Intensive care management of head injury

Introduction

In the UK 1.4 million people with head injuries are seen annually in the emergency department (National Institute for Health and Care Excellence, 2013). Of these, 200 000 patients require inpatient admission (National Institute for Health and Care Excellence, 2013). Head injuries occur more frequently in men and are commonly caused by road traffic accidents, assaults and falls (Murray et al, 1999), with alcohol an important contributing factor. The elderly are an important group presenting with head injuries, as they have multiple comorbidities and are often on anticoagulant and antiplatelet medications.

Table 1. Glasgow Coma Score

Score		Modality
Eyes	4	Opens spontaneously
	3	Open to voice
	2	Open to pain
	1	Not open
Voice	5	Orientated
	4	Confused conversation
	3	Inappropriate words
	2	Incomprehensible sounds
	1	No vocalisation
Motor	6	Obeys commands
	5	Localizes pain
	4	Withdraws to pain
	3	Limb flexion to pain
	2	Limb extension to pain
	1	No movement

From Teasdale and Jennett (1974)

Dr N Sriram *is Senior House Officer in the Department of Anaesthesia, Northwick Park Hospital, London and* **Dr S Yarrow** *is Consultant Neuroanaesthetist in the Department of Anaesthetics, John Radcliffe Hospital, Oxford*

Correspondence to: Dr N Sriram, Department of Anaesthesia, St Mary's Hospital, London W2 1NY (nisha.sriram@nhs.net)

The severity of traumatic brain injury is classified based on the Glasgow Coma Score. A Glasgow Coma Score which totals 13–15 is classified as mild traumatic brain injury, one of 9–12 as moderate injury and one of 3–8 as severe injury (National Institute for Health and Care Excellence, 2013) (*Table 1*).

This review describes the pathophysiology underlying brain injury and the principles that guide its management in an intensive care setting.

Primary and secondary brain injury: the pathophysiology of traumatic brain injury

Primary brain injury occurs at the time of the initial insult. Brain tissue damage can be either focal or diffuse depending on the nature of the injury (Helmy et al, 2007). At present, primary injury is untreatable and is a major determinant of survival, with increased mortality associated with a lower Glasgow Coma Score at presentation. It begins a cascade of treatable secondary events detailed below (*Table 2*). Aggressive treatment of secondary injury may not alter mortality rates, but will improve the quality of recovery in survivors.

In many cases of severe head injury, the ability to autoregulate cerebral blood flow is lost. The brain is unable to guarantee cerebral perfusion, leaving it more vulnerable to secondary injury.

Initial management

When a patient arrives in the emergency department with a severe head injury, it is important to follow Advanced Trauma Life Support principles (Maas et al, 1997). Careful assessment and imaging of other injuries (for example to the cervical spine) must occur alongside brain imaging. Currently, computed tomography is the initial imaging recommendation for significant brain injury (National Institute for Health and Care Excellence, 2013).

Before transfer from the emergency department, patients with severe head injuries are likely to require intubation and ventilation. Indications for this include:

1. Inability to maintain an adequate airway (e.g. maxillofacial trauma)
2. Respiratory failure, or to allow control of oxygen or CO_2 levels
3. Seizures
4. Reduced conscious level.

Intubation should be considered if a 2 or more point reduction has occurred in the baseline Glasgow Coma Score. In patients who have a Glasgow Coma Score of ≤8 or a 2 or more point reduction in the motor score, intubation is recommended (Association of Anaesthetists of Great Britain and Ireland, 2006). Targets for ventilation are PaO_2 >13 kPa and $PaCO_2$ of 4.5–5.0 kPa (Association of Anaesthetists of Great Britain and Ireland, 2006).

Table 2. Secondary insults and mechanisms of injury

Secondary injury	Mechanism
Hypoxia	Reduced oxygen availability to the brain
Hypotension	Leads to reduced cerebral perfusion
Raised intracranial pressure	Can reduce cerebral perfusion and lead to herniation
Cerebral vasospasm	Reduced blood flow through constricted vessels
Hyperthermia	Causes increased metabolic demand, neutrophil activation and neuronal damage
Cerebral hyperaemia	Leads to increased blood supply beyond metabolic need and raised intracranial pressure
Disorders of sodium balance	Can cause seizures and altered conscious level. May worsen cerebral oedema
Seizures	Can lead to raised intracranial pressure, blood pressure changes. Increases metabolic demands

Patients with a serious head injury (Glasgow Coma Score <8) benefit from transfer to a neuroscience unit for ongoing management. If this is not possible, frequent discussions with the local neuroscience unit are recommended (National Institute for Health and Care Excellence, 2013).

Intensive care management priorities

The priorities of intensive care management are:

1. General supportive measures
2. Prevention of secondary injury
3. Control of intracranial pressure.

Patient outcomes are improved by adhering to evidence-based protocols when managing traumatic brain injury (Helmy et al, 2007) (*Figure 1*).

General measures

General care

Patients should be nursed head up (15–30°) to reduce intracranial pressure. Regular turning to avoid pressure ulcers, eye care and physiotherapy are important. Stress ulcer prophylaxis and laxatives should be prescribed if required.

Sedation, analgesia and neuromuscular block

Adequate sedation and analgesia is required for patient comfort. Sedation reduces the cerebral metabolic rate for oxygen and hence the oxygen demand, and provides a margin of security for brain tissue with borderline perfusion. Agents used frequently are listed in *Table 3*. Simple analgesia (e.g. paracetamol) can be used as well. Neuromuscular blocking agents (e.g. rocuronium, atracurium) can be used to prevent coughing but should be used with care, as they are associated with the development of peripheral neuropathy in critically ill patients (Helmy et al, 2007).

Nutrition

The Brain Trauma Foundation guidelines suggest that feeding should begin within 72 hours, with full caloric requirements met by 7 days. Current data suggest that early nutrition (<24 hours) is beneficial in reducing mortality and morbidity. Parenteral nutrition can be used if the patient is unable to absorb enteral feed. Jejunal feeding can also be considered, While not specific for traumatic brain injury, current European Society for Clinical Nutrition and Metabolism guidelines for intensive care suggest that caloric replacement during the initial phase of illness should not exceed 20–25 kcal/kg body weight/day. When recovery occurs, caloric replacement should be 25–30 total kcal/kg body weight/day. An immune-modulating formula is recommended over the standard enteral formulation in trauma patients (Wang et al, 2013).

Deep vein thrombosis prophylaxis

The risk of developing a venous thromboembolism after traumatic brain injury can be up to 20% (Brain Trauma Foundation et al, 2007). Current guidelines recommend the use of mechanical methods of prophylaxis such as compression stockings; the benefits of low-dose unfractionated or low molecular weight heparin must be set against the risks of intracranial bleeding and expansion of existing haematomas. Heparin prophylaxis is thought to be safe when any intracranial haemorrhage begins to stabilize and resolve, but the exact timing of this is unclear. Some studies suggest this may be as early as 24 hours after the initial injury (Phelan, 2012).

Secondary injury prevention

Avoidance of hypoxia

Hypoxia in patients with traumatic brain injury is associated with increased morbidity and mortality (Brain Trauma Foundation et al, 2007). Mechanical ventilation is instituted to maintain a PaO_2 >11 kPa and $PaCO_2$ between 4.5–5.0 kPa (Helmy et al, 2007).

Avoidance of hypotension

Patients with traumatic brain injuries are vulnerable to hypotension. This leads to reduced cerebral blood flow and increased

Figure 1. Protocol for the management of traumatic brain injury. Adapted from the protocol used in the John Radcliffe Hospital, Oxford. $PaCO_2$ = partial pressure of carbon dioxide in blood.

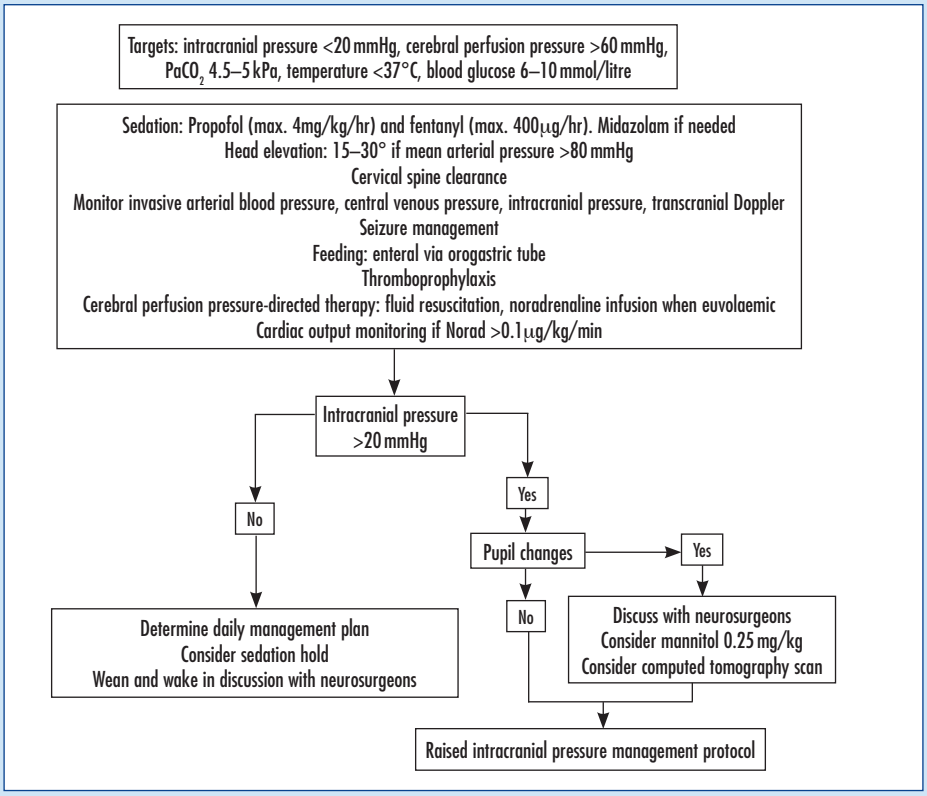


Table 3. Agents used in sedation and analgesia in traumatic head injury

Agent	Dose
Propofol	2–5 mg/kg/hr
Fentanyl	2–5 μg/kg/hr
Midazolam	2–4 mg/hr
Morphine	4 mg/hr

Doses are for guidance only (Brain Trauma Foundation et al, 2007)

morbidity and mortality (Brain Trauma Foundation et al, 2007). An adequate cerebral perfusion pressure (further discussion below) should be maintained with fluid resuscitation and vasoactive agents such as noradrenaline, if required (Maas et al, 1997). For patients continuing to deteriorate, cardiac output monitoring may be instituted.

Glycaemic control

In a meta-analysis by Kramer et al (2012) loose glycaemia control (insulin started when glucose >11.1 mmol/litre) was associated with worse neurological outcomes than tight (glucose 4.4–6.1 mmol/litre) and intermediate glucose control (6.1–10 mmol/litre). The group with tight glycaemic control showed greater incidence of hypoglycaemic episodes with no improvement in mortality. While clear cutoffs for glucose levels remain unclear, achievement of intermediate glucose control may represent the safest strategy.

Antiepileptic medications

Seizures occur frequently after traumatic brain injury. There is no evidence to support the use of prophylactic anticonvulsant medication (Brain Trauma Foundation et al, 2007). However, prompt treatment of seizures is important to prevent further secondary injury to the brain.

Temperature management

The avoidance of hyperthermia (temperature >37.5°C) is important, as it can cause secondary injury if uncontrolled. This occurs as a result of the raised cerebral metabolic demands. Additionally, blood flow can increase leading to raised intracranial pressure (Maas et al, 1997).

Management of raised intracranial pressure

The Monroe–Kellie doctrine states that the sum of the volume of the brain, blood, CSF and any other contents (e.g. haematoma, tumour) is constant (equation 1).

Volume (brain + blood + CSF + other contents) = constant (equation 1)

The enclosing skull is a fixed container, thus any alteration in volume in any of intracranial contents must be offset by a reduction in volume of another. CSF and blood can decrease in volume, but this ability to compensate is eventually exhausted. Intracranial pressure then increases rapidly leading to cerebral herniation (Dunn, 2002) (*Figure 2*).

Intracranial pressure frequently rises as a result of underlying brain injury, contusions, haematomas, infarction, hyperaemia, seizures, oedema and space-occupying lesions (Steiner et al, 2007). Intracranial pressure also rises if hydrocephalus occurs secondary to the obstruction of flow or reabsorption of CSF.

An early consequence of raised intracranial pressure is reduced cerebral perfusion pressure. Cerebral perfusion pressure is defined as the pressure gradient leading to blood flow to the brain. Cerebral perfusion pressure is calculated as:

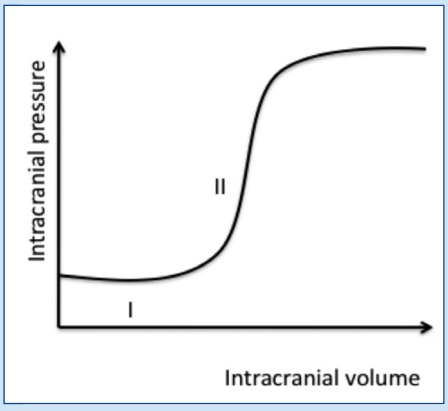
Cerebral perfusion pressure = mean arterial pressure – intracranial pressure where (mean arterial pressure) = diastolic pressure + 1/3 (systolic – diastolic pressure)

Currently, intracranial pressure is measured routinely in neuro-intensive care units, and a value of 20–25 mmHg is the threshold for treatment (Helmy et al, 2007). Raised intracranial pressure is associated with poor neurological outcomes (Ghajar, 2000), and is important to monitor and control.

Intracranial pressure monitoring

Intracranial pressure monitoring is indicated in severe traumatic brain injury with an abnormal computed tomography scan appearance (e.g. contusion, haematoma or cerebral oedema). It is also recommended in patients with severe traumatic brain injury and a normal computed tomography scan if underlying risk factors (age >40 years, systolic blood pressure <90 mmHg, posturing) exist (Brain Trauma Foundation et al, 2007).

Figure 2. As intracranial volume increases initially intracranial pressure remains constant (I – compensatory phase). As compensation is overwhelmed, intracranial pressure rises rapidly with intracranial pressure (II – decompensatory phase).



Intracranial pressure can be monitored via intraventricular catheters. They are the current reference standard, and CSF can also be drained therapeutically. A significant risk of infection is associated with these devices. Parenchymal catheters can also be used. They cause less trauma on insertion and are associated with a reduced rate of infection. However, they cannot be recalibrated, leading to measurement drift (Ghajar, 2000). Other devices including subarachnoid, epidural and subdural catheters are not recommended, as they are not accurate compared to the ventricular catheter (Ghajar, 2000).

Medical management of raised intracranial pressure

Hypertonic therapy

Mannitol, an osmotic diuretic, is used to reduce intracranial pressure. It acts by initial plasma expansion and increasing the osmotic gradient across the blood–brain barrier, which it is unable to cross. Water leaves the brain, with a subsequent reduction in oedema (Torre-Healy et al, 2012). It is used when impending herniation is likely (*Table 4*).

Hypertonic saline can also be used to reduce intracranial pressure. It is able to reduce brain water content via an osmotic gradient. It may improve circulation via endothelial cell shrinkage, and improve cerebral blood flow, increasing cardiac output and mean arterial pressure (Torre-Healy et al, 2012) (*Table 4*). Hypertonic saline is available in various different concentrations (e.g. 1.8%, 3% and 7.5%), and referral to local protocols is essential before instituting this therapy.

Furosemide (1 mg/kg), a loop diuretic, can also be used to reduce raised intra-cranial pressure.

Induced hyperventilation

Hyperventilation reduces intracranial pressure by cerebral vasoconstriction. However, the concomitant reduction in blood flow reduces perfusion to the injured brain (Helmy et al, 2007). Current guidelines advocate the use of hyperventilation as a temporising measure with appropri-

Table 4. Mannitol and hypertonic saline use

Drug	Dose	Administration	Contraindications	Adverse effects
Mannitol	0.25–1 g/kg (4–6-hourly)	Intravenous infusion over 20–30 minutes	Previous sensitivity, anuria as a result of renal disease, plasma osmolarity >320 mosms, severe cardiac failure	Hypernatraemia, rebound increase in intracranial pressure, anaphylaxis, metabolic acidosis, fluid overload, renal failure
Hypertonic saline	2.7% NaCl infusion at 0.5 ml/kg/hr, adjust infusion rate by 0.2 ml/kg/hr based on serum Na. Aim for daily increase in serum Na <10 mmol/day. Only for 48 hours	Via central line	Renal impairment, cardiac failure, initial serum Na >150 mmol/litre, initial serum osmolality >320 mosmol/litre	Volume overload, renal failure, electrolyte disturbance, risk of central pontine myelinolysis, dilutional coagulopathy, rebound cerebral oedema

Adapted from protocols used in the John Radcliffe Hospital, Oxford, for reference only

ate monitoring, until definitive management occurs (Brain Trauma Foundation et al, 2007). Initially $PaCO_2$ is targeted to 4.5–5 kPa, with lower targets (4.0–4.5 kPa) for intractable raised intracranial pressure (Helmy et al, 2007).

Further management

Therapeutic hypothermia is used for the reduction of intracranial pressure and neuroprotection after traumatic brain injury. Currently, only level III evidence exists supporting its use (Brain Trauma Foundation et al, 2007). Adverse effects include coagulation disturbance, thrombocytopaenia, shivering and increased risk of infections.

Barbiturates are used to reduce intracranial pressure when it is refractory to all other treatment modalities. Side effects such as severe hypotension can occur (Brain Trauma Foundation et al, 2007). Barbiturates (e.g. thiopentone) can accumulate after prolonged infusion, leading to delayed awakening and delays in brainstem testing.

Surgical management of raised intracranial pressure

Initial surgical management of raised intracranial pressure involves removal of space-occupying lesions if present. External ventricular drains can also be inserted to drain CSF and measure intracranial pressure (Helmy et al, 2007).

Decompressive craniectomy can be used when medical management is unable to control refractory intracranial pressure. A large multicentre trial (DECRA) was conducted to evaluate craniectomy after traumatic brain injury. Patients who had surgery had reduced intracranial pressure and reduced duration of intensive care stay compared to the medical management group. However, their functional outcomes were worse after 6 months (Bohman and Schuster, 2013). There are many criticisms made of the trial protocol, and currently the RESCUEicp study (www.rescueicp.com/) is being conducted to clarify the issue. This is an international prospective multicentre trial, comparing best medical management *vs* decompressive craniectomy for raised intracranial pressure after traumatic brain injury.

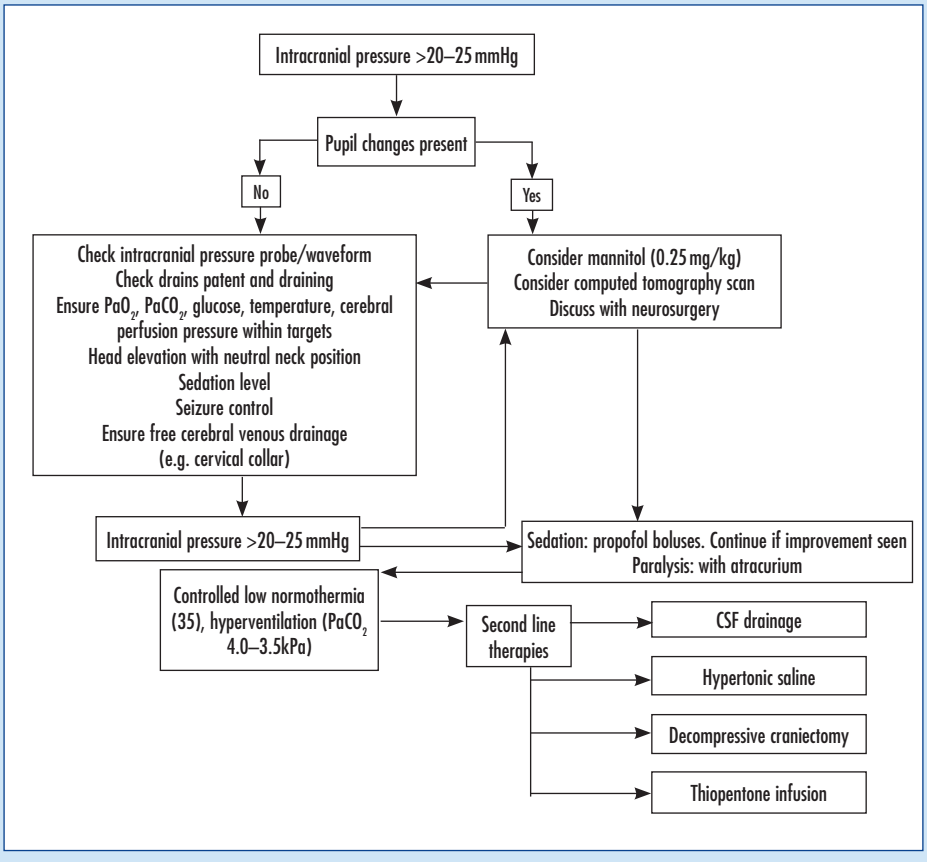
Figure 3 shows an algorithm for the structured management of raised intracranial pressure.

Cerebral perfusion pressure

The concept of measuring and managing cerebral perfusion pressure was introduced by Rosner et al (1995), who showed an improved morbidity and mortality in a group of patients whose cerebral perfusion pressure was maintained at >70 mmHg (Brain Trauma Foundation et al, 2007).

Currently, while it is recognized that low cerebral perfusion pressure is harmful, data does not support elevating cerebral perfusion pressure to limits above the

Figure 3. Protocol for the management of raised intracranial pressure. Adapted from the protocol used in the John Radcliffe Hospital, Oxford. $PaCO_2$ = partial pressure of carbon dioxide in blood; PaO_2 = partial pressure of oxygen in blood.



critical threshold for ischaemia (between 50–70 mmHg). Some studies have shown a significant increase in acute respiratory distress syndrome in patients when the cerebral perfusion pressure was maintained at >70 mmHg (Steiner and Andrews, 2006). Currently, further studies are required to define cerebral perfusion pressure thresholds for treatment, and define which patient subgroups will benefit from elevated cerebral perfusion pressures.

Measuring cerebral perfusion and metabolism

There are a variety of techniques whereby cerebral metabolism can be directly measured, but they are not routinely used in many centres.

The jugular venous saturation can be measured via retrograde insertion of a catheter into the internal jugular vein. It is a surrogate marker of global cerebral blood flow and metabolic demand (Steiner and Andrews, 2006). Low venous saturations indicate high oxygen extraction, which imply a mismatch between cerebral perfusion and demand. Additionally, desaturations can be measured, which are associated with worse clinical outcomes in patients (Steiner and Andrews, 2006).

Oxygen sensors can also be inserted intraparenchymally to measure brain tissue oxygenation in small areas of injured brain (Ghajar, 2000).

Non-invasive methods of measurement of cerebral perfusion include near-infrared spectroscopy and the transcranial Doppler. Near-infrared spectroscopy is based on the principle that near-infrared light penetrates the skull and is absorbed differentially by oxygenated and deoxygenated blood. The proportion of oxygenated *vs* deoxygenated blood can be quantified in brain tissue (Steiner and Andrews, 2006). Transcranial Doppler is used to detect vasospasm, raised intracranial pressure and reduced cerebral blood flow (Ghajar, 2000).

Cerebral microdialysis is a technique, where a catheter is inserted into the area of injury, and various cerebral metabolites are measured (e.g. glucose, glutamate) in the injured brain (Ghajar, 2000).

Currently, all these monitoring techniques show promise, but their use in clinical practice requires further evaluation.

Conclusions

Traumatic brain injury can have devastating long-term consequences for sufferers and their families. Currently, treatment is focused on the maintenance of basic physiological parameters and good general intensive care principles. Further research is required to validate many of the treatments in current use, and improve the general quality of current treatment recommendations.

In summary, the principles are simple. It is important to keep the brain well perfused with oxygenated blood (via reduction of intracranial pressure and maintaining cerebral perfusion pressure). While primary injury may be untreatable, it is important to recognize that secondary injury is treatable and must be managed aggressively to improve the quality of recovery. **BJHM**

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KEY POINTS

- Primary brain injury cannot be treated and is a major factor in determining mortality from traumatic brain injury.
- Secondary brain injury can be treated, and is a major factor in determining quality of recovery from traumatic brain injury.
- Priorities in intensive care management are general supportive measures, prevention of secondary injury and control of intracranial pressure.
- Cerebral perfusion pressure = mean arterial pressure – intracranial pressure.
- Intracranial pressure is determined by the Monroe–Kellie doctrine.