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### **Anaesthesia management of a child with brain injury**

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#### **Introduction**

Brain injury in children is a life-threatening situation that requires specific and immediate management. Brain injury may be of traumatic or medical origin (ruptured cerebral arterio-venous malformation, CNS infectious diseases, brain tumour etc.). Some patients suffering from brain injury may require an emergency surgical procedure as part of their initial management.

The initial management of a brain injury includes a precise assessment of the cerebral status, as well as of any associated systemic disturbance. Secondary brain insults must be minimised by optimising cerebral perfusion and oxygenation [1], while the risk of cerebral herniation must be reduced and the surgical procedure facilitated. The anaesthesiologist in charge of the brain injured child plays a key role during the peri-operative period. In order to succeed in this complex task he/she needs to have a good knowledge of underlying pathophysiological mechanisms, as well as of the effects of the most commonly used drugs on cerebral haemodynamics.

#### **Pre-operative assessment**

##### Neurological examination

A thorough neurological examination must be performed as soon as the child is clinically stable to serve as a reference for future assessments. In life-threatening situations, evaluation of neurological status relies upon the determination of the paediatric Glasgow Coma Scale (GCS) score, evaluation of pupillary diameter and reactivity, and examination of the brain stem reflexes. In less acute situations, the examination will also include a search for evidence of increased intracranial pressure (ICP) and associated focal deficits.

Physiologically, ICP progressively increases with aging, with ICP values ranging from 0 to 6 mmHg in infants and reaching normal adult values at the beginning of adolescence (10-18 mmHg). Children are at increased risk of intracranial hypertension and subsequent cerebral herniation. Intracranial compliance in children is lower than in adults, explaining why children may demonstrate rapid alterations in neurological function, passing from normal status to almost coning over a few minutes. The fontanelles and non-fused cranial sutures provide protection only from progressive (chronic) increases in ICP. Cerebral disorders may damage cerebral autoregulation - a dynamic process where arteriolar diameter changes to preserve normal cerebral blood flow (CBF). Loss of cerebral autoregulation after brain injury may contribute to cerebral ischaemia and/or cerebral hyperaemia and may worsen outcome. In children aged < 4 yr, use of volatile anaesthetics, severe traumatic brain injury (TBI), and hypercarbia are risk factors for impaired cerebral autoregulation [2].

##### Assessment of cardio-respiratory status

Respiratory or circulatory distress may be responsible for, or aggravate, the neurological disturbance. Hypotension and hypoxaemia are the main determinants of outcome from secondary brain injury. Shock and hypotension result in a fall in cerebral perfusion pressure (CPP) and increased morbidity and mortality [3]. Hypovolaemia is frequent and may result from haemorrhage, mannitol induced diuresis or diabetes insipidus.

##### CT scan

Non-contrast CT scan is the radiological examination of choice for the immediate assessment of a child with severe brain injury. In cases of traumatic brain injury, an associated bodyscan is useful as extra-cranial injuries may be associated with up to 50% of cases.

### Transcranial Doppler ultrasonography

Transcranial Doppler ultrasonography (TCD) is a non-invasive tool providing information on the cerebral circulation [4]. The obtained signal provides information about the systolic, diastolic, mean blood flow velocity and cerebrovascular resistances, quantified by the Pulsatility Index (PI,  $PI = (FV_{sys} - FV_{dias}) / FV_{mean}$ ). Early TCD goal-directed therapy can help in restoring normal cerebral perfusion before surgery in high-risk patients [5].

## **Peri-operative monitoring**

### Haemodynamic monitoring

Invasive arterial pressure monitoring is mandatory as these patients are frequently hypovolaemic and unstable. In combination with ICP monitoring, it permits the calculation of CPP. In addition, an arterial catheter enables performing arterial blood samplings and predicting fluid responsiveness. In contrast, central venous pressure monitoring provides poor guidance for fluid replacement, but a central venous catheter may be useful, especially for vasoactive drugs administration.

### Respiratory monitoring

Continuous monitoring of pulse oximetry and capnography, as well as frequent arterial blood gas analyses are required. Frequent blood samplings are justified because capnography may under-estimate PaCO<sub>2</sub> in these brain injured patients in whom an increased alveolo-capillary gradient is frequently present.

### ICP and CPP monitoring

Several studies have shown that mortality increases with increased ICP and decreased CPP [6, 7]. Some authors advocate that the ICP threshold for treatment is 20 mmHg for children and 15 mmHg for infants. In children with severe traumatic brain injury, it is recommended that CPP be maintained > 40 mmHg [1]. Taking into account the age-related continuum for the optimal treatment threshold for CPP, it has been recommended that CPP be maintained between 40 and 65 mmHg according to the age of the child [1]. In accordance with these guidelines, the results of a retrospective study have shown that CPP of 53, 63 and 66 mmHg should be the minimum for children aged 2-6, 7-10 and 11-16 yr, respectively [6]. While most studies on ICP and CPP monitoring in children have been performed following traumatic brain injury, their conclusions are valid for brain injury from other causes [8].

### Monitoring of cerebral oxygenation

Only a few methods of cerebral monitoring are currently available for use in the operating room. Monitoring the jugular bulb blood oxygenation (SjvO<sub>2</sub>) provides a measurement of global cerebral oxygen extraction, which assists assessment of the optimal CPP and provides information about cerebral perfusion and risk of cerebral ischaemia [4]. Near-infrared spectroscopy (NIRS) is a non-invasive technique for monitoring cerebral oxygenation during anaesthesia. However, conflicting results have been obtained in children [4]. Other methods of cerebral oxygenation monitoring, such as brain tissue oxygenation measurement, have been proposed but further evaluation is required before routine use in children. The effects of brain hypoxia-targeted treatment appear promising but also needs to be established in children.

## **Peri-operative critical care management**

Initial critical care management of neurosurgical emergencies is based upon common general principles that apply whatever the causes of brain injury. The experience derived from acute management of severe traumatic brain injury has benefit for other types of neurological emergencies, such as cerebrovascular disorders [8]. The aim of management is to stabilise the patient, control as quickly as possible the increased ICP and optimise the CPP, thus avoiding further deterioration and preventing the development of secondary brain injury. The acknowledged negative influence of secondary injuries on outcome promotes cardio-respiratory resuscitation as the cornerstone upon which treatment of severe brain injury must be based [1].

### Intra-operative CPP-specific treatments

First, general manoeuvres are applied, including avoidance of jugular venous outflow obstruction (if possible – depending on the surgical position), maintenance of normovolaemia, normoxia ( $\text{PaO}_2 > 13.3 \text{ kPa}$ ) and normocarbica ( $\text{PaCO}_2 \geq 4.7 \text{ kPa}$ ), as well as deliverance of an adequate level of anaesthesia and analgesia [1]. Maintaining CPP requires optimisation of MAP with fluid therapy and vasoactive drugs if necessary, and treatment of increased ICP.

### Optimisation of mean arterial pressure

During emergency decompressive craniotomy for traumatic brain injury intra-operative hypotension occurred in more than 50% of children [9]. CT lesion volume, CT midline shift, blood loss and Emergency Department hypotension are independent risk factors for intra-operative hypotension [9]. Optimisation of blood pressure is of the utmost importance and relies mainly upon vascular loading and vasoactive drug infusion.

As these patients are at particular risk of hypovolaemia upon arrival in the operating room, a loading volume of 10 ml/kg is best administered during induction. The choice of the loading solution - crystalloids or colloids, is still controversial. There is no evidence that resuscitation with colloids reduces the risk of death, compared with resuscitation with crystalloids, in patients with trauma or following surgery [10]. Therefore, crystalloids are frequently used as the first option in these patients. 'Normal' 0.9% saline (osmolarity: 308 mOsm/l) should be preferred over Ringer Lactate's solution, which is mildly hypotonic (273 mOsm/l). However, only 20% of a normal saline bolus remains in the intravascular space and large volumes may cause hyperchloraemic acidosis and plasma protein dilution. Moreover, colloids have the advantage of stabilising blood pressure more rapidly than crystalloids in children [11]. There seems to be no evidence that one colloid solution is more effective or safer than any other in critically ill patients. However, low molecular weight hydroxyethyl starch (130/0.4) may be the colloid of choice in children [12]. In case of massive haemorrhage, blood transfusion is mandatory. The optimal haemoglobin value in head injured children is unknown, but the threshold for transfusion could be set at 10 g/dl.

Few studies have compared the cerebrovascular effects of catecholamines after severe brain injury [13]. The available data suggest that norepinephrine is associated with an improved restoration of global and regional oxygenation when compared with dopamine [13]. There is insufficient data for all the other vasopressors and norepinephrine is considered the most suitable catecholamine to maintain or restore adequate CPP [13].

Glucose-containing solutions should be avoided because of their hypo-osmolarity, the risk of hyperglycaemia and the possibility of managing most paediatric patients using glucose-free solutions without increasing the risk of hypoglycaemia [14]. In addition, many authors have warned against the risk of postoperative symptomatic hyponatremia in children due to hypotonic fluids administration [14].

### Treatment of intracranial hypertension

In case of acute intra-operative intracranial hypertension, moderate hyperventilation ( $\text{PaCO}_2$  4-4.7 kPa) or, if necessary, more profound hyperventilation ( $\text{PaCO}_2$  3.3-4 kPa) may be required [1]. Osmotic agents are used extensively for management of intracranial hypertension. Mannitol remains the cornerstone of these treatments. In children there are little data on mannitol, but a long-standing clinical use [1]. On the other hand, hypertonic saline has become increasingly popular in brain injured children. There is no clear recommendation towards one or the other of these therapies [1].

Hyperthermia (body temperature  $> 38^\circ \text{C}$ ) is known to worsen outcome through several mechanisms and must be avoided. However, the results of a recent study on moderate hypothermia have shown that it does not improve neurological outcome and may increase mortality [15]. A hypothermic strategy in children with severe brain injury cannot be recommended, however, intra-operative hyperthermia should be avoided.

## Intra-operative management of anaesthesia

### Induction of anaesthesia

If emergency surgery is required, the patient must be considered to have a full stomach. In traumatic brain injury the patient should be treated as having a cervical spine lesion. Orotracheal intubation following rapid sequence induction (RSI), with in-line stabilisation of the cervical spine is required. Classical RSI includes pre-oxygenation with 100% oxygen, cricoid pressure, administration of a predetermined induction dose of hypnotic and suxamethonium to facilitate orotracheal intubation with a cuffed tracheal tube [16]. However, even with optimal pre-oxygenation by mask ventilation using 100% oxygen, apnoea tolerance in infants is decreased and desaturation may occur within <1 min. Therefore, pressure-limited mask ventilation (< 10-12 cmH<sub>2</sub>O) with 100% oxygen has been proposed after induction of anaesthesia to avoid hypoxaemia and significant hypercapnia in infants [16]. Adequate anaesthesia should be provided before tracheal intubation to limit the rise in ICP and because even at the lowest GCS scores, airway reflexes of many patients are sufficiently intact to make tracheal intubation difficult and dangerous. All intravenous hypnotic induction agents including barbiturates, propofol and etomidate are potent cerebral vasoconstrictors and lead to a coupled reduction in CBF and CMRO<sub>2</sub>. Each of these agents can decrease ICP [17] and can be employed depending on the cardiovascular status of the child. Etomidate is preferred when there is haemodynamic instability [18]. Prior administration of a fast acting opioid such as alfentanil or remifentanil may attenuate the haemodynamic response to tracheal intubation [17, 19].

### Maintenance of anaesthesia

There is no consensus regarding maintenance of anaesthesia in this setting and a variety of agents may be used - depending on their effect on cerebral haemodynamics, although total intravenous anaesthesia (TIVA) seems preferred by more authors.

### Volatile agents

All inhalational agents are cerebral vasodilators to various degrees; the degree of vasodilatation correlating with dose. Cerebral vasodilation from volatile anaesthetics may be reduced, but not abolished, by concomitant hyperventilation. The available evidences suggest that sevoflurane is more appropriate than halothane and desflurane for intracranial neurosurgery [20]. In addition, sevoflurane has cerebrovascular effects equivalent to isoflurane while allowing more rapid recovery after prolonged administration [20]. In healthy children, sevoflurane preserves cerebral autoregulation up to 1.5 MAC and carbon dioxide reactivity at 1.0 MAC [21]

### Nitrous oxide

Nitrous oxide (N<sub>2</sub>O) is known to cause cerebral vasodilatation and to increase CBFV in healthy children anaesthetised with propofol or sevoflurane [20]. Furthermore, N<sub>2</sub>O may expand the volume of an intracranial air collection – which is frequently present following a craniotomy. For these reasons N<sub>2</sub>O is not recommended for urgent neurosurgical procedures in patients with intracranial hypertension [20]. In less acute situations, others have recommended stopping N<sub>2</sub>O before closure of the dura in order to decrease the incidence of tension pneumocephalus.

### Propofol

Propofol has cerebrovascular effects similar to thiopental, with both agents being able to decrease significantly the systemic blood pressure, CBF, CMRO<sub>2</sub> and ICP [20]. Propofol does not impair autoregulation and CO<sub>2</sub> reactivity, but hyperventilation to EtCO<sub>2</sub> < 4 kPa may not be necessary in children receiving propofol, as no further reduction in CBFV will be achieved [22]. In children prolonged administration of propofol should be avoided because of the risk of metabolic acidosis and propofol infusion syndrome (PRIS) [23]. Short-term use of propofol in children may still be considered as safe. However, a high level of suspicion is required in case of metabolic acidosis in a child receiving a propofol infusion, because early stages of PRIS have been reported after short-term administration of propofol [23]. When the diagnosis of PRIS is considered early and the propofol infusion is discontinued immediately, recovery is good [23].

## Opioids

Opioids do not impair cerebral autoregulation, CO<sub>2</sub> reactivity or flow-metabolism coupling. Opioids have little effects on CBF and ICP unless respiration is depressed and hypercarbia occurs [20]. Nevertheless, since they may cause hypotension, an increase in CBF may occur related to cerebral autoregulation, which may adversely impact on ICP and CPP [20]. Remifentanyl and sufentanil are both suitable adjuncts to propofol for TIVA in neurosurgical patients. A remifentanyl/propofol regimen provided quicker recovery, but patients receiving sufentanil have reduced analgesic requirements and better cognitive function postoperatively [24].

## Muscle relaxants

Non-depolarizing muscle relaxants have no direct effect on cerebral circulation.

## Associated extracranial surgical emergencies in children with head trauma

Children with severe traumatic brain injury may also present with associated extracranial injuries. The combination of head injury and extracranial injury in the paediatric population contributes to poor outcome from the intracranial injury. A classic error is to focus only on a potential severe cerebral lesion while neglecting a bleeding abdominal lesion or underestimating the role of a pulmonary contusion in producing respiratory distress. Therefore, children with traumatic brain injury should be considered as multiple trauma patients until the diagnostic primary and secondary survey is completed. Immediate surgery (including neurosurgery) is indicated only when there is impending death; otherwise a period of pre-operative stabilisation is preferred. The timing of non-vital surgery, such as orthopaedic surgery, requires discussion. The risk of intra-operative hypotension advocates caution during the first 24 h following trauma. On the other hand, delayed surgery is associated with more respiratory and neurologic complications and to a poorer outcome. Therefore, early orthopaedic treatment is recommended only in patients with stable haemodynamics and respiratory function.

## Conclusion

Anaesthesia management of children with brain injury should achieve the following goals: stabilising the patient and avoiding secondary brain insults, decreasing ICP and optimizing CPP, facilitating surgery and enabling a fast and adequate postoperative recovery. Pre-operative evaluation is very important but should not delay vital surgery. Multi-parameter monitoring is mandatory and should never be interrupted during surgery. Rapid sequence induction, followed by total intravenous anaesthesia appears the best choice in the most severely brain injured patients. Intra-operative critical care management of neurosurgical emergencies is based upon the experience derived from acute management of severe traumatic brain injury. Finally, most of these patients will benefit from postoperative mechanical ventilation with sedation and CPP-targeted treatment.

## Key Learning Points

- Anaesthesia management of children with brain injury should aim at avoiding secondary brain insults, decreasing intracranial pressure, optimizing cerebral perfusion pressure and facilitating surgery.
- Systemic hypotension and hypoxia are the main determinants of secondary brain insults and must be avoided.
- Rapid sequence induction, followed by total intravenous anaesthesia appears the best choice in the most severely brain injured patients.
- Intra-operative critical care management of neurosurgical emergencies is based upon the experience derived from acute management of severe traumatic brain injury in children.
- The same is true for the postoperative period and most of the severely brain injured children will benefit from postoperative mechanical ventilation with sedation-analgesia and cerebral perfusion pressure-targeted treatment.

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