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Neurocritical Care

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1. Introduction

Neurocritical care is at the forefront of bringing effective new therapies to patients with life threatening neurological diseases. Neurocritical care units have evolved from neurosurgical units focused primarily on postoperative monitoring to units that provide comprehensive medical and specialized neurological support for patients with life-threatening neurological diseases. In addition to standard interventions, areas of expertise unique to neurocritical care include management of intracranial pressure, hemodynamic augmentation to improve cerebral blood flow, therapeutic hypothermia, and advanced neuromonitoring. Neurointensivists defragment care by focusing on the interplay between the brain and other systems, and by integrating all aspects of neurological and medical management into a single care plan. Outcomes research has established that victims of traumatic brain injury and hemorrhagic stroke experience reduced mortality, better functional outcomes, and reduced length of stay when cared for by neurointensivists in a dedicated neurointensive care unit (Rincon & Mayer 2007). This chapter aims to provide an overview of global organ support of the critically ill neurosurgical patient.

2. Critical care for neurosurgical patients

The neurocritical care unit provides a venue where advanced monitoring enables optimisation of oxygen and metabolite delivery to the neurons by aggressive, often invasive interventions within a controlled environment.

2.1 Brain monitoring

The word "monitor" originates from the Latin *monere* (to warn). Monitoring merely provides warning of pathology and may track its progression long before it becomes clinically obvious thus allowing earlier aggressive management of underlying disease and assessment of response to therapy. The superiority of any one mode of monitoring over another has never been proven.

Available forms of brain monitoring include

Measurement of intra cranial pressure (ICP): ICP has traditionally been measured by a ventricular drain connected by a fluid coupled system to an external strain gauge.

Currently, available options include systems with micro strain gauges or fibreoptics built into the tip. Catheters may be placed in the parenchyma, subarachnoid, epidural or

subdural spaces in addition to the ventricles. Generally, parenchymal catheters with micro strain gauges in the tip have good correlation with ventricular drain pressures. Subarachnoid, subdural and epidural catheters are thought to be less accurate.

Micro strain gauge and fibreoptic catheters need to be calibrated prior to insertion and cannot be recalibrated in situ. Theoretical concerns have been raised about measurement drift and resulting inaccuracy of measurement. There is little by way of published literature and the actual device selection is guided by institutional preference.

Measurement of cerebral blood flow: Transcranial Doppler monitoring is an easily available, reproducible, non invasive and inexpensive means of measuring cerebral blood flow by measuring flow velocity in the middle cerebral artery (MCA). It has been used to assess for cerebral vasospasm, to assess cerebral autoregulation (Reinhard et al, 2010) and diagnose traumatic dissection of the internal carotid artery (Bouzat et al, 2010).

Measurement of brain oxygenation: Jugular venous oxymetry (SjO2) has been used to assess oxygen delivery to the brain. Both low (<55%) and high (>75%) SjO2 have been associated with poor outcomes. The arterio jugular difference in oxygen content has been measured to assess cerebral oxygen extraction.

Brain tissue oxygenation (PBrO2) can be directly measured by placing catheters into affected areas of the brain to detect focal ischaemia. PBrO2<15 mmH is associated with poor neurologic outcome.

Near infra red spectroscopy (NIRS) has been mooted as a non invasive measure of regional transcranial oxygen saturation (rSO2). Though promising, its routine use in neurocritical care is potentially impeded by the presence of scalp wounds, hematoma and intracranial catheters.

Assessment of metabolic state: Cerebral microdialysis catheters placed directly into brain tissue have been used to measure levels of brain metabolites. The commonly measured ones are glucose, lactate, glutamate, pyruvate and lactate/pyruvate ratio. The use of these devices is uncommon outside of larger academic centres. Given the paucity of correlation with outcomes data, their routine use cannot currently be recommended.

Assessment of electrical activity: This has traditionally been done using electroencephalography (EEG). Its widespread use in critical care has been impeded by difficulties in the interpretation of EEGs by non neurologists.

Bispectral index (BIS) is a processed EEG monitoring tool that evaluates brain electrical activity for zero (flat line EEG) to 100 (awake patient). It is not in routine use currently in critical care environments.

Somatosensory evoked potentials (SEP) have been validated for prognostication after hypoxic brain injury. Delayed N20 bilaterally has been shown to correlate with poor neurologic outcome.

2.2 Management of ICP

ICP in normal subjects is usually less than 10 mmHg. It is generally accepted that active treatment for elevated ICP should be initiated for sustained rises in ICP to greater than 20 mmHg. The definitive treatment of elevated ICP remains, of course, management of the underlying pathology.

The following sequence of events is a suggested escalating way of medically managing elevated ICP to return it to <20mmHg. It is useful to simultaneously maintain a cerebral perfusion pressure (CPP) >60 mmHg, where CPP is the difference between mean arterial pressure (MAP) and ICP

- If the patient is not already intubated, consideration should be given to intubating and mechanically ventilating the patient to facilitate deep sedation
- The patient should be nursed 30-45° head up, if possible with head in neutral position and ties around the neck (eg. endotracheal tube tapes, cervical collars) loosened or repositioned if possible
- Ventilation titrated to normoxia (SaO2>90 mmHg, PaO2>70 mmHg) and normocapnia (PCO2 35-45 mmHg)
- Liberal opiate analgesia
- Liberal sedation targeting Richmond Agitation and Sedation Scale (RASS) -4 or lower.
- Neuromuscular blockade if frequent shivering or coughing
- Prompt treatment of any seizure activity
- Addition of phenobarbitone
- Hyperosmolar therapy (either 0.5-1 gm/kg of mannitol or 3% NaCl to target serum sodium ~150)
- Hyperventilation to PCO2<25 mmHg
- At this stage, consideration should be given to immediate evacuation of any mass lesions. Consideration should also be given to placing a ventricular catheter to drain CSF.
- Induction of hypothermia
- Consideration should be given at this stage to extreme measures like decompressive craniotomy or thiopentone infusion

2.3 Sedation, analgesia and neuromuscular blockade

A variety of drugs are commonly used to sedate and treat pain in critically ill ventilated patients.

It is inhumane to deny analgesia to a patient for fear of clouding neurologic signs. Adequate analgesia minimises noxious stimuli which may contribute to elevated ICP, ventilator dyssynchrony and reactive hypertension. In addition, opiates have sedative properties and can be used alone for sedation or in combination with other sedative agents. Morphine is traditionally the drug of choice. The author's practice is to be liberal with opiates and wherever possible, to use patient controlled analgesia. Fentanyl and sufentanyl have been associated with small but definite rises in ICP. To minimise this, they may be administered slowly intravenously. Regular administration of paracetamol may reduce opiate requirements. In a peri operative setting, non steroidal anti inflammatories may be used with caution, allowing for the impact on kidneys, gastrointestinal tract and platelet function.

Sedation allows tube tolerance in most intubated critical care patients. In a neurosurgical setting, sedation is neuroprotective and reduces cerebral oxygen demand and cerebral metabolism. The commonly available agents available for sedation are benzodiazepines and

propofol. Given the association between benzodiazepines and increased delirium, the author's preferred first line agent is propofol, where haemodynamics permit. Caution needs to be exercised where more than 5 mg/kg/hour is being infused for more than 24 hours. Midazolam infusion is a reasonable alternative and, where clinically indicated, the two may be combined. The author's practice is to give daily sedation breaks as soon as clinically feasible. Alpha blockers like clonidine or dexmedetomidine should be considered for emergence delirium and as adjuncts to analgesia. Barbiturates are not routinely used for sedation in an ICU setting.

Neuro muscular blockade may be necessary for ongoing shivering, coughing or movement causing significant rise in ICP. It may also be needed to facilitate procedures and intra and/or inter hospital transport. This needs to be balanced against the association between neuromuscular blockade and the development of critical illness polymyoneuropathy which, in turn, can worsen outcomes prolong time on ventilator, ICU stay and hospital stay. The author's practice is to use small doses of non depolarising agents (vecuronium or atracurium) when clinically indicated.

2.4 Seizure management and prophylaxis

Craniotomies, especially supratentorial ones, are associated with a high incidence of post operative seizures. Depending on the reason for surgery, up to 50% patients have at least one seizure treated postoperatively (Shaw & Foy, 1991). There are no formal guidelines for routine seizure prophylaxis after neurosurgery in general.

Prophylactic anticonvulsants should not be used routinely in patients with newly diagnosed brain tumours. Anti convulsants should be tapered and discontinued after the first postoperative week in patients who have not had seizures (Glantz et al, 2000).

In traumatic brain injury, anticonvulsants are indicated to decrease the incidence of early post traumatic seizures (within 7 days of trauma). Early post traumatic seizures are not associated with worse outcomes. Phenytoin has been shown to reduce the incidence of early post traumatic seizures. Valproate has an effect comparable to phenytoin in reducing early post tramatic seizures but may be associated with higher mortality (Brain Trauma Foundation Guidelines, 3rd ed). Routine use of anticonvulsants is not recommended later than 1 week following head injury to prevent late post traumatic seizures and does not reduce their incidence.

2.5 Hyperosmolar therapy

Hyperosmolar therapy is often used to treat elevated ICP. It may buy time to do diagnostic (eg. imaging) or therapeutic (eg. evacuation of mass lesion) interventions. In the absence of ICP monitoring, its use should be restricted to patients with signs of transtentorial herniation or deteriorating neurologic state not attributable to extra cranial causes.

The two agents in common use are mannitol and hypertonic saline.

Mannitol in the dose range of 0.25-1 gm/kg as a bolus is effective in reducing ICP. While it has been used as prolonged therapy for raised ICP, there is lack of evidence to recommend repeated regular administration of mannitol over several days. Serum osmolarity should be

monitored when mannitol is being administered, especially if repeated doses are being considered. While mannitol acts by increasing serum osmolarity, there is significant risk of acute kidney injury at high serum osmolarities. While there is no absolute threshold for a particular patient, osmolarities of more than 320 mOsm/L are likely to be hazardous. In the neurosurgical patient with a compromised blood brain barrier, theoretical concerns have also been raised regarding mannitol causing osmotic oedema in the injured areas of the brain, further compromising perfusion to these areas.

Hypertonic saline acts by osmotic mobilisation of water and reduction of total cerebral water content. It is usually well tolerated, cheap and easy to titrate off serum sodium levels, which are routinely measured in most intensive care units. Caution must be exercised in its liberal use in patients with chronic hyponatremia due to the risk of inducing central pontine myelinolysis. There is not enough strong evidence at present to make recommendations regarding the concentration or method of administration of hypertonic saline for treatment of raised ICP. As unmeasured hyperosmolar particles (such as mannitol) are not introduced to the serum, adequate osmolar monitoring is readily available from the serum sodium level. The author's practice is to use 20 ml aliquots of 3% NaCl aiming for a serum sodium level ~150 mmol/L.

There is a paucity of data on the safety and efficacy of combined hyperosmolar therapy with mannitol and hypertonic saline.

2.6 Induced hypothermia

Mild induced hypothermia (core temperature 32-34°C) has been thought to offer neuroprotection by reducing cerebral oxygen demand, altering the inflammatory cascade and reducing ICP.

There is no clear evidence that induced hypothermia reduces mortality in a neurosurgical population. In patients undergoing temporary clipping for aneurysm surgery, hypothermia was not associated with improved neurologic outcomes (Hindman et al 2010). A multi centre trial is currently under way to assess 6 month functional outcome after induction of hypothermia in patients with brain trauma (North American Brain Injury Study: Hypothermia IIR, Clifton et al, 2009).

3. Extracranial organ support in the neurocritical care unit

Critically unwell neurosurgical patients also need ongoing management of other organ systems and management of other non brain pathologies. Critical care interventions on extra cranial organs have implications for cerebral circulation and metabolism. Appropriate care also minimises secondary injury to the brain after primary insults like trauma.

3.1 Respiratory support

Mechanical ventilation has rapidly evolved in recent years, guided primarily by improved understanding of pathophysiology. Neurosurgical patients heavily rely on ventilation for support, and less commonly, for therapy. Meeting ventilation needs of these patients while minimising ventilator induced lung injury can be challenging (Johnson et al, 2007).

The purpose of ventilator support may loosely be divided into those of optimising systemic arterial oxygenation (PaO_2) and oxygen saturation (SaO_2) and regulating partial pressure of carbon dioxide in arterial blood ($PaCO_2$).

Hypoxia ($PaO_2<60$ and/ or $SaO_2<90$) is associated with poor neurologic outcomes in patients with acute brain injuries (Young et al 2010). The duration of hypoxia itself is an independent predictor of mortality (Jones et al 1994). The physiologic response to cerebral hypoxia is increased cerebral blood flow. In the context of elevated intracranial pressure, the resultant increase in intracranial blood volume is likely to exacerbate intracranial hypertension. This can be rapidly corrected by ventilating to normoxia ($SaO2>90$, $PaO2>70$) and often requires intubation and mechanical ventilation.

While primary insults like trauma cause areas of focal hypoperfusion of the brain, there is no conclusive evidence supporting attempts to achieve supra normal PaO_2 to improve local oxygen delivery. Extreme hyperoxemia may be detrimental in patients with severe traumatic brain injury (Davis et al 2009). Certainly, among patients admitted to intensive care after resuscitation from cardiac arrest, hyperoxia ($PaO_2>300$) is associated with increased risk of in hospital mortality (Kilgannon et al, 2010).

Historically, aggressive hyperventilation to induce hypocapnia ($PaCO_2<25$) has been advocated to reduce intracranial pressures (ICP). While hyperventilation certainly reduces ICP, the mechanism by which this occurs is cerebral vasoconstriction, reducing cerebral blood flow and ultimately, compromising blood flow to brain tissue. Prophylactic hyperventilation is no longer recommended and this intervention should be limited to being a temporising measure in the management of intractably elevated ICP. Its benefits may be outweighed by risks in the first 24 hours after acute brain insult when perfusion to the brain is poor and, where available, should be used in conjunction with monitoring of cerebral perfusion like jugular venous saturation ($JvSO_2$). (Brain trauma foundation guidelines edition 3). Hypercapnia ($PCO2>50$) causes cerebral vasodilation, increasing cerebral blood volume and thereby ICP. The optimal strategy would be to aim for normocapnia ($PaCO_2$ 35-45).

Positive end expiratory pressure (PEEP) improves oxygenation and forms part of routine lung protective ventilation strategies. Traditionally, concerns have been raised regarding the use of PEEP in ventilating neurosurgical patient as it may increase ICP and, by extension, reduce cerebral perfusion pressure (CPP). Low levels of PEEP to improve alveolar recruitment have been shown to not change ICP (Mascia et al 2005). Increasing PEEP to as high as 15 cmH2O to improve oxygenation was paradoxically associated with decreases in ICP and improved CPP (Huynh et al 2002).

Reasonable goals of ventilation would be to achieve SaO2>90, PaO2>70, PCO2 35-45. Lung protective ventilator strategies (low tidal volumes 6-8 ml/kg, judicious use of PEEP) would meet the ventilatory requirements of the majority of neurosurgical patients. Additional measures such as loosening tapes securing endotracheal tubes and optimum head positioning and head elevation to prevent jugular outflow obstruction would be of benefit to maintaining adequate CPP.

3.2 Cardiovascular support

The goal of all resuscitation is the delivery of oxygen and metabolites to end organs. Hypotension, defined as a systolic blood pressure less than 90 mmHg, has been shown to

worsen outcomes from acute brain injury. Even isolated episodes of in hospital hypotension have been associated with increased mortality and morbidity (Jones et al, 1994). Due to ethical considerations, there is no Class I evidence on the effect of haemodynamic resuscitation on outcomes. However, raising the blood pressure improves outcome in proportion to the efficacy of the resuscitation (Vassar et al 1993).

The ideal fluid for volume resuscitation remains controversial. 0.9% NaCl remains the most commonly used fluid for this purpose, probably for reasons of familiarity, cost and ease of use. There is little conclusive evidence to support colloid over crystalloid therapy. The SAFE study suggested similar outcomes from fluid resuscitation with saline or 4% albumin. A post hoc analysis of the SAFE study data suggested higher mortality rates associated with fluid resuscitation with albumin compared to saline in patients with traumatic brain injury (SAFE study investigators, 2007). A multi centre randomised trial is currently under way comparing outcomes of resuscitation with saline and starch.

It is reasonable to use vasopressors and inotropes as needed to defend MAP and, by extension, CPP. There is no conclusive evidence to prove the superiority of any vasoactive agent over another. The use of these drugs is often determined by local critical care practice. The author's vasopressor of choice is noradrenaline.

The systolic blood pressure of 90 mmHg itself is a statistical rather than a physiological threshold. It makes more sense to try and approximate the patient's baseline blood pressure with hemodynamic therapies than chase an artificial statistical target. The author's practice is to stay within 20% of the patient's baseline blood pressure, where known.

Cerebral perfusion is reliant more on the systemic mean arterial pressure (MAP) and ICP. The MAP may be a more meaningful end point of resuscitation to aim for. Autoregulation of blood flow breaks down in most vascular beds below ~60 mmHg. Thus, assuming a "normal" ICP of 10 cmH_2O and intact cerebral vasculature, a MAP of 70 mmHg would be a reasonable initial target. Clearly, the above caveats are not necessarily true for many neurosurgical patients and, in the presence of ICP monitoring, the MAP can be titrated to maintain a CPP>60 mmHg. Alternately, in the presence of cerebral oxygenation monitoring (eg. JvSO2), the MAP can be titrated to adequate cerebral oxygenation.

There is no conclusive evidence for elevating MAP to supra normal targets. This may well be hazardous in the context of trauma or recent surgery, with concomitant disruption of the blood brain barrier and cannot be recommended in routine neuro critical care practice.

3.3 Nutrition

There is no disease process that benefits from lack of nutritional support. Critically unwell patients are hypercatabolic and at risk of losing significant lean body mass in the absence of nutritional support. Current practice would be to attempt to initiate nutrition early (within 72 hours) aiming to establish full calorific replacement within 7 days. Clearly this would be modified for patients presenting with evidence of poor nutritional state at baseline. Enteral nutrition, by gastric or jejunal routes, is the preferred route. In the event of inability to access the gut or failure to establish enteral nutrition within a reasonable time frame, parenteral nutrition should be considered.

Patients with traumatic brain injuries often have gastroparesis. Many drugs routinely administered in a critical care setting further alter gut motility. This is particularly true of opiates. Prokinetics (eg metoclopramide 10-20 mg 6 hourly) should be considered early in the establishment of enteral nutrition.

Reasonable goals of nutrition support should aim for 25-30 kcal/kg/day, of which 0.5-2 gm/kg/day should be protein content and 30-40% non protein content should be lipids. It is important to also supplement fat and water soluble vitamins and trace elements.

3.4 Glycemic control

Hyperglycemia is common in critically ill patients and is associated with morbidity and mortality in varying groups of patients.

In 2001, the Leuven Intensive Insulin Therapy Trial was published (van den Berghe et al, 2001), suggesting dramatic reductions in mortality in critically ill surgical patients with tight glycaemic control (target blood sugar 4.4-6.1 mmol/L). Subsequent studies failed to replicate these findings. Concerns were also raised regarding the risks of hypoglycaemia, increased resource use and the difficulty of achieving tight normoglycemia in critically ill patients.

The NICE-SUGAR study (Finfer et al, 2009) suggested blood glucose levels less than 10 mmol/L resulted in lower mortality than a target of 4.5-6 mmol/L. The author's current practice is to aim for a blood sugar level of 5-10 mmol/L.

3.5 Stress ulcer prophylaxis

Stress ulcers are a known complication of a variety of critical illnesses. They occur as a consequence of hypoperfusion of the mucosa of the upper gastro intestinal tract. It is common practice to provide prophylaxis to decrease the incidence of clinically significant bleeding.

The most commonly used classes of drugs used for this purpose are H2 antagonists, proton pump inhibitors and sucralfate. To a large extent, the agent used is dictated by local critical care practice.

H2 antagonists have been shown to be more effective than sucralfate, antacids and placebo in preventing stress ulcers (Stollman & Metz, 2005). However, concerns have been raised regarding the association between acid suppressive treatment and ventilator associated pneumonia (Cook et al, 1998). Ranitidine has been associated more strongly with nosocomial pneumonia than sucralfate (Messori et al, 2000). Further concerns have been raised regarding encephalopathy and cytochrome P450 induction by H2 antagonists. Omeprazole was shown to reduce clinically significant gastrointestinal bleeding compared to ranitidine (Levy et al, 1997). A recent single centre study found a higher association of nosocomial pneumonia with pantoprazole compared to ranitidine in cardiac surgical patients (Miano et al, 2009). Both H2 antagonists and proton pump inhibitors have been associated with increased risk of developing community and hospital acquired Clostridium difficile associated disease (CDC, 2005).

In keeping with the above, a recent systematic review was unable to find the most appropriate form of prophylaxis for neurocritical care patients (Schirmer et al, 2011). The

most sensible approach appears to be aggressive haemodynamic resuscitation to improve mucosal perfusion in the upper gastrointestinal tract and the establishment of early enteral nutrition, where possible. It is standard Australian practice to prescribe stress ulcer chemoprophylaxis and both H2 antagonists and proton pump inhibitors are commonly used.

3.6 Thromboprophylaxis

Critically ill neurosurgical patients are at high risk of developing venous thromboembolism. The incidence of deep vein thrombosis (DVT) in patients with traumatic brain injury is estimated to be as high as 20% (Brain Trauma Foundation Guidelines, 3rd ed.). Pulmonary emboli (PE) are associated with high rates of mortality and morbidity in hospitalised patients. Treatment of PE in neurosurgical patients is often complicated by uncertainty regarding the safety of anticoagulation soon after craniotomy or intracranial haemorrhage. It makes sense to try and prevent DVT than have to treat the PE.

Options for DVT prophylaxis are mechanical (graduated compression stockings and sequential calf or foot compression devices) or chemical (low dose heparin or low dose low molecular weight heparin). Recent studies have failed to prove the superiority of low molecular weight heparins over low dose unfractionated heparin (Cook et al 2011, Goldhaber et al 2002)

Mechanical interventions have low risk of complications and should be offered to all patients. Caution needs to be exercised in patients with severe peripheral vascular disease and limb trauma may preclude their use in some cases.

Both low molecular weight heparin and unfractionated heparin have been shown to be effective for prophylaxis of venous thromboembolism in elective neurosurgery (Ioro & Agnelli, 2000). In traumatic brain injury, the risk versus benefit analysis must be made on a case by case basis. There appears to be little difference in the incidence of DVT or PE in patients receiving chemical prophylaxis after 72 hours of admission compared to those receiving prophylaxis earlier than 72 hours (Kim et al, 2002). In the event that chemical prophylaxis cannot be initiated within 72 hours of admission, consideration should be given to a vena caval filter.

4. Prognostication in neurocritical care

The outcome of critically ill neurosurgical patients after significant brain insult remains uncertain. Patients may survive to a cognitively impaired dependent state or worse, in a minimally conscious or persistently vegetative state with resultant implications for resource use.

Prediction of outcome involves making probability statements that depend on a logical relationship between outcome and features encapsulated in antecedent data. It still remains impossible to predict with certainty the outcomes of an individual patient.

In a neurocritical care population, the groups most widely studied in this context are those with traumatic brain injury and hypoxic brain injury.

4.1 Traumatic brain injury

The brain trauma foundation has published prognostic parameters for traumatic brain injury. The following factors have been considered

- Glasgow Coma Scale (GCS) score: If the initial GCS is reliably obtained and not tainted by pre hospital medications or intubation, there is increasing probability of poor outcome with a low GCS in a continuous stepwise manner. Approximately 20% patients with initial GCS 3 will survive and 8-10% will have a functional survival.
- Age: There is increasing probability of poor neurologic outcome with age, with a significant rise in poor outcomes in age>60 years.
- Bilaterally absent pupillary light reflex is a predictor of poor neurologic outcome
- Hypotension (systolic BP<90 mmHg) alone has a positive predictive value (PPV) of 67% for poor neurologic outcome. In conjunction with hypoxia (SaO2<90%), the PPV for hypotension rises to 79%
- Presence of abnormalities on initial CT study: Compressed or absent basal cisterns, traumatic subarachnoid haemorrhage and midline shift at the level of the foramen of Monro are predictive of poor neurological outcomes.
- The Marshall score (Marshall et al, 1991) was developed from the Trauma Coma Data Bank (TCDB) for estimating the severity of diffuse axonal injuries seen on CT (Table 1). Marshall scores of 3 or higher are associated with dramatically higher incidence of mortality.

Grade	Definition
I	No visible intracranial pathology seen on CT scan
II	Cisterns present; midline shift 0–5 mm and/or lesion densities present; no high or mixed density lesion >25 cc
III	Cisterns compressed or absent with midline shift 0–5 mm; no high or mixed density lesion >25 mm
IV	Midline shift >5 mm; no high or mixed density lesion >25 cc

Table 1.

4.2 Hypoxic brain injury

Attempts have been made to identify prognostic factors for poor outcomes in patients with hypoxic brain injuries at up to 3 days after admission (Levy et al, 1985 and Zandbergen et al, 2006). The American Academy of Neurology has published guidelines for prediction of outcomes in comatose survivors of cardiopulmonary resuscitation (Wijdicks et al 2006).

Development of myoclonus status epilepticus within the 1st day, bilaterally absent cortical response on somatosensory evoked potentials (delayed N20) at day 1-3, serum neuron specific enolase (NSE) >33micrograms/L at day 1-3, absent pupillary or corneal reflexes on day 3 or extensor or absent motor response to stimulus on day 3 are predictive of poor neurologic outcomes.

Burst suppression or generalised epileptiform activity on EEG was predictive of poor outcome but with insufficient prognostic accuracy. Imaging (CT, MRI, PET) and duration of CPR were not reliable predictors of poor outcome.

5. Determination of brain death

Death has always had immense cultural and religious significance for human societies across the world. Until the Renaissance, there was no biological understanding of death. William Harvey's seminal paper "On the Motion of the Heart and Blood in Animals" in the 17th century laid the foundation to the understanding of death as irreversible cessation of cardiovascular function. In 1959, Wertheimer et al first described "death of the central nervous system" as a syndrome of coma, areflexia and apnoea. Later that year, Mollaret and Goulon coined the term "coma depasse" to describe this syndrome.

Brain death is defined as irreversible cessation of brain function. Prior to the diagnosis of brain death being made, the following preconditions must be met

- Definite clinical and/ or neuro imaging evidence of acute brain pathology consistent with irreversible loss of neurologic function (eg. traumatic brain injury, intracranial haemorrhage, hypoxic ischaemic encephalopathy)
- Normothermic (temperature >35°C), normotensive (systolic BP>90 mmHg, MAP>60 mHg) patient
- Severe electrolyte (specifically sodium, magnesium, calcium, phosphate), metabolic (blood sugar, renal and hepatic functions) and endocrine disturbances ruled out
- Effect of sedative drugs ruled out
- Intact neuromuscular function

For further clinical testing, the following are also essential

- Ability to adequately examine brainstem reflexes including at least one ear and one eye
- Ability to safely perform apnoea testing, which may be precluded by severe hypoxia or high cervical spine injury

If the preconditions are met, brain death may be diagnosed by

- Clinical examination OR
- Demonstration of absence of intra cranial blood flow

Clinical examination consists of

- Absence of responsiveness for a period of observation AND
- Absence of brainstem reflexes to clinical examination AND
- Apnoea despite arterial pH<7.3, PaCO2>60 mmHg

The American Academy of Neurology (AAN) guidelines (Wijdicks et al, 2010) comment that there is lack of evidence for a minimally acceptable observation period. The Australasian guidelines currently recommend a minimum 4 hour period of observation for unresponsiveness (The ANZICS Statement on Death and Organ donation).

It is common practice in Australasia for clinical testing to be carried out independently by 2 senior clinicians to confirm the diagnosis of brain death. This has been challenged in recent

times and, under the current AAN guidelines, confirmatory clinical testing by an independent clinician is no longer required.

If clinical testing is inconclusive or cannot be carried out, Australasian practice would be to demonstrate absence of intra cranial blood flow by

- 4 vessel (both carotid arteries, both vertebral arteries) intra arterial angiography with digital subtraction to demonstrate lack of blood flow above the level of the carotid siphon (anterior circulation) and the foramen magnum (posterior circulation)
- Technetium 99m labelled hexamethyl propylene amine oxime (Tc-99m HMPAO) radionuclide scan demonstrating absence of intra cranial perfusion
- Single photon emission computerised tomography (SPECT)
- CT angiography 60 seconds after contrast bolus at the level of Circle of Willis demonstrating contrast enhancement of the external carotid but not of middle cerebral artery cortical branches, P2 segment of posterior cerebral arteries, pericallosal arteries and internal cerebral veins

There is no documented case of a person who fulfils the preconditions and criteria for brain death ever subsequently developing any return of brain function.

6. Illustrative cases

6.1 Traumatic brain injury

A 32 year old man was brought in by ambulance to the Emergency Department after being assaulted in a pub.

At scene, he was noted to eye open to voice, localise to noxious stimuli and had incoherent speech. His heart rate was 98 and regular and his systolic blood pressure was 110 mmHg. The paramedics at the scene had basic life support skills only. Two large bore intravenous cannulae were inserted, fluid resuscitation with 0.9% NaCl commenced and the patient transferred with spinal precautions to the nearest trauma centre, about 5 minutes away.

On arrival to hospital, he was moaning and unresponsive to pain. His haemodynamic status remained unchanged.

In the trauma room, he was intubated with in line manual stabilisation, a cervical collar was applied and the head supported with sandbags and tape. He was ventilated with 100% oxygen to a PCO_2 of 35-40 and sedated with morphine and midazolam. Primary and secondary surveys revealed no major limb, thorax, abdominal, pelvic or spinal trauma. There was no clinical evidence of base of skull fracture and his pupils were equal and reactive. He was taken for a non contrast CT of his head and neck. His cervical spine was intact and he was diagnosed as having an acute subdural haemorrhage about 15 mm in thickness over the left temporoparietal hemisphere with 5 mm midline shift. Subarachnoid blood was also noted.

In the operating room, the subdural haemorrhage was evacuated with a craniotomy and an external ventricular drain (EVD) inserted. The patient was transferred to the intensive care unit intubated and ventilated.

Over the next 24 hours, he remained deeply sedated with a combination of benzodiazepines, propofol and opiates and needed intermittent neuromuscular blockade with vecuronium. He required repeated drainage of CSF through his EVD and several administrations of 3% NaCl

to keep his ICP <20 mmHg. His MAP was manipulated with noradrenaline to maintain a CPP >60 mmHg. His pupils remained equal and reactive and normothermia and euglycemia maintained. In terms of extracranial organ support, he was ventilated to normocapnoea and SaO_2 were maintained >92% at all times, with PEEP of 5 cmH$_2$O. Apart from manipulation of MAP to maintain CPP >60mmHg, he remained cardiovascularly stable and his ECG remained unchanged from normal sinus rhythm. Enteral nutrition was commenced through an orogastric tube. Ranitidine was given intravenously for gut protection. Only mechanical thromboprophylaxis with sequential calf compressors was provided.

Over the subsequent 72 hours, the ICP remained stable at less than 20 mmHg and sedation was lightened. Pupils remained equal and no seizure activity was noted. The CT showed no further progression of brain pathology and some resolution of cerebral oedema. There were no other extracranial organ support issues. On day 5, the EVD was removed. On day 7, on sedation break, the patient was noted to eye open to voice, appropriately follow simple commands and cough to endotracheal suction. The patient was extubated and discharged to the neurosurgical ward for ongoing management.

6.2 Posterior fossa bleed

A 54 year old man with a background history of treated hypertension and a known posterior fossa arterio venous malformation presented to the Emergency Department with a decreased level of consciousness after complaining of a headache, slurred speech and unsteady gait. A CT scan revealed a large posterior fossa bleed from the AV malformation.

The haematoma was emergently evacuated, the posterior fossa was decompressed and an external ventricular drain inserted. The patient was transferred to the intensive care unit.

He was sedated with propofol and morphine, ICP maintained at <20 mmHg and the MAP was manipulated with noradrenaline to sustain a CPP >60 mmHg. Normocapnoea, normothermia, normoxia, normotension and euglycemia were maintained and routine postoperative cares were provided. His care was complicated by a rebleed in the posterior fossa on day 3 needing further decompression and ongoing sedation and CSF drainage. The ICP finally stabilized on day 6, a subsequent CT was satisfactory, the EVD was removed and on day 8, on sedation break, the patient was noted to be eye opening to voice and following simple commands. He was extubated the next day but needed to be re intubated soon after for inability to clear secretions.

His stay was further complicated by a nosocomial pneumonia and a tracheostomy was performed to facilitate liberation from the ventilator over several days. There was reasonable recovery of motor and intellectual function, however, he failed attempts at decannulation due to inability to cough and clear secretions adequately. Interestingly, he was also noted to have central alveolar hypoventilation needing ventilator support during sleep (Ondine's curse). A tracheostomy was left in situ and the patient transferred to a chronic ventilation service under the care of the respiratory medicine team.

7. Conclusion

Neurocritical care is a relatively new sub speciality of medicine. Critical care physicians in these units defragment the care of critically ill neurosurgical patients, often with other organ pathologies, by

- optimising treatment of the underlying brain pathology
- preventing of secondary injury to neurons
- providing global extracranial organ support

The critical care unit itself provides a venue for advanced monitoring allowing

- continuous monitoring of respiratory and haemodynamic function
- continuous monitoring of ICP, allowing ongoing defence of CPP
- monitoring of cerebral perfusion and cerebral tissue oxygenation

This enables targeted aggressive invasive organ support to prevent or minimise secondary neuronal injury. Reasonable goals of resuscitation include

- CPP>60 mmHg
- PBrO2>15 mmHg
- SjO2 55-75%
- MAP>70 mmHg, ideally titrated to CPP if ICP measurement in situ or within 20% of patient's baseline MAP, if known
- SaO_2>90%
- PO_2>70 mmHg
- PCO_2 35-45 mmHg
- Temperature 36-37°C
- Blood sugar 5-10 mmol/L
- Urine output> 30 ml/hour (or at least 0.5 ml/kg/hour)

Early aggressive management and prevention of secondary tissue injury in close coordination with neurosurgical teams is thought to improve neurologic outcomes for critically ill neurosurgical patients.

There is now accumulating evidence of outcomes after critical illness. In neurosurgical populations, significant advances have been made in identifying indicators of poor outcome. A thorough understanding of these factors and their significance arms the bedside clinician in prognosticating for individual patients in their care.

It is now about half a century since brain death as a phenomenon has been recognised. It is interesting that the diagnostic criteria and clinical examination to determine brain death have remained largely unchanged for over 30 years. Accumulating experience with various modalities of neuroimaging allow newer, more elegant ways of demonstrating absence of cerebral perfusion and are increasingly being used to diagnose brain death.

8. Acknowledgment

9. References

Brain Trauma Foundation Guidelines 3rd edition, available from http://tbiguidelines.org

Bouzat P.; Francony G.; Brun J.; Lavagne P.; Picard J.; Broux C.; Declety P.; Jacquot C.; Albaladejo P.; Payen J.F. (2010) *Detecting traumatic internal carotid artery dissection using transcranial doppler in head injured patients* Intensive Care Med 36 :1514-1520

Centers for Disease Control and Prevention (CDC) (2005) *Severe clostridium difficile associated disease in populations previously at low risk- four states* MMWR Morb Mortal Weekly Rep 54(47) :1201-05

Clifton G.L.; Drever P.; Valadka A.; Zygun D.; Okonkwo D. (2009) *Multicentre trial of early hypothermia in severe brain injury* J Neurotrauma 26(3) :393-397

Cook D.; Meade M.; Guyatt G; Walter S.; PROTECT investigators (2011) *Dalteparin versus unfractionated heparin in critically ill patients* N Engl J Med 364(14) :1305-14

Cook D.; Guyatt J.; Marshall J.; Leasa D.; Fuller H.; Hall R. (1998) *A comparison of sucralfate and ranitidine for the prevention of upper gastrointestinal bleeding in patients requiring mechanical ventilation* N Engl J Med 338 :791-7

Davis D.P.; Meade W.; Sise M.J.; Kennedy F.; Simon F.; Tominaga G.; Steele J.; Coimbra R. (2009). *Both hypoxemia and extreme hyperoxemia may be detrimental in patients with severe traumatic brain injury* J Neurotrauma 26(12) :2217-23

Finfer S.; Bellomo R.; Boyce N.; French J.; Myburgh J.; Norton R. (2004) *A comparison of albumin and saline for fluid resuscitation in the intensive care unit* N Engl J Med 350(22) :2247-56

Glantz M.J.; Cole B.F.; Forsyth P.A.; Recht L.D.; Wen P.Y.; Chamberlain M.C.; Grossman S.A.; Cairncross J.G. (2000) *Practice parameter : anticonvulsant prophylaxis in patients with newly diagnosed brain tumours : report of the quality standards subcommittee of the American Academy of Neurology* Neurology 54 :1886-93

Goldhaber S.Z.; Dunn K.; Gerhard- Herman M.; Park J.K.; Black P.M. (2002) *Low rate of venous thromboembolism after craniotomy for brain tumor using multimodality prophylaxis* Chest 122(6) :1933-37

Hindman B.J.; Bayman E.O.; Pfisterer W.K.; Torner J.C.; Todd M.M.; the IHAST investigators (2010) *No association between intraoperative hypothermia or supplemental protective drug and neurologic outcomes in patients undergoing temporary clipping during cerebral aneurysm surgery* Anesthesiology 112 :86-101

Huynh T.; Messer M.; Sing R.F.; Miles W.; Jacobs D.G.; Thomason M.H. (2002) *Positive end-expiratory pressure alters intracranial and cerebral perfusion pressure in severe traumatic brain injury* J Trauma 53(3) : 488-92

Ioro A.; Agnelli G. (2000) *Low molecular weight heparin and unfractionated heparin for prevention of venous thromboembolism in neurisurgery : a meta analysis* Arch Intern Med 160(15) :2327-32

Johnson, V.E.; Huang J.H & Pilcher W.H. (2007). *Special cases : mechanical ventilation of neurosurgical patients* Crit Care Clin 23(2) :275-90,x

Jones P.A.; Andrews P.J.; Midgley S.; Anderson S.I.; Piper I.R.; Tocher J.L. et al (1994). *Measuring the burden of secondary insults in head- injured patients during intensive care* J Neurosurg Anesthesiol 6(1) :4-14

Kilgannon J.H.; Jones A.E.; Shapiro N.I.; Angelos M.G.; Milcarek B.; Hunter K.; Parillo J.E.; Trzeciak S. (2010) Association between arterial hyperoxia following resuscitation from cardiac arrest and in- hospital mortality JAMA 303(21) :2165-71

Kim J.; Gearhart M.M.; Zurick A.; Zuccarello M.; James L.; Luchette F.A. (2002) *Preliminary report on the safety of heparin for deep vein thrombosis prophylaxis after head injury* J Trauma 53(1) :38-42

Levy D.E.; Caronna J.J.; Singer B.H.; Lapinski R.H.; Frydman H.; Plum F. (1985) *Predicting outcome from hypoxic ischaemic coma* JAMA 253 :1420-26

Levy M.J.; Seelig C.B.; Robinson N.J.; Ranney J.E. (1997) *Comparison of omeprazole and ranitidine for stress ulcer prophylaxis* Dig Dis Sci 42(6) :1255-59

Marshall L.F.; Gantille T.; Klauber M.R. (1991) *The outcome of severe closed head injury* J Neurosurg (Suppl) 75 :28-36

Mascia L.; Grasso S.; Fiore T.; Bruno F.; Bernardino M.; Ducati A. (2005) *Cerebro- pulmonary interactions during the application of low levels of positive end- expiratory pressure* Intensive Care Med 31(3) :373-9

Messori A.; Trippoli S.; Valani M.; Gorini M.; Corrado A. (2000) *Bleeding and pneumonia in intensive care patients given ranitidine and sucralfate for prevention of stress ulcer : meta-analysis of randomised controlled trials* BMJ 321 : 1103-06

Miano T.A.; Reichert M.G.; Houle T.T.; MacGregor D.A.; Kincaid E.H.; Bowton D.L. (2009) *Nosocomial pneumonia risk and stress ulcer prophylaxis : A comparison of pantoprazole versus ranitidine in cardiothoracic surgery patients* Chest 136(2) :440-47

Mollaret P. & Goulon L. (1959) *Le coma depasse (memoire preliminaire)* Rev Neurol (Paris) 101 :3-15

Myburgh J.; Cooper D.J.; Finfer S.; Bellomo R.; Norton R.; Bishop N.; Kai Lo S.; Vallance S. (2007) *Saline or albumin fluid resuscitation in patients with traumatic brain injury* N Engl J Med 357(9) :874-84

Reinhard M.; Neunhoffer G.; Gerds T.A.; Niesen W.G.; Buttler K.J.; Timmer J.; Schmidt B.; Czosnyka M.; Weiller C.; Hetzel A. (2010) *Secondary decline of cerebral autoregulation is assosciated with worse outcome after intra cerebral haemorrhage* Intensive Care Med 36 :264-271

Rincon, F. & Mayer S.A. (2007). *Neurocritical care : a distinct discipline?* Curr Opin Crit Care 13(2) : 115-21

Schirmer C.M.; Kornbluth J.; Hellman C.B.; Bhardwaj A. (2011) *Gastrointestinal prophylaxis in neurocritical care* Neurocrit Care Jul 12 [Epub ahead of print]

Shaw M.D.M.; Foy P.M. (1991) *Epilepsy after craniotomy and the place of prophylactic anticonvulsant drugs : discussion paper* J R Soc Med 84(4) :221-23

Stollman N.; Metz D.C. (2005) *Pathophysiology and prophylaxis of stress ulcer in intensive care unit patients* J Crit Care 20(1) :35-45

The Australian and New Zealand Intensive Care Society (ANZICS) Statement on Death and Organ Donation, Edition 3.1 (2010), available from http://www.anzics.com.au/death-and-organ-donation

Vassar M.J; Perry C.A.; Holcroft J.W. (1993) *Prehospital resuscitation of hypotensive trauma patients with 7.5% NaCl versus 7.5% NaCl with added dextran : a controlled trial* J Trauma 34(5) :622-32

Wijdicks E.F.M.; Hijdra A.; Young G.B.; Bassetti C.L.; Wiebe S. (2006) *Practice parameter : Prediction of outcome in comatose survivors after cardiopulmonary resuscitation (an evidence based review)* Neurology 67(2) :203-10

Wijdicks E.F.M.; Varelas P.N.; Gronseth G.S.; Greer D.M. (2010) *Evidence based guideline update : Determining brain death in adults* Neurology 74 :1911-18

Young N.; Rhodes J.K.; Mascia L.; Andrews P.J. (2010). *Ventilatory strategies for patients with acute brain injury* Curr Opin Crit Care 16(1) :45-52

Zandbergen E.G.J; Hijdra A.; Koehlman J.H.T.M.; Hart A.A.M.; Vos P.E.; Verbeek M.M.; de Haan R.J. (2006) *Prediction of poor outcomes within the first 3 days of postanoxic coma* Neurology 66(1) :62-68
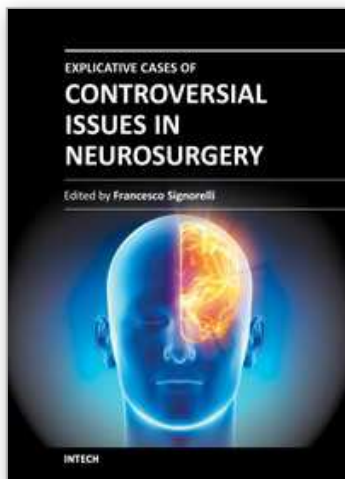
Explicative Cases of Controversial Issues in Neurosurgery

Edited by Dr. Francesco Signorelli

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