Controlling the increased intracranial pressure – a neurointensivist's point of view

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Abstract

The management of severe traumatic brain injury still represents a challenge for the neurosurgeons and neurointensivist specialists. The central aim of the therapy is lowering the intracranial pressure. There are many ways of accomplishing this goal, by means of medical or surgical treatment. This article is a review of the papers and guidelines in the literature regarding the control of the elevated intracranial pressure.

Keywords: severe traumatic brain injury, intracranial pressure monitoring, neurointensive care

Introduction

The intracranial pressure (ICP) refers to the compartment inside the skull - since the brain is almost completely incompressible and the skull is a rigid structure with only one outlet (the formaen magnum), expansion of the volume in any component within the skull causes an increase in the pressure of the cranial compartment.

The principles of increased intracranial pressure are defined by the modified Monro-Kellie doctrine: the normal components within the intracranial space are the brain, blood, and cerebrospinal fluid (CSF). To these three sometimes is added a mass lesion such as a hematoma or a tumor which can also contribute to the volume of the intracranial space.

An increase in the volume of one of the components contained within the intracranial space can occur only at the expense of the other components. As the volume of edema in the brain or an expanding mass lesion increases, initially the CSF volume decreases, then the blood volume decreases. Continued expansion of intracranial volume after these compensatory mechanisms are exhausted causes a rapid increase in ICP and herniation of the brain.

Monitoring the intracranial pressure

Due to specific technical problems, sometimes arise the question – when, how and which patients need monitoring of the ICP, not mentioning the costs of the procedure? Generally admittance is that patients having suffered mild / moderate head injuries (Glasgow Coma Scale (GCS) 9 to 15) do not undergo ICP monitoring. However, patients with severe head injuries (GCS 8 to 3) have a significant chance of developing intracranial hypertension which varies from 5 % to 67% with the descent of GCS [1].

Intracranial volume = (constant)		**Cerebral parenchymatous volume**	+	**Blood volume**	+	**Volume of cerebrospinal fluid**	+	**Pathological Supplementary volume**

According to data from Brain Trauma Foundation, published in 2007 [2]:

- there are insufficient data for recommending level I indications (based on good quality randomized control trials (RCT's))

- level II (moderate quality RCT's) – ICP should be monitored in all salvageable patients with a severe TBI in terms of GCS and an abnormal CT scan (considering hematomas, contusions, swelling, herniations or compressed basal cisterns)

-level III (poor quality RCT's, moderate or poor quality cohorts) – ICP monitoring is indicated in patients with severe TBI, normal CT scan but two or more of the followings noted on admission : age over 40, unilateral or bilateral posturing, systolic blood pressure < 90 mm Hg

To these are added some of the neurointensivists recommendations, whenever possible in comatose patients with intracranial lesions : malignant sylvian infarction, acute hydrocephalus after aneurismal SAH, due to the direct data on ICP offered.

The gold standard for monitoring ICP is a ventriculostomy catheter inserted through a burr hole into one of the lateral ventricles. The ventriculostomy catheter is connected to a drainage system and can be used to monitor the ICP through a fluid-coupled external pressure transducer. This system provides the most accurate measurement of ICP and is stable over time. A ventriculostomy catheter will also allow drainage of CSF for control of ICP. Problems associated with ventriculostomy catheters include blockage of the catheter, displacement of the catheter from the ventricle, and infection. Antibiotic-impregnated ventriculostomy catheters reduce the risk of infection from 9.4% to 1.3% [3].

Other invasive monitors for ICP include intraparenchymal, subdural, and epidural monitors. These probes use either a strain gauge or a fiberoptic probe. These probes require zeroing prior to insertion and are subject to drift over time. Of these probes, intraparenchymal probes are the most accurate with the least amount of drift. The advantage of these probes is that they do not have to be inserted into the ventricle, which may be difficult to locate if it is collapsed or if there is significant midline shift.

A problem in ICP monitoring arises from the fact that ICP is not identical throughout all the intracranial space. From patients with bilateral symmetric transducers but lesion in one hemisphere, the difference between the 2 sensors can be up to 25 mm Hg, especially for acute SDH or contusions[4]

The intracranial pressure as a function of increasing volume in the intracranial space is a nonlinear function (figure 1) . Early increases in volume of a mass lesion result in displacement of CSF from the cranial compartment into the spinal compartment and cause little increase in ICP. Once the maximal amount of CSF has been displaced from the intracranial compartment, the ICP increases rapidly.

Cerebral Perfusion

Cerebral perfusion pressure (CPP) is defined as the mean arterial pressure (MAP) minus the ICP and is the driving pressure for cerebral blood flow (CBF).

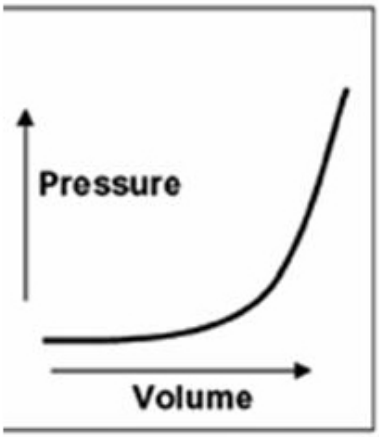

Figure 1 The relationship between intracranial pressure and volume

Pressure autoregulation is the intrinsic ability of the cerebral vasculature to maintain flow constant over a wide range of CPP values. Normally, the brain is able to autoregulate and to maintain an adequate CBF at CPP values ranging from 50 to 140 mm Hg. However, dynamic pressure autoregulation is commonly dysfunctional in the injured brain . When pressure autoregulation is impaired, the lower limit of autoregulation can be shifted upward from 50 to 60 to 90 mm Hg [5]. When pressure auto regulation is entirely absent, perfusion passively follows CPP. This loss of normal autoregulation requires careful maintenance of a sufficient MAP and adequate control of ICP to avoid hypoperfusion of the brain. Extremely elevated MAP should also be avoided as it can cause increased ICP.

The influence of CPP relies in its influence on patients outcome: in traumatic comatose patients with ICP over 20 mm Hg, the maximizing of CPP over 70 mm Hg leaded to a mortality of only 29% with over 80% of the survivors with no or minimal neurological deficits [6]. To maintain such perfusion, aggressive CSF drainage was used, together with an association of vasopressors : phenylephrine max. 4ug/kg/min, norepinephrine max. 0.2-0.4 ug/kg/min and dopamine at renal protection dose. The authors suggest that there is no tendency for high CPP to potentate elevated intracranial pressure.

To this maximal CPP theory is opposed "the LUND concept"[7] from Sweden considering that maintaining CPP at high values may result in vasogenic edema by transudation of fluid through the altered vasculature of the brain. This transcapillary leakage together with inotropic stimulation results in vasodilatation and interstitial edema which contributes in raising the ICP. According to them, reduction of ICP must be realized with a combination of low dose thiopental (1-3 mg/kg/h) , fentanyl (2-5 ug/kg/h) and dihydroergotamine (0.1-0.9 ug/kg/h infusion) which acts like a precapillary and large vein vasoconstrictor. Metoprolol as β1 antagonist and α2 agonist clonindine may be added to reduce medium arterial pressure to normal age-indexed values. Fluid balance is maintained slight negative. While the LUND therapy achieved excellent survival (49/53 comatose patients, 92%) and recovery (85% had GOS 4 and 5), there are no actually randomized studies to compare the two strategies[8].

Brain metabolism

Indirectly connected to the perfusion of the brain is the way the cerebral tissue utilizes glucose and oxygen provided.

The insertion of a brain tissue pO_2 probe allows continuous monitoring of oxygenation in a local region of the brain. The location of the probe is critical and determines the nature of the pO_2 information that will be obtained. If the probe is inserted near a focal lesion,

oxygenation can be monitored in the tissue at greatest risk should the injury expand. Insertion of the probe in uninjured brain allows monitoring of a local area that should be representative of the overall less-injured oxygenation status of the brain. Normal values and critical threshold values for PbO_2 are somewhat less accepted. In normal anesthetized subjects, PbO_2 in normal brain ranges from 20 to 40 mm Hg. Recent studies comparing PbO_2 values to PET measurements of oxygen extraction fraction (OEF) found that the PbO_2 value associated with an OEF of 40% (the mean value for OEF in normal subjects) was 14 mm Hg [9]. Values of PbO_2 that indicate tissue hypoxia / ischemia are probably considerably less than 14 mm Hg.

Prospective studies have demonstrated that PbO2 less than 15 mm Hg is associated with poor outcome. Some studies have suggested that a treatment protocol aimed at keeping brain pO_2 higher than 25 mm Hg may reduce mortality when compared to patients treated similarly with no brain pO_2 probe[10].

Jugular venous oxygen saturation (SjvO2) can be measured by inserting a catheter into the internal jugular vein and advancing it to the skull base. This allows measurement of the oxygen saturation of the blood exiting the brain, which provides information on the adequacy of cerebral blood flow and oxygen delivery to the brain. Fiberoptic continous oxygen saturation monitoring or frequent jugular blood sampling are used to compute the cerebral oxygen consumption:

CMR O2 = CBF x difference [Conc Art. O2 – Conc.Jug.Vein O2]

Use of $SjvO_2$ and of the cerebral metabolic rate allow an assessment of both brain hemodynamic reserve and its metabolic resolution, limiting potentially deleterious side effects of therapeutic interventions aimed at ICP control. $SjvO_2$ is normally between 55-75% and a value less than 50% suggest the use of a therapy aimed at increasing oxygen delivery (raising CBF, ventilation). As long as $SjvO_2$ remains at normal values, it allows the decrease of CPP to lower levels and consecutive ICP, by increasing the ventilation level and diminishing $PaCO_2$.

Episodes of jugular venous oxygen desaturation are associated with worse neurologic outcome. Increased $SjvO_2$ may indicate decreased oxygen uptake in the brain. The major limitation of SjO_2 monitoring is that it cannot detect local ischemia within the brain. Serial measurements of both $SjvO_2$ and PbO_2 suggest that a PbO_2 of 8.5 mm Hg indicates a similar level of oxygenation as a $SjvO_2$ of 50% [11].

Treatment thresholds

As it has become possible to measure additional brain-specific physiologic parameters in the ICU, different management strategies have evolved that place special emphasis on parameters other than ICP.. However, all of these physiologic parameters are related to outcome, and there is no clear evidence that one parameter is more important than the others. The best circumstance occurs when ICP, CPP, and brain oxygenation are all maintained in normal ranges, and this should probably be the goal of management. When this is not possible, it is important to understand the limitations of each of the monitors when making therapeutic decisions. Additionally, clinical studies are needed to demonstrate what management strategies may best improve neurologic outcome.

Table 1
Normal values and treatment thresholds for physiologic parameters [12]

	NORMAL	*TREATMENT THRESHOLD*
ICP	0-10 mm Hg	20-25 mmHg
CPP	50 mm Hg	60 mm Hg
SjvO2	55-75%	50%
PbO2	20-40 mm Hg	8-10 mm Hg

Principles of therapy of elevated intracranial pressure

A thorough examination by a neurointensivist is mandatory, despite the fact that the patient has been already examined by the neurologist / neurosurgeon. Particular attention must be given to the ABC of resuscitation: stability and validity of endotracheal tube, ventilation status, arterial blood samples, cardiac rhythm and hemodynamic adequacy. Also should be considered the possibly iatrogeniccaly worsened cerebral edema by intravenous fluid at high rate or inappropriate, other injuries that may have escaped at the first examination in the Emergency Dept. or neurological status aggravated since the first examination.

General measures

Specific factors that may aggravate intracranial hypertension include obstruction of venous return (head position, agitation), respiratory problems (airway obstruction, hypoxia, hypercapnia), fever, severe hypertension, hyponatremia, anemia, and seizures. Routine critical care management of the patient at risk for intracranial hypertension should include measures to prevent these factors.

•Positioning - while elevation of the head in order to lower the ICP is a well known principle, only later was found that while ICP does not significantly decrease when raising from 10 to 45 degrees, CPP, CVP and blood systolic pressure did diminish[13]. Among other studies, the best option appear to maintain only a slight elevation, 15-30 degrees, which has little or no effect on CBF and CPP, with the head in neutral position to minimize the decrease in jugular venous outflow

•Sedation and neuroparalysis - sedation with Propofol (10-100 ug/kg/min) is preferred to neuromuscular block because it can be quick and completely reversed in minutes. Other sedatives can be used as well as short acting benzodiazepine Midazolam or longer acting Lorazepam, but Propofol is preferred due to its fast-off properties, that allow a patient to be sedated and awakened when necessary, not to mention its possible neuroprotective action. If sedatives alone are not capable of controlling an agitated patient, a neuromuscular blocking agent can be added (Atracurium or Pancuronium).

•Maintain normoglycemia - in any cerebral lesion, hyperglycemia (>150 mg/dL) has been noted to worsen outcome, through decreased oxidative metabolism in local ischemic areas, increase lactate production and cellular disfunctions. Ischemic strokes need an even tighter control [14]

•Hyperventilation - therapy is based on the idea that a decrease in $paCO_2$, from 30 to 35 mm Hg, can reduce intracranial pressure by constricting cerebral blood vessels and reducing cerebral blood volume, effects mediated by the change in pH induced in the extracellular fluid. The effects of hyperventilation on ICP are immediate, but the duration of the effect is brief because the pH of the brain, at least in normal individuals, soon equilibrates to the lower pCO_2 level. After several studies[15,16], despite good initial results, no significant improve in outcome was

found at 6-12 months (even with THAM to resolve CSF acidosis or clinical introduction of $SjvO_2$ to evaluate exaggerate hyperventilation to $paCO_2$ of 25-30 mm Hg) with long-term hyperventilation, even worse outcomes after traumatic brain injury, possibly secondary to reduction in CBF. The concomitant adverse effect of progressive decreasing PbO_2 in the first 5 days[17] make hyperventilation to be used only as a short-term therapeutic intervention, only to control acute increase of the ICP after the first 24 hours after injury [18]

• Osmotic therapy - one of the mainstays of treatment of elevated ICP is osmotic therapy with either mannitol or hypertonic saline. This treatment can be initiated prior to insertion of an ICP monitor if signs and symptoms of herniation are present.

The effects of mannitol are correlated to its hyperosmolality, creating an osmolar gradient between the vascular space and the normal brain tissue space, whilst in lesional areas the membrane pump failure prevents partially the movement of water. The initial bolus is 0.25-0.5 g/kg - in the first 10 minutes there is an improvement of CBF due to the plasma expansion and improved blood fluidity, then at 30-60 minutes a decrease in ICP and cerebral brain volume. The use of small bolus dosages decreases the daily total dose when compared to continuous administration. Care should be taken to maintain serum osmolality below 320 mOsm, by checking serum sodium levels every 8 hours (max of 150 mEq/l) and avoid hypovolemia in order to prevent renal failure. The prolonged use of mannitol over 3 days or in severe lesions with blood-brain barrier destroyed may lead to aggravation of cerebral edema by penetration of mannitol in the interstitial space [19].

Although mannitol has been more widely studied, there are studies suggesting that hypertonic saline is more effective at lowering intracranial pressure. These studies have been small and have not demonstrated a statistically significant difference in outcome. The usual dose form is boluses of 7.5% hypertonic saline [20]. Other agents that are under investigation include hypertonic saline hetastarch, with studies to compare bolus doses of 7.2% hypertonic saline hetastarch 200/0.5 with 15% mannitol or 7.5% hypertonic saline/6% dextran solution to bolus dosing of 20% mannitol. Both studies showed improved reduction of ICP over mannitol but no difference in outcome [12,21].

• Steroids - several randomized, controlled studies have demonstrated no benefit in treating patients with traumatic brain injury with steroids. The recently completed Corticosteroid Randomization After Significant Head injury (CRASH) trial observed an increased risk of death in patients receiving methylprednisolone for 48 hours after injury [22]. Steroids are also not recommended for treatment of the cellular edema accompanying stroke. Steroids can be useful in treating vasogenic edema associated with brain tumors or selected parasitic infections.

• Last theoretic options - hypothermia and barbiturates. While hypothermia is seldom used due to its uncertain effects besides lowering ICP (increased coagulability, increased rate of infections), barbiturates are used sometimes in order to decrease CMRO2 and inhibition of free radicals. To achieve a barbituric coma and burst suppression on EEG the loading dose of 10 mg/kg intravenously (IV) over 30 minutes is followed by 5 mg/kg per hour for three doses and maintenance dose of 1 mg/kg per hour, with continuous EEG monitoring if available. However pentobarbital coma is associated with significant morbidity, mainly hypotension which require concomitant administration of vasopressors, high risk of pneumonia, pressure ulcers, and paralytic ileus.

• Non ICU options are those provided

by neurosurgeons - removal of CSF by ventricular drainage or decompressive craniectomy.

Conclusions

High ICP can be caused by several lesions, including stroke, subarachnoid hemorrhage, mass lesion, hydrocephalus, and trauma. Initial management is focused on maintaining oxygenation and perfusion using the ABCs of resuscitation. If signs of herniation are present, an initial bolus of mannitol should be given. A ventriculostomy catheter should be inserted to allow monitoring of ICP. Treatment should be initiated with the goal of maintaining ICP below 20 to 25 mm Hg and the CPP at 60 mm Hg. Initial treatments of elevated ICP include sedation and paralysis, drainage of CSF, mild hyperventilation, and bolus administration of osmotic agents such as mannitol. If ICP is not controlled with these measures, additional treatments including pentobarbital coma, hypothermia, or decompressive craniectomy can be considered. Last problem is that high ICP for a stroke or traumatic brain injury may be a normal ICP in brain tumors or chronic hydrocephalus.

References

1. www.braintrauma.org/coma-guidelines 2009
2. Guidelines for the management of severe brain injury. A joint project of the Brain Trauma Foundation. Journal of Neurotrauma, vol. 24, suppl. 1, 2007
3. Chambers IR, Kane IJ, Signorini PF et al – Bilateral ICP monitoring- its importance in detecting the severity of secondary lesions, Acta Neurochir, 1998, Suppl, 71 : 42-43
4. Hlatky R, Furuya Y, Valadka AB, et al. Dynamic autoregulatory response after severe head injury. J Neurosurg. 2002;97:1054
5. Rosner MJ, Rosner SD, Johnson AH – Cerebral perfusion pressure – Management protocol and clinical results, J.Neurosurg, 1995, 83:949-962
6. Eker C., Asgeirsson, B., Grande PO et al - Improved outcome after severe head injury with a new therapy based on principles for brain volume regulation and preserved microcirculation, Critical Care Medicine. 26(11):1881-1886, November 1998.
7. Schneck, Michael J. - Treating elevated intracranial pressure: Do we raise or lower the blood pressure? Critical Care Medicine. 26(11):1787-1788, November 1998.
8. Johnston AJ, Steiner LA, Coles JP, et al. - Effect of cerebral perfusion pressure augmentation on regional oxygenation and metabolism after head injury. Crit Care Med. 2005;33:189
9. Stiefel MF, Spiotta A, Gracias VH, et al. Reduced mortality rate in patients with severe traumatic brain injury treated with brain tissue oxygen monitoring. J Neurosurg. 2005;103:805
10. Kiening KL, Unterberg AW, Bardt TF, et al. - Monitoring of cerebral oxygenation in patients with severe head injuries: brain tissue PO2 versus jugular vein oxygen saturation. J Neurosurg. 1996;85:751
11. Elevated intracranial pressure in Civetta, Taylor and Kirby's Critical Care, Lipincott 2008, chapter 146
12. Feldman Z., Kanter M - Effect of head elevation on intracranial pressure, cerebral perfusion pressure, and cerebral blood flow in head-injured patients, J.Neurosurg, 1992 Vol. 76, 2: 176-183
13. Bruno A, Biller B, Adams HP – Acute blood glucose level and outcome in ischemic stroke, Neurology, 2004, 57: 280-284
14. Muizelaar JP, Marmarou A, Ward JD, et al. - Adverse effects of prolonged hyperventilation in patients with severe head injury: a randomized clinical trial. J Neurosurg. 1991;75:731
15. Cruz J, The first decade of continuous monitoring of jugular bulb oxyhemoglobin saturation. Management strategies and clinical outcome, Crit. Care Med, 1998, 26: 344-351
16. Suazo, J., Antonio C., Maas A, et al - CO2 reactivity and brain oxygen pressure monitoring in severe head injury, Crit Care Med. 28(9):3268-3274, Sept 2000
17. Layon AJ, Gabrielli A - Elevated Intracranial Pressure in Neurointensive Care- Specific Problems in Textbook of Neurointensive Care, Saunders, 2004
18. Brain Trauma Foundation.- Hyperosmolar therapy. J Neurotrauma. 2008; 24:S14-S20
19. Vialet R, Albanese J, Thomachot L, et al. - Isovolume hypertonic solutes (sodium chloride or mannitol) in the treatment of refractory posttraumatic intracranial hypertension: 2 mL/kg 7.5% saline is more effective than 2 mL/kg 20% mannitol. Crit Care Med. 2003;31:1683
20. Battison C, Andrews PJ, Graham C, et al. - Randomized, controlled trial on the effect of a 20% mannitol solution and a 7.5% saline/6% dextran solution on increased intracranial pressure after brain injury. Crit Care Med. 2005;33:196
21. Edwards P, Arango M, Balica L, et al. Final results of MRC CRASH, a randomised placebo-controlled trial of intravenous corticosteroid in adults with head injury-outcomes at 6 months. Lancet. 2005;365:1957