disease coexistent with brain injury.

Monitoring is only indicated if the underlying disease is amenable to treatment, thus is not indicated in isolated hypoxic-ischemic injury (ie, after cardiopulmonary arrest). Indications are often controversial

b. Types of monitors: intraventricular drain, intraparenchymal catheter (Camino catheter), subarachnoid bolt. Each has its own indications and risks. The risk of bleeding and infection is common to all.

c. Both ICP and cerebral perfusion pressure should be monitored. An arterial line is necessary, and in many patients, central venous pressure

monitoring is also indicated.

$$\text{CPP} = (\text{MAP} - \text{ICP}) \text{ or } (\text{MAP} - \text{CVP})$$

2. Goals of ICP monitoring

- a. Maintain cerebral perfusion pressure 50-70mm Hg.
- b. Maintain ICP < 20, excluding brief spikes related to nursing care (suctioning, turning), if brief.
- c. Detect “events”: rebleed, herniation, etc.

3. Medical manipulation of intracranial pressure

Manipulation of intracranial pressure involves manipulation of the volume of the contents of the intracranial vault: blood, brain, and CSF. Some therapies are indicated only for certain disease processes, most therapies are to some degree controversial.

a. Mechanical ventilation

Oxygen saturations should be kept >95%. Sometimes PEEP is necessary in order to achieve this. Remember ABCs first-do not sacrifice oxygenation in order to keep off PEEP. It is usually relatively unimportant in altering cerebral venous return and CPP. Hypoxia will cause vasodilation and hence increases in cerebral blood volume (autoregulation).

PaCO₂ has a significant effect on cerebral blood flow if autoregulation is intact (and sometimes even when it is not). Hypercapnia will greatly increase CBF, via an indirect mechanism which occurs rapidly (seconds to minutes). Hyperventilation is quite useful acutely, to reduce the intracranial volume and prevent herniation while awaiting the effect of other maneuvers or medications. When used to a moderate degree long term (pCO₂ < 28 for greater than 5 days), it has been shown to correlate with worse outcome. The key is to avoid hypercapnia. Mild hyperventilation (pCO₂ 32-36) is often used in the presence of significant head trauma. ETCO₂ monitoring is sufficient once accuracy of the ETCO₂ monitor is established with a blood gas.

b. Mannitol-many mechanisms of action

- i. Decreases blood viscosity by lowering the hematocrit, leading to lower cerebral vascular resistance and higher cerebral blood flow, followed rapidly by vasoconstriction of the arteriolar vessels, and reduction in cerebral blood volume. This effect occurs quickly (minutes).
- ii. There is no proof that mannitol works by decreasing brain water content in the injured brain. It may reduce brain water content in the uninjured portion of the brain, which may give the injured brain more room to swell. This may be what the patient needs.
- iii. Mannitol is an osmotic diuretic, hence it may be necessary to support the vascular volume-5% albumin may be used.
- iv. Rapid administration is more effective than slow infusion in

lowering ICP.

v. Dose for “chronic” use in monitored patients should be 0.25-0.5 grams/kg. There is no evidence that larger doses necessarily work better than small doses, and there are fewer side effects with smaller doses. In the setting of impending herniation, especially in the unmonitored patient, a large (1.0 grams/kg) dose should be pushed quickly.

vi. Frequent high doses of mannitol can lead to renal failure. Follow the serum osmolality (“osmolar gap” as well as absolute osmolality) if using large amounts of mannitol.

c. Lasix--when used in combination with osmotic agents (mannitol or albumin), the ICP lowering effect is synergistic. The best response should occur if mannitol is given 15 minutes before lasix. If using both, be especially careful about volume status and electrolyte management.

d. Barbiturates

i. Barbiturates will reduce intracranial pressure, at least in part by reducing the cerebral metabolic rate with an attendant reduction in cerebral blood flow which is mediated by vasoconstriction, and hence reduction in the **cerebral blood volume**.

ii. There is no evidence that the use of barbiturates improves outcome in head injured patients. This is a very difficult area to study effectively.

iii. Barbiturates will cause cerebral vasoconstriction but systemic vasodilation, and hence will lower systemic blood pressure, hence careful attention to volume status and BP must occur if barbiturates are used.

iv. Thiopental is short acting, and can be used to blunt the ICP response to suctioning or other particularly noxious stimuli. Dose is 2-4 mg/kg in the hemodynamically stable patient.

v. Pentobarbital “coma” -boluses of 5 mg/kg X 3-4, followed by an infusion of 1-5 mg/kg/hour, titrating to level (20-40) and ICP control. Again, monitor cardiovascular stability carefully.

e. Steroids--Decadron will help reduce vasogenic edema surrounding brain tumors and abscesses, and after neurosurgical manipulation (ie, tumor resection). It has no effect on cytotoxic brain edema (infectious, metabolic, hypoxic-ischemic), or in the management of head trauma. Steroids may have a role in treating some inflammatory or auto-immune diseases which are complicated by cerebral edema (ie, SLE, acute demyelinating encephalopathies)

4. Fluid Management

a. “Traditional” views of head injury advocated restricting fluid administration in hopes of preventing cerebral edema in areas of injured brain. This is controversial.

b. Severe intravascular dehydration can lead to cardiovascular compromise, episodes of hypotension and ischemia, and is thus to be

avoided at all costs in the head injured patient.

c. Hypo-osmolality (ie, decreased serum Na) as a result of SIADH or inappropriately hypo-osmolar fluid regimens is relatively common, and can lead to increased edema and/or seizures, both to be avoided in the head injured patient.

d. Reasonable regimens include D51/2 NS or D5NS at slightly less than maintenance (so as to avoid Na overload). Follow serum sodium, glucose and volume status closely.