Chapter

26 Anaesthesia for Neurosurgery in Children

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Introduction

Neurosurgery is a rapidly evolving field with innovative techniques and novel procedures frequently being developed. The children undergoing these procedures are often complex and have a range of cognitive abilities demanding a tailor-made approach to their care. An understanding of normal development and neurophysiology is key to delivering an anaesthetic appropriate for both patient and procedure.

This chapter addresses some of the challenges faced by the paediatric neuroanaesthetist, with specific attention being paid to some of the more common and complex procedures.

Anatomy and Physiology

In the neonate, the calvarium is composed of ossified plates covering the dura, which are separated by fibrous sutures and two fontanelles. The posterior fontanelle closes during the second or third month, whilst the anterior fontanelle usually closes between 10 and 18 months. Both fontanelles fully ossify in the second decade. These fontanelles and non-fused sutures can separate up to early adolescence, providing some protection from a chronic increase in intracranial pressure (ICP). When ICP is acutely elevated, the compliance of the cranium is limited by the dura mater. A clinical assessment of intracranial pressure in infancy can be made by examination of the fontanelles.

Intracranial Pressure

Intracranial pressure in neonates and infants is normally in the range 0–6 mmHg. It increases until adulthood when values of 7–17 mmHg are normal. Brain tissue, blood and cerebrospinal fluid (CSF) are contained within the cranium in the proportions 80%, 10% and 10% respectively. Intracranial pressure may be increased by cerebral oedema, intracranial masses and rises in cerebral blood or CSF volumes. As the skull is essentially a closed box, ICP rises rapidly once compensatory mechanisms have been exhausted. Clinical signs of increased ICP include vomiting, irritability, drowsiness, bulging fontanelles, 'sun-setting eyes' (downward gaze) and increased head circumference. If ICP continues to rise, the Cushing reflex of systolic hypertension, bradycardia and respiratory irregularity occurs, which are signs of imminent brainstem coning, coma and death. ICP can be affected by surgery and anaesthesia, and a clear understanding of the many factors involved is essential knowledge for those undertaking neuroanaesthesia.

Cerebral Blood Flow and Perfusion Pressure

Much of neuroanaesthesia is directed towards controlling ICP. Central to this is the ability to manipulate cerebral blood flow (CBF) which is related to cerebral blood volume (CBV) and in turn to ICP. CBF varies with age (see Table 26.1) and is affected by a number of additional factors, some of which can be manipulated by the anaesthetist in order to reduce ICP when this is indicated.

Cerebral blood supply is coupled to the cerebral metabolic rate. Autoregulation, vasoconstriction or vasodilation of the cerebral vasculature

Table 26.1 Cerebral blood flow: normal range at different ages

Age	Cerebral blood flow (ml min^{-1} 100 g^{-1})
Neonate	40–42
6 months to 3 years	90
3–12 years	100
Adult	50

changes cerebral blood supply to meet the metabolic demands of the tissue. Metabolic demands are increased in conditions such as sepsis or seizures. Here blood flow increases, leading to a rise in cerebral blood volume and consequently ICP. In conditions of decreased metabolic activity such as hypothermia, the reverse is true, and blood flow decreases. Cerebral metabolic rate is higher in children than in adults, as is the demand for both glucose (child 6.8 mg min^{-1} 100 g^{-1}, adult 5.5 mg min^{-1} 100 g^{-1}) and oxygen (infant 5.8 ml min^{-1} 100 g^{-1}, adult 3.5 ml min^{-1} 100 g^{-1}). In the presence of oxygen, the substrate for cerebral metabolism is glucose. There are limited stores of glucose and glycogen in cerebral tissue, so normal cerebral blood flow is essential to maintain glucose and oxygen levels. The high metabolic rate in infants and children increases the impact of any interruption in cerebral blood supply.

Cerebral perfusion is controlled by autoregulatory mechanisms within the normal range of mean arterial pressure (MAP). If excessive hypo- or hypertension, hypoxia, hypercapnia or cerebral ischaemia occurs, these mechanisms fail, and cerebral perfusion becomes dependent on systolic blood pressure. Where there is anaemia or haemodilution, leading to decreased blood viscosity, then viscosity autoregulation also plays a role. Lower viscosity increases oxygen delivery and vasoconstriction occurs. Here CBV decreases, although CBF is constant.

Cerebral perfusion pressure (CPP) is defined according to the formula:

$$CPP = MAP - (ICP + CVP)$$

where MAP is mean arterial pressure, ICP is intracranial pressure and CVP is central venous pressure.

Volatile anaesthetic agents inhibit autoregulation via dose-dependent cerebral vasodilation. In children, this impairment of autoregulation is presumed to be due to the lower MAP. When CPP falls below this lower limit, autoregulation is impaired, and CBF falls in proportion with MAP. Sick neonates have impaired autoregulation, and CBF in this group is highly dependent on systolic pressure. Fluctuations in MAP may explain the occurrence of intraventricular haemorrhage in this patient group. The effects of carbon dioxide on CBF appear to be the same as in adults, but a linear relationship exists between $PaCO_2$ and CBF in sick neonates; hyperventilation has been demonstrated to restore autoregulation in this group. Cerebral steal may occur in some circumstances; hypercapnia results in vasodilation of normal vessels and diversion of blood away from abnormal vessels, for example in tumours or ischaemic areas. Inverse steal may occur in the presence of hypocapnia; normal vessels become constricted, and there is preferential flow to the abnormal vasculature, which is less able to regulate flow.

Control of $PaCO_2$ is an essential tool for the reduction of CBF and therefore ICP. In raised ICP, the interventions that can help to reduce it are mild hyperventilation, moderate hypothermia, cessation of seizure activity, osmodiuresis, increasing sedation/depth of anaesthesia, a head-up tilt, treatment of sepsis and haemodilution. Hypoxia, vasodilators and high concentrations of volatile agent as well as pathological changes (tumour, abscess, trauma) will also adversely affect autoregulation, potentially increasing CBF and consequently ICP.

Cerebrospinal Fluid

CSF surrounds the brain, circulating nutrients, removing waste, supporting structures and offering some protection against trauma. CSF is mainly produced by the choroid plexus. It flows from the lateral ventricles through the foramen of Monro into the third ventricle, then through the cerebral aqueduct of Sylvius to the fourth ventricle and out via the foramina of Luschka and the foramen of Magendie to the subarachnoid space, where it is absorbed by the arachnoid villi. Furosemide or acetazolamide can be used to reduce CSF production in an effort to control ICP. The contribution of these interventions to ICP regulation is very small, and manipulations of CBF and CBV have far greater impact. CSF production is relatively constant in children and adults, but there is a lower storage capacity for CSF in children, so disturbed CSF reabsorption has a far greater effect.

Conduct of Anaesthesia for the Neurosurgical Patient

Preoperative Management

Inclusion of a neurological assessment is essential. Signs of raised ICP, altered conscious level and focal findings should be noted. Vomiting due to raised ICP may cause dehydration and electrolyte

imbalance. Brain stem lesions can be associated with bulbar palsies that may result in aspiration with pulmonary consolidation. Some children have multi-system disease, such as ex-premature infants (chronic lung disease), those with cerebral abscesses (e.g. cyanotic heart disease) and those with major spinal defects (renal disease).

Preoperative investigations should include a full blood count for all patients and electrolytes in those with a history of vomiting or a ventricular drain. Neurosurgery in children can be associated with significant blood loss if sinuses or dilated veins from raised ICP are disrupted. Blood must be cross-matched for children undergoing craniotomy. A clotting screen may be required as anticonvulsant treatment can cause coagulopathy.

Sedative premedication is avoided in children with significantly raised ICP, as further elevation of ICP due to hypercapnia may be catastrophic. Atropine or glycopyrrolate can reduce oral secretions, the pooling of which, especially in the prone or the sitting position, may result in reduced adhesion of tracheal tube fixation tape. Their use has the added benefit of providing a degree of protection against bradycardia.

Induction of Anaesthesia

General anaesthesia remains the norm for craniotomy in children, although awake craniotomy has been reported in adolescents. Induction may be inhalational or intravenous. A thorough explanation and understanding of the process of induction will ideally help assure a calm patient and family, as the anaesthetist needs to be mindful of the ICP at this time. An intravenous technique might have to be adapted to avoid upset should cannulation prove difficult:

- Sevoflurane has become the volatile agent of choice for gas induction in children. It causes cerebral vasodilation, but this may have less effect on the intracranial pressure than an intravenous induction accompanied by crying or breath-holding.
- If intravenous induction is preferred and feasible, then propofol is commonly used.
- A non-depolarising muscle relaxant is used, such as atracurium or vecuronium.
- Suxamethonium may be used if a rapid sequence induction is indicated, although there is a theoretical risk of raising ICP.

Surges in arterial pressure at laryngoscopy should be prevented using fentanyl or remifentanil, and the airway should be secured with an armoured tracheal tube of appropriate size to avoid undue leak and hypoventilation. Consider nasal intubation if advantageous for prone position or postoperative management on the intensive care unit. Satisfactory bilateral lung ventilation should be assessed with the head in a neutral position and then once more in its position for surgery. Cerebral venous obstruction should be avoided by careful patient positioning, 'head-up' tilt and taping rather than tying the tracheal tube. The tape must be moisture-proof, as surgical prep solutions or blood can jeopardise its security. Prophylactic antibiotics are indicated for most neurosurgery, and it is imperative that their administration is appropriately timed.

Intraoperative Monitoring

Routine monitoring includes electrocardiogram (ECG), non-invasive blood pressure (BP), pulse oximetry, capnography, temperature probes (both central and peripheral) and a peripheral nerve stimulator. Capnography also vitally alerts the anaesthetist to the occurrence of venous air embolism (VAE). All major cases require direct arterial pressure measurement to maintain BP close to baseline. If central venous pressure monitoring is required for assessment of intraoperative fluid balance, the most appropriate route is via the femoral vein. This avoids potential obstruction of cerebral venous drainage and raised ICP. Two peripheral cannulae are required in case rapid fluid resuscitation is necessary. Urinary catheters are not used routinely but are indicated in patients at risk of diabetes insipidus, those undergoing prolonged surgery or where large blood loss is anticipated.

The large surface area to volume ratio of paediatric patients makes temperature control difficult. It is essential to monitor body temperature and to maintain it between 36°C and 36.5°C using patient warming devices and fluid or blood warmers.

If the patient's temperature rises, all warming devices should be switched off, and this is usually sufficient to reduce temperature.

Hypothermia has a cerebral protective effect, and temperature reduction can allow surgery to continue in cases where cerebral perfusion is compromised. Moderate hypothermia of 34–36°C post-ischaemia has neuroprotective benefits

without the additional risk of cardiac arrhythmias and metabolic changes.

Post-ischaemic neurological function and cerebral histopathology appear to be detrimentally affected by 1–2°C increases in temperature; hyperthermia should therefore be avoided.

Postoperative hyperpyrexia, which is more likely after craniopharyngioma resection and hypothalamic, pontine and midbrain manipulations, should be treated urgently, especially if the temperature exceeds 40.5°C

Anaesthetic Agents

Balanced anaesthesia should be maintained, with 0.5–1.0 minimum alveolar concentration (MAC) of sevoflurane or isoflurane in air/oxygen. Nitrous oxide should be avoided when ICP is critically raised, or there is a risk of venous air embolism. The ideal agent for neuroanaesthesia should maintain cerebrovascular autoregulation, allow the continued coupling between CBF and metabolism, avoid an increase in CBV or ICP, have no impact on the electroencephalogram (EEG) and have both neuroprotective and anticonvulsant potential.

Volatile agents at low dose cause cerebral vessels to constrict by suppressing metabolism. Sevoflurane has been demonstrated to have the most favourable profile as it is the least vasoactive volatile agent. This results in less vasodilation for the same depth of anaesthesia, with little or no effect on autoregulation, CBV and ICP below 1 MAC. Its fast elimination also allows neurological status to be assessed more reliably in the immediate postoperative period. With increasing concentrations of volatile agent, vasodilatory effects predominate, and whilst ICP may only increase marginally, the effects on CPP are clinically significant owing to a decrease in MAP. Whilst sevoflurane causes less suppression of somatosensory-evoked potentials than isoflurane, it significantly attenuates motor-evoked potentials.

Propofol, in contrast, does not impair autoregulation; it decreases CBF and ICP and has a lesser effect on somatosensory and motor-evoked responses. This makes it an attractive option in instances when intraoperative neuromonitoring (IONM) is required, and total intravenous anaesthesia (TIVA) is now the preferred technique in these circumstances.

Neuromuscular blocking agents (NMBA) can also be problematic, as their action may be prolonged in patients taking anti-epileptic medication. NMBA use after intubation is precluded when IONM is needed.

Ventilation

Mild to moderate hyperventilation ($PaCO_2$ approx. 3.8–4.2 kPa) will cause vasoconstriction, reducing cerebral blood volume, and is useful when ICP is elevated. Cerebral ischaemia has been described if $PaCO_2$ is allowed to fall below 3.5 kPa, although paediatric patients are less prone to focal ischaemia due to healthier blood vessels.

Control of the fractional inspired oxygen is important, and the anaesthetist should aim for normoxia. Hypoxia increases the risk of ischaemia and subsequently leads to an increase in CBF. Conversely, hyperoxia promotes excitotoxic damage through the generation of oxygen free radicals.

Analgesia

The intraoperative analgesic of choice has traditionally been fentanyl, which, unlike alfentanil and sufentanil, does not increase CBF or ICP. Unless the procedure is prolonged or postoperative ventilation is planned, the maximum dose should not exceed 7–10 mcg kg^{-1}. Remifentanil is now widely used, as its short duration of action enables easy titration in response to surgical stimulus and facilitates rapid recovery from anaesthesia. Supplementation with alternative analgesia on cessation of a remifentanil infusion prior to emergence is essential. On completion of surgery, muscle relaxation is reversed with neostigmine and glycopyrrolate if necessary. Children should be extubated when breathing well with a normal end-tidal carbon dioxide. Excessive coughing can be avoided by a deep extubation if it is possible.

Fluid Replacement and Haemodynamic Parameters

In a normal brain, osmotic forces produce fluid fluxes. A fall in osmotic pressure of 5–10 mOsmol kg^{-1} may result in cerebral oedema. A balanced fluid such as Hartmann's solution can be used for intraoperative fluid maintenance in neurosurgery, but where large volumes are required this mildly hypo-osmolar solution is not ideal and normal saline may be preferable. Hyperglycaemia is

associated with adverse outcomes in head injuries, and blood sugar should be monitored regularly. Glucose-containing infusions should be used cautiously and only when indicated.

It is difficult to measure blood loss accurately in neurosurgery, and the relatively large head size of children results in proportionately larger blood loss compared with adults. An assessment of blood loss can be made by reviewing haemodynamic parameters, in particular heart rate and arterial pressure. Massive blood transfusions may be required for some neurosurgical procedures in small children and are generally well tolerated provided clotting, blood gases and potassium levels are checked regularly. Rapid and large transfusion of blood carries several risks in the infant and is discussed in Chapter 14. The use of antifibrinolytics such as tranexamic acid should be considered when blood loss is a risk.

Optimal surgical conditions are associated with a relatively slow heart rate, and this can be achieved with deep anaesthesia and normovolaemia. Induced hypotension should be used with great caution. Remifentanil facilitates intraoperative haemodynamic control, and when necessary its hypotensive effects may be offset using $\alpha 1$ agonists such as phenylephrine. Acute rises in ICP can usually be managed with moderate hyperventilation and mannitol. Dexamethasone may be used to decrease cerebral oedema but should be used with caution in the presence of infection such as cerebral abscess.

Postoperative Management

The majority of patients do not require postoperative ventilation. The decision to ventilate a patient may be made preoperatively where specific indications exist, or intraoperatively if surgery has been unexpectedly prolonged, the patient has been cardiovascularly unstable or if there is a neurosurgical indication. Patients who are slow to wake up may require radiological imaging in the immediate postoperative period.

Patients undergoing craniotomy require high-dependency care postoperatively. Direct arterial pressure monitoring should be maintained for 24 hours, and cardiorespiratory function, fluid balance and neurological status should be monitored. Analgesia for these patients includes regular intravenous paracetamol and an opioid, with the addition of an NSAID if no contraindication exists. Oral morphine is often used postoperatively, but reduced doses may be necessary to avoid undue reduction in conscious level or pupil size. Patient- or nurse-controlled intravenous morphine analgesia is useful, particularly for patients who have had posterior fossa craniotomy or spinal surgery. Antiemetics should be administered to mitigate postoperative nausea and vomiting.

Specific Considerations

Acute Head Injury

The force required to produce a skull fracture in a child is large, so an associated brain injury is more likely than in an adult. Rapid increase in ICP from cerebral oedema and subdural haematoma may necessitate urgent surgical intervention. Secondary injury; scalp lacerations resulting in large blood loss; facial injuries causing airway compromise; and additional thoracic, abdominal or limb injuries need to be considered. This is particularly true for cervical spine injuries which can occur in children without radiological evidence.

Brain Tumours

Tumours may be vascular lesions, and some are suitable for preoperative embolisation of large feeding vessels to reduce operative blood loss. Neurosurgery for tumours is still not without significant risk of morbidity and mortality. The majority of brain tumours in children occur in the posterior fossa. Surgery performed with the child in the sitting position provides excellent surgical access, improved cerebral venous drainage, decreased blood loss, lowering of ICP and improved postoperative recovery, including preservation of cranial nerve function. This position provides an anaesthetic challenge, as there is increased risk of VAE, and it can be associated with cardiovascular instability, pneumocephalus, compression injuries due to pressure on neurovascular structures and quadriplegia due to spinal cord infarction. Hypotension is unusual in the paediatric population provided the patient is adequately fluid loaded.

Posterior fossa syndrome is a unique postoperative complication of this procedure. It consists of several components, including ataxia, nerve palsies, hemiparesis, irritability and cortical blindness. It is often associated with symptoms of cerebellar mutism, resulting in loss of speech and

occasionally loss of the ability to eat or drink. Recovery over time is variable and has been reported to take anything from days to years. The cause remains debated, but focal decrease in cerebral blood flow is considered most probable.

Venous Air Embolus

VAE is uncommon, but the consequences can be significant in children. The problem is amplified in neonates and babies whose heads are proportionally larger and sit higher than the heart when lying supine. This pressure differential is exaggerated in the sitting position. If it occurs, VAE can be catastrophic in those with congenital heart disease such as a patent foramen ovale. Nitrous oxide should not be used in cases where there is a risk of VAE.

Diagnosis of VAE can be made using several methods, including oesophageal stethoscope, precordial Doppler or transoesophageal echocardiography. Capnography is used in many units to monitor for VAE; the alarm limits are set close to the end-tidal carbon dioxide level ($ETCO_2$), so that the anaesthetist is immediately alerted if the $ETCO_2$ falls. Significant emboli are those which cause a fall in blood pressure of more than 10%, or changes in heart rate and in particular arrhythmias. If VAE is suspected, immediate management is to flood the surgical site with fluid to seal the veins, provide 100% oxygen, administer jugular venous compression and resuscitate with fluid to raise the venous pressure and limit the embolus size. Head-down tilt or even CPR may become necessary, and the anaesthetist should know how to release the child from the sitting position should this uncommon event occur.

Craniopharyngioma

Craniopharyngioma is a slow-growing cystic suprasellar tumour arising from remnants of the craniopharyngeal duct. It has benign histology, but insidious growth may produce significant mass effect, including progressive neurological and endocrine deterioration as the tumour expands into the hypothalamus, optic nerves and pituitary stalk. These children are often either small owing to growth failure or obese because of hypothalamic dysfunction. The major problems in the perioperative period are likely to be related to blood loss or diabetes insipidus (DI), the latter due to failure of antidiuretic hormone (ADH) secretion from the posterior pituitary. Involvement of the endocrinology team is essential as these patients may be on steroids, and synthetic vasopressin (DDAVP) may be required in the perioperative period to control DI.

CVP monitoring, arterial access and an indwelling catheter are essential, as measuring perioperative urine specific gravity and plasma osmolality will be needed to assess DI. There is also an increased incidence of seizures and hyperpyrexia requiring treatment after craniopharyngioma surgery.

Epilepsy surgery

There are two major types of surgery for intractable epilepsy:

- Excision of a specific seizure focus (e.g. temporal lobe resection)
- Interruption of neural transmission (e.g. corpus callosotomy)

Developmental delay and behavioural issues as well as coexisting disease make anaesthesia for patients with epilepsy a challenge. Anaesthetic agents can display pro- and anticonvulsant properties depending on the dose being administered. Less than 1 MAC sevoflurane minimises the effects on the EEG and facilitates mapping of the lesion. The patient's anticonvulsant medications may produce a number of side effects, including sedation, altered drug metabolism (both enhanced and inhibited), platelet abnormalities, liver dysfunction, metabolic acidosis and increased risk of idiosyncratic drug reactions. An increased tolerance to neuromuscular blockade and opioid analgesia is of particular relevance in these cases. Children with refractory epilepsy on a ketogenic diet will need acid–base balance and blood glucose monitored throughout the perioperative period.

Significant advances have been made in paediatric epilepsy surgery. Awake craniotomy techniques have been used in older children to minimise intraoperative iatrogenic injury. This approach requires multidisciplinary team input and careful patient selection. The implantation of a vagal nerve stimulator is another contemporary treatment which inhibits seizure activity with minimal side effects. Laser ablation may also be employed to destroy seizure foci located within deep structures of the brain. This technique involves the stereotactic-guided insertion of a laser catheter via a burr hole to enable thermal

destruction of the epileptogenic focus, thus negating the need for craniotomy. The procedure requires a series of transfers between the operating theatre, CT and MRI scanners and requires strict adherence to standard laser and MRI precautions.

Neural Tube Defects

Exposed neural tube defects, such as encephalocele or myelomeningocele in neonates, should be repaired as an emergency. Early surgery may be indicated for large lesions, or where there is a risk of rupture and meningitis. In other instances, surgery can be deferred until all investigations, including imaging, have been completed.

Traditionally, intubation has been in the left-lateral position, but the supine position can be used if the lesion is protected adequately from pressure. A Montreal mattress (Figure 26.1) with the head and body supported and the defect in the central space of the mattress is ideal. Surgery is usually performed in the prone position, and care is needed to ensure the eyes are free from pressure and to avoid inferior vena caval compression, which causes engorgement of the paraspinal veins. Haemangiomas in the surrounding tissues may increase surgical blood loss. Long procedures in the prone position also place the patient at risk of airway and tongue oedema. Intraoperative opioids are avoided or minimised unless postoperative ventilation is planned. Wound infiltration with 0.25% bupivacaine is a useful adjunct.

Hydrocephalus

Hydrocephalus can be acquired (e.g. intrauterine infection, meningitis, tumour, haemorrhage) or congenital (e.g. Arnold Chiari malformation, myelomeningocele) with these patients presenting for surgery as neonates. Ventriculo-peritoneal (VP) shunt insertion is the usual treatment for this condition. In the premature infant, coexisting inguinal hernias may have to be repaired to prevent CSF accumulating in the hernial sacs. The peritoneal route is avoided if there is intra-abdominal pathology that may require surgical intervention in the future. Ventriculo-atrial shunts are rarely used and are potentially complicated by bacterial endocarditis. Alternatively, a ventriculo-pleural shunt may be used, but this is usually reserved for cyst or subdural fluid drainage.

Many infants requiring a VP shunt will have received neonatal intensive care and will be less than 44 weeks postgestation at surgery. A subgaleal shunt may be indicated in particularly small neonates for whom a VP shunt would be too large. This procedure presents the anaesthetist with all the problems associated with surgery in the ex-premature neonate (see Chapter 19). Exposure of skin surfaces and the surgical field preparation make temperature control difficult. Although blood loss is minimal, there is a potential risk of air embolism with catheter insertion, and excessive drainage of CSF can result in cardiac instability.

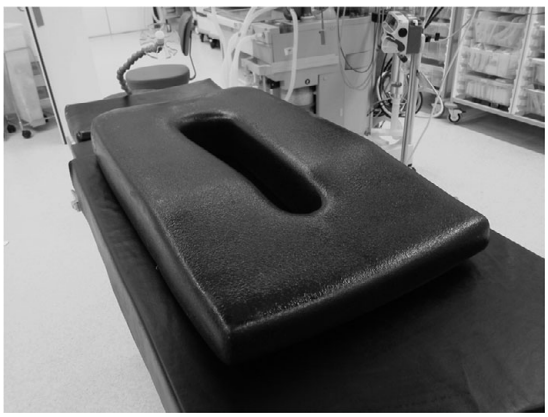

Figure 26.1 Montreal mattress.

Spinal and Craniocervical Surgery

Congenital Abnormalities

Abnormalities in the lumbar region include dermal sinus tracts or tethered filum terminale. They present with minimal clinical features, but a dermal pit or hair tuft may be apparent. Dermal sinus tracts predispose to meningitis and may present with progressive paraplegia. Tethered filum terminale may present with leg weakness or bowel and bladder symptoms. These abnormalities are usually avascular, and intraoperative transfusion is rare. An anaesthetic technique, such as TIVA, should be used to facilitate spinal monitoring when required. The patient is positioned prone with all the accompanying risks that this may present.

Spinal Tumours

Extramedullary spinal tumours arise from abnormal embryogenesis or as metastases. Intramedullary tumours, most commonly astrocytomas or ependymomas, are a greater

surgical challenge as they involve the spinal cord itself. IONM is usually required, and anaesthesia will need to facilitate it.

Spinal tumours are often extremely vascular, and despite optimal positioning and induced hypotension, patients can require large-volume transfusions. Surgical manipulation of the spinal cord may be associated with arrhythmias and hypotension. This is especially true in the thorax, and suboptimal anaesthesia may exacerbate this picture.

Instability of the Craniocervical Spine

This can be acquired or congenital. Congenital cases may be associated with inherited disorders such as Down syndrome, Morquio syndrome and pseudoachondroplasia. Atlanto-axial subluxation (Figure 26.2) may be posterior but is much more commonly anterior.

Subluxation creates a kyphosis over C2. The spinal cord, tethered by the dentate ligament, is compressed primarily by the dens. Flexion is more hazardous than extension, with sudden flexion causing cord contusion.

Instability of the craniocervical spine in patients presenting for corrective surgery presents several significant problems. The main problem initially is inducing anaesthesia and intubation prior to fixation of the neck in a halo jacket or surgery. Intubation is usually achieved by standard techniques, but the neck must be held in line by an assistant, who prevents flexion or extension. In adult practice, videolaryngoscopy or awake fibreoptic intubation (FOI) is often the first choice for securing the airway; at the author's institution, asleep FOI is the method of choice where difficulty is anticipated. Cricoid pressure is contraindicated.

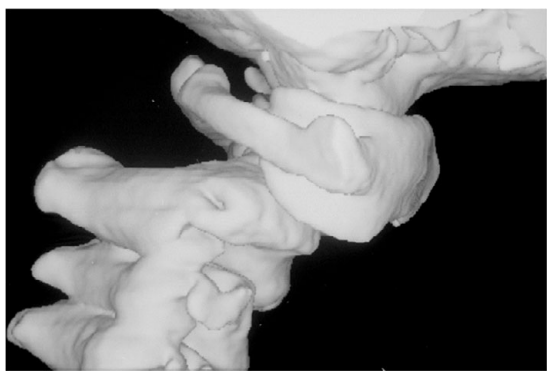

Figure 26.2 Atlanto-axial subluxation.

Depending on the lesion, the surgical approach will either be posterolateral or transoral. With the latter approach, the child remains intubated post-operatively until all oral swelling has settled, usually within 24–48 hours. Once the child is in the halo jacket, it is essential to appreciate that the previous laryngoscopic view is altered by the fixation position, and intubation may no longer be straightforward. The standard laryngoscope handle normally clashes with either the lateral rods or the top of the jacket, and therefore a polio handle is advantageous. The option of FOI should always be available when anaesthetising a child in a halo jacket, although many procedures can be performed safely with a supraglottic airway device (SAD). A SAD not only provides an airway but may also facilitate intubation where indicated.

Stereotactic Surgical Techniques

Stereotactic surgery allows precise mapping and access to small, deep-seated lesions of the brain, with decreased neurological morbidity. In the past, the application of the stereotactic headframe in children required general anaesthesia and involved moving the anaesthetised patient between CT scanner and operating theatre. These devices have now been superseded by frameless stereotaxy, for which general anaesthesia is still required, but movement of the anaesthetised patient between different clinical areas is not. External markers on the patient's scalp act as reference points for a pair of cameras above the operating field, which feed back the position of the tip of a chosen surgical tool to a 3D computer-generated image. Intraoperative MRI may also be used to improve the precision of tumour resection and epilepsy surgery. The development of a dedicated suite incorporating an MRI scanner and operating theatre is a costly endeavour, but it enables contemporaneous imaging providing information about the anatomical changes which have occurred during the resection and avoids a separate post-operative scan and general anaesthetic. Procedures integrating MRI are time consuming and require extra care with patient positioning and thermoregulation. Airway access is limited once the headframe is in place and the anaesthetist must be ready and equipped to remove it if necessary. The requirement for MRI-compatible equipment (e.g. non-reinforced endotracheal tube [ETT]), and monitoring introduces additional complexity.

All personnel involved must be familiar with MRI safety, and a dedicated procedural checklist should be used.

Neuroendoscopic Techniques

Neuroendoscopy is a helpful technique in the treatment of several disorders, including hydrocephalus, cyst puncture and periventricular tumour biopsy. Its indications and applications continue to expand. The procedure requires minimal anaesthesia once the burr hole has been made. The patient's age and clinical state usually guide the choice of anaesthetic technique for this minimally invasive procedure. Video facilities allow the anaesthetist as well as the surgeon to view the surgery as it proceeds, and this improves communication. Patient positioning varies, and access can be limited. Invasive monitoring may be used for prolonged cases or where there is a patient-specific indication.

Third Ventriculostomy

Third ventriculostomy is an alternative to a VP shunt. It involves fenestration of the floor of the third ventricle, allowing it to communicate with the basal cisterns facilitating reabsorption of CSF. It is relatively contraindicated in individuals with abnormal ventricular anatomy, ventricular haemorrhage or a history of meningitis. Endoscopic ventriculostomy eliminates the risk of shunt-related complications and decreases the necessity for repeated operations after VP shunt insertion.

Complications of third ventriculostomy include haemorrhage, particularly injury to the basilar or perforating arteries (which can result in intraoperative death) and transient or permanent sequelae from midbrain manipulation (variable cardiovascular instability, bradycardia and asystole). Increases in ICP due to pre-existing disease, irrigation fluid or bleeding are also possible, and hypertension and tachycardia may offer the most reliable clue to the development of significantly raised ICP rather than the classic Cushing reflex.

Altered mental state, cranial nerve palsies, vomiting and aspiration, syndrome of inappropriate antidiuretic hormone (SIADH) and ventriculitis may all complicate recovery. Electrolyte imbalance postoperatively has been attributed to several factors including irrigation fluid, disturbance of the hypothalamic nuclei and hormonal imbalance.

Endoscopic Transphenoidal Surgery

Endoscopic transphenoidal surgery can be used for removal of various lesions, including pituitary tumours and craniopharyngiomas. Surgical access to the pituitary gland is achieved without brain retraction, and the associated morbidity and mortality are decreased.

A preoperative endocrine assessment as for patients with pituitary tumours should occur. It is useful to insert central venous access at induction, as these patients may require repeated blood tests to monitor endocrine function postoperatively.

Cardiovascular instability may be encountered on application of nasal epinephrine at the start of the procedure, and there is potential for intraoperative haemorrhage.

On extubation, the airway may be jeopardised in obligate nasal breathers by pharyngeal blood, gastric blood and nasal packs. Acute haematoma may present with sudden blindness, ophthalmoplegia, hypotension and decreased conscious level.

Revascularisation Surgery/Extracranial–Intracranial Bypass

Children presenting for this procedure have Moyamoya disease, a progressive chronic occlusive cerebrovascular disease. It usually presents in childhood with symptomatic stenosis of the arteries of the circle of Willis and the internal carotid arteries. These children may have had transient ischaemic attacks or strokes, indicating significantly compromised cerebral blood flow. Medical treatment consists of anti-platelet therapy with aspirin in most cases.

The anaesthetist's aim is to avoid ischaemia and its sequelae. Preoperative fluids will maintain hydration for surgery. Patient distress needs to be minimised, and premedication is advisable.

Normocapnia should be maintained intraoperatively, as hyperventilation reduces cerebral blood flow and can precipitate an ischaemic event; carbon dioxide retention may cause 'steal' from compromised vessels by areas of healthy vasculature. Normocapnia is also of importance in the postoperative period and adequate analgesia provided to avoid crying and hyperventilation.

Normothermia, normovolaemia and normotension are also essential during recovery. Careful perioperative control of these parameters helps avoid hyperperfusion injury. Hyperperfusion of previously hypoperfused regions of the brain where autoregulation is no longer functioning can be detrimental, resulting in nausea, vomiting, seizures, haemorrhage and permanent neurological deficit.

Conclusion

Paediatric neuroanaesthesia is complex. It requires knowledge of neuroanatomy, neuropathology and pharmacology as well as an insight into what is practical for the patient. Some of the points to consider are summarised in Table 26.2. With suitable planning and preparation, the perioperative period can be managed to optimise the outcome for the patient and their family.

Table 26.2 Considerations for paediatric neurosurgery

Procedure	Preoperative considerations	Intraoperative considerations	Postoperative considerations
Acute head injury	Time critical Secondary damage Airway compromise C-spine stabilisation Blood loss Limb/organ injury	Fluid management Blood loss ICP	May require HDU/ICU
Sitting craniotomy	Oral secretions and stability of ETT	VAE Cardiovascular instability Pneumocephalus	HDU Cord infarction Posterior fossa syndrome
Craniopharyngioma	Increased BMI Endocrine review DDAVP	Risk of DI Central monitoring/ urinary catheter	Risk of DI Endocrine follow-up
Epilepsy surgery	Developmental delay/ behavioural issues Coexisting disease Medication effects (coagulopathy)	Idiosyncratic drug reactions Altered drug metabolism Intraoperative monitoring (EEG effects)	Increased risk of seizures
Stereotactic surgical techniques	Universal MRI precautions	Limited airway access Intraprocedure transfers Temperature control	May need HDU
Neural tube defects	Timing of procedure Neonates/ex-premature infants Intubation position	Prone position Blood loss Temperature control	May require ICU
Hydrocephalus	Coexisting conditions Prematurity	Temperature control VAE Cardiac instability with CSF drainage	May require ICU

Table 26.2 (*cont.*)

Procedure	Preoperative considerations	Intraoperative considerations	Postoperative considerations
Spinal surgery	Instability of C-spine FOI may be required Halo/jacket in situ Associated syndromes	Neurophysiological monitoring Prone position Arrhythmias/ hypotension Blood loss	Halo/jacket in situ +/– altered laryngoscopic view May require ICU
Transphenoidal surgery	Endocrine review	Cardiovascular instability Blood loss +/– central monitoring	Airway management (pharyngeal blood/ nasal packs) Acute haematoma
EC–IC bypass	Premedication Associated disease process Anti-platelet therapy +/– preoperative fluids	Maintain normocapnia/ normotension/ normothermia	Maintain normocapnia/ normotension/ normothermia Adequate analgesia

Key Points

- Paediatric neuroanaesthesia sometimes requires compromise between theory and practicality.
- Knowledge of neurophysiology and the ability to manipulate it is key.
- Preoperative assessment must pay particular attention to the symptoms and signs of raised ICP.
- Extreme vigilance is required where VAE is a risk.
- Provision for appropriate postoperative care is essential.

Further Reading

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