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Pediatric neurosurgical patients present a unique set of anesthetic challenges that include treatment of increased intracranial pressure (ICP), the use of positions other than supine, and the anesthetic implications of neurophysiologic monitoring. These and other general considerations are addressed in the first part of this chapter, followed by a discussion of anesthetic techniques for common pediatric neurosurgical procedures.

PATHOPHYSIOLOGY AND TREATMENT OF INCREASED ICP

There are structural and functional differences in cranial anatomy between children and adults that influence cerebral physiology and management of increased ICP. Whereas the normal adult ICP measures between 8 and 18 mmHg, normal ICP in small children ranges from 2 to 4 mmHg. The skull of newborns does not completely fuse until the latter part of the first year of life. Consequently, the intracranial space is relatively compliant and the dura is able to expand when brain tissue becomes edematous as a result of trauma or mass lesions. Therefore, neonates and small infants may not exhibit signs and symptoms of the early stages of pathologic processes that increase brain mass. An important clinical correlate is that, when a small infant or neonate presents with signs or symptoms of increased ICP, there may already be advanced disease. Later in childhood, after fusion of the cranial sutures, children may exhibit less intracranial compliance than adults. This is postulated to be caused by a relatively higher percentage of brain tissue to CSF and blood vessels in children. Thus, children may be at higher risk of dangerous increases in ICP with relatively less edema or tumor mass.

In cases of increased ICP, the general management goal is to achieve an ICP <20 mmHg in all ages. Numerous studies have verified that cerebral perfusion pressure (CPP), the difference between the mean arterial pressure and the ICP, varies directly with age. In other words, younger children require lower CPP. In children younger than 8 years, a CPP >40 mmHg is recommended, whereas in older children, the CPP should be >60 mmHg. It is unknown whether it is more important to decrease ICP or optimize CPP during conditions of acutely increased ICP. Nevertheless, in pediatric patients, CPP values <40 mmHg are strongly correlated with worse outcomes at any ICP.

Methods to lower ICP are the same in children as in adults. Standard therapies include elevation of the head, avoidance of jugular kinking by keeping the head positioned in the midline, hyperventilation to decrease $P_{CO_2}$, and administration of diuretics such as mannitol and furosemide. Recent reports of the efficacy of hypertonic saline are encouraging as another possible treatment modality.

Administration of volatile anesthetics will cause generalized cerebral vasodilation. In adults, an acute increase in ICP will render the patient more susceptible to the deleterious effects of volatile anesthetics. This is probably true in the pediatric population as well. Furthermore, neonates and infants appear to maintain the same degree
of cerebral vasoconstriction in response to decreased $P_{CO_2}$ as seen in adults. However, there is evidence that in anesthetized infants and children, cerebral vasodilation may occur at lower levels of $P_{CO_2}$ than observed in adults.

There has been a major shift in the way $P_{CO_2}$ is managed during adult neurosurgery, and this has extended into pediatric practice. In general, the $P_{CO_2}$ is no longer maintained below 30 mmHg for fear of vasoconstriction-induced aggravation of cerebral ischemia. Rather, mild hyperventilation ($P_{CO_2}$ in low-to-mid 30's) is most often employed, the major reason being to offset the possible vasodilatory effects of general anesthetics. However, in the face of acutely increased ICP, lowering the $P_{CO_2}$ below the previous level will usually result in cerebral vasoconstriction and, at least temporarily, decrease ICP. This principle may extend to $P_{CO_2}$ levels below 20 mmHg. When managing increased intracranial pressure, $F_{O_2}$ (fractional inspired oxygen concentration) should always be set to 1.0 to maximize oxygen delivery to the brain cells.

**PREOPERATIVE ASSESSMENT**

Most children presenting for neurosurgery have been hospitalized for evaluation of a recently diagnosed brain mass or malfunctioning shunt. In the course of this hospitalization, it is expected that normal baseline laboratory studies have been performed. Other children with known brain pathology have had their evaluation as an outpatient, and may be admitted to the hospital on the day of the surgery. Required blood tests include a hemoglobin, and in most tumor cases, a type and screen. Electrolytes should be obtained if there is a possibility of hormonal alterations of sodium homeostasis. Many children who present for neurosurgery are being treated with anticonvulsants. Unless the drug regimen is changing, or the child’s seizures are uncontrolled, preoperative anticonvulsant levels are not indicated.

The majority of children presenting for neurosurgery will benefit from preoperative anxiolysis. Since most
of these children already have indwelling intravenous catheters, intravenous midazolam can be titrated to effect in the preoperative holding area. Oral or rectal midazolam may also be administered in children without IV access. Intravenous fentanyl can also be administered if the child is having ongoing pain. There is a concern in neurosurgical patients that administration of preoperative sedation will lead to hypoventilation and, thus, hypercarbia which contributes to worsening of increased ICP. However, this situation is unusual in children. Those children with acutely increased ICP will present emergently and are often obtunded or too ill to benefit from preoperative anxiolysis.

It is commonly believed that increased ICP slows gastric emptying and renders the patient at risk for aspiration of gastric contents. Yet very few data exist, especially in children, to substantiate this fact. In addition, clinical experience has shown that aspiration is quite rare in this population. Therefore, premedication with H₂-antagonists and metoclopramide is rarely indicated unless the procedure is emergent and the child had a recent meal, or if there are other reasons to suspect that the child has abnormally increased gastric contents.

### ANESTHETIC TECHNIQUES

A modified rapid sequence induction of general anesthesia is the preferred technique because of the possibility of increased gastric contents in patients with increased ICP. Any IV induction agent can be used, along with a nondepolarizing neuromuscular blocker, while an assistant provides cricoid pressure during bag-mask positive-pressure ventilation. Succinylcholine is generally avoided because of its propensity to increase ICP. If, however, a reasonable risk of pulmonary aspiration of gastric contents exists, a full rapid sequence induction using succinylcholine or high-dose rocuronium is indicated. Alternatively, if the child does not have an indwelling intravenous catheter, and there is no reasonable risk of pulmonary aspiration of gastric contents, then an inhalational induction can be performed. Cricoid pressure is applied as soon as the child loses consciousness, and IV access is rapidly attained to permit continuation of a modified rapid sequence technique.

Succinylcholine is traditionally avoided in neurosurgery because of its ability to transiently increase ICP. Although the precise cause of this is unknown, evidence suggests that it is caused by afferent neuronal muscle spindle activity that results from succinylcholine-induced muscle fasciculations. Indeed, in adults, pretreatment with a small dose of a nondepolarizing muscle relaxant may prevent this increase in ICP from succinylcholine. Since small children tend not to exhibit muscle fasciculations, this effect of succinylcholine may not be observed.

Nevertheless, unless succinylcholine is indicated based on the nature of the child’s condition, it is best avoided during induction of general anesthesia.

When control of potential increases in ICP is of concern during induction of anesthesia, additional therapies are indicated. These include IV opioids, and lidocaine (1 mg/kg), both of which will blunt the hemodynamic response to laryngoscopy and tracheal intubation, and thus help prevent dangerous increases in ICP. In addition, scalp infiltration with a local anesthetic will limit the hemodynamic response to the surgical incision. Traditionally, the bulk of the opioid dose is given toward the beginning of the neurosurgical case, because tracheal intubation, positioning, and scalp incision are the most painful and stimulating events. Furthermore, residual opioid effect is undesirable at the end of the procedure when the goals are the rapid attainment of consciousness and tracheal extubation, to facilitate an immediate neurological exam. Fentanyl 4–6 µg/kg is commonly used during induction. Remifentanil is a reasonable alternative and can be used as a continuous infusion throughout the procedure. Some adult studies have suggested that alfentanil and sufentanil may increase ICP by either increasing CSF volume or increasing cerebral blood flow. A study in children examined the effect of alfentanil (10–40 µg/kg) on ICP in children with moderately elevated ICP presenting for revision of VP shunts. Alfentanil consistently produced a decrease in cerebral perfusion pressure that was largely accounted for by decreases in blood pressure. Increases in ICP were not observed. Ketamine is usually avoided in neuroanesthesia because of its propensity to increase ICP.

Any volatile agent can be used for maintenance of general anesthesia; in adults, this choice does not affect the outcome of neurosurgical procedures. All volatile general anesthetic agents can cause cerebral vasodilation and increase ICP by increasing cerebral blood flow and volume. Studies in children have used the transcranial Doppler technique to measure the blood flow velocity of the middle cerebral artery, which in turn may represent overall cerebral blood flow and volume. Halothane is generally considered to be the most potent cerebral vasodilator and is consequently not used during neurosurgery. In children, isoflurane appears to have minimal effects on cerebral blood flow and cerebrovascular reactivity to CO₂ between 0.5 and 1.5 MAC (minimum alveolar concentration). Furthermore, administration of a constant concentration of isoflurane over time does not affect cerebral hemodynamic variables. Sevoflurane appears to have similar effects as isoflurane, although it has not been well studied in children to date. Desflurane has been shown to increase ICP in adults despite application of hyperventilation, but has not been directly studied in children. Nitrous oxide increases cerebral blood flow when used alone, and in combination with propofol or sevoflurane.
However, it does not appear to increase cerebral blood flow when combined with desflurane. This lack of effect may be explained by the potent baseline cerebrovascular dilation effect of desflurane. Overall, the vasodilatory cerebrovascular effects of all inhalational anesthetics in children are similar to that of adults. With normal levels of ICP, there is probably no clinical difference between agents. In conditions of increased ICP, although effects on cerebral blood flow are believed to be mitigated by moderate hyperventilation for all volatile anesthetic agents, minimal concentrations of inhalational agents should be used with primary reliance on an opioid-based technique.

Normally, fentanyl 1–2 μg/kg/h is continued throughout the procedure, or remifentanil is targeted to desired hemodynamic parameters. In adults, studies that have examined the role of remifentanil as the primary anesthetic agent to facilitate early extubation have not demonstrated any differences in short- or long-term outcome. Similar studies have not been performed in children. Neuromuscular blockade throughout the procedure is encouraged to facilitate positioning, and to assure lack of patient movement during brain dissection. Children on chronic anticonvulsant therapy will require more frequent dosing of aminosteroidal muscle relaxants. If the child has a preexisting hemiparesis, the twitch monitor should be placed on the nonhemiparetic side.

Use of N₂O is controversial in neurosurgery because it raises cerebral metabolic oxygen consumption and may increase cerebral blood flow and, thus, ICP. No outcome studies exist that influence the decision to include it in the anesthetic management of children. However, since N₂O is not essential for any reason in neuroanesthesia, it should not be used when increased ICP is a possibility. In addition, N₂O is contraindicated in any child who returns for a repeat craniotomy within 1 month because of the possibility of development of pneumocephalus secondary to air remaining within the ventricles or cisternal system.

A general rule in pediatric neuroanesthesia is that if a child’s trachea was not intubated on arrival to the OR, then he or she should be awakened at the completion of the procedure with the intent of tracheal extubation and immediate neurological evaluation. Exceptions include cases where adverse intraoperative events occurred that would likely cause postoperative cardiorespiratory depression or the inability of the child to protect their airway from obstruction or pulmonary aspiration of gastric contents. Children with acute head trauma who underwent tracheal intubation in the field or the emergency department are also candidates for tracheal extubation after a successful evacuation of a blood clot or hemorrhage, assuming all cardiorespiratory parameters have normalized. Children in whom life-threatening period should receive continuous intravenous sedation and neuromuscular blockade, and should be managed postoperatively with mechanical ventilation.

The positioning of pediatric patients for neurosurgery entails proactive attention to details that will prevent complications or problems during the procedure. This includes secure taping of the endotracheal tube, atraumatic placement of an orogastric tube and esophageal stethoscope, administration of petroleum-based eye lubrication, careful taping of arterial and intravenous catheters, and careful positioning of an indwelling urinary catheter. Most often the patient will be positioned supine with the head turned to the side, but many procedures require prone, lateral, or head-up (semi-sitting) positioning. All anesthetic monitors and access lines should be placed and their adequacy confirmed prior to draping. In addition, the anesthesiologist must plan his or her workspace so as to include adequate access to the patient during the surgery. Padding pressure points may help prevent compression injuries. If the patient is prone, free and easy abdominal movement with ventilatory movements should be confirmed by inspection of the abdomen and confirmation that ventilatory compliance is unchanged from baseline. Attention should also be paid to ensuring lack of compression of the eyes and other facial structures.

Though declining in frequency, the sitting position may occasionally be used in pediatric patients for surgical access to the posterior fossa; it entails the same monitoring and safety considerations as for adults in the sitting position. In children there is also the risk of venous air embolism from entrainment of air into open vessels. A recent retrospective audit of complications associated with the sitting position in children reported the incidence of venous air embolism to be 9.3%. All were detected and treated appropriately, and none directly caused morbidity or mortality. Other pediatric studies have reported an incidence of venous air embolism in the sitting position as high as 37%. Some evidence exists that children have higher dural sinus pressures than adults, and may account for the generally lower incidence of venous air embolism in children compared to adults. However, some studies suggest that venous air embolism is more likely to result in hypotension in pediatric patients because, in theory, the same-sized air bubble would be larger relative to the smaller blood volume of children, and therefore, cause greater hemodynamic instability. Overall, outcome studies in children in the sitting position do not show greater risk than in adults. If one is planning to use the sitting position in a child,
it is strongly recommended to obtain preoperative echocardiography to rule out any interatrial or interventricular communications. Even when the standard sitting position is not used, the head of the table may be elevated to improve surgical access and cerebral venous drainage. Thus, venous air embolism may occur through open venous channels in the bone and dural sinuses.

When a child is positioned for neurosurgery in a head frame device, there is often flexion of the neck. This maneuver may result in downward displacement of the endotracheal tube within the trachea, and cause the endotracheal tube to enter the right main bronchus. Therefore, in anticipation of neck flexion, the endotracheal tube should be positioned ‘high’ within the trachea, to compensate for its descent. Once positioning is finalized, bilateral breath sounds should be confirmed; in children with healthy lungs, any unexplained oxygen saturation below 96% should prompt an exploration for a right main bronchial intubation.

**NEUROPHYSIOLOGIC MONITORING**

Many neurosurgeons employ the use of neurophysiologic monitoring to detect intraoperative cerebral or spinal cord ischemia. This may include electrocorticography (ECoG), electroencephalography (EEG), somatosensory-evoked potentials, and motor-evoked potentials. When these modalities are used, the anesthesiologist should proactively discuss with the neurophysiologist the implications of anesthetic management on the accuracy of the monitoring. In most cases, clinically useful concentrations of volatile agents will interfere with neurologic signals. Therefore, an opioid-based technique is indicated, with either low-dose volatile agent or a continuous infusion of propofol to maintain unconsciousness and prevent intraoperative recall. Use of remifentanil is advantageous in these situations, as it will be rapidly eliminated at the end of the procedure. Muscle relaxants are contraindicated when motor-evoked potentials are used. In most instances, it is appropriate to use an intermediate-acting muscle relaxant such as vecuronium or rocuronium to facilitate tracheal intubation. In virtually all cases, preparation time is sufficiently long so that the effects of the relaxant have dissipated by the time monitoring is required.

**FLUID MANAGEMENT DURING PEDIATRIC NEUROSURGERY**

Except for neonates or other children who may be at risk for development of hypoglycemia, glucose-containing solutions are generally avoided during neurosurgical procedures. Though definitive outcome studies are lacking, hyperglycemia has been associated with worse outcomes during episodes of brain ischemia. Isotonic solutions such as normal saline are advocated during neurosurgery to lessen the risk of excess brain water. However, Lactated Ringers solution can also be used if ICP is not increased.

**ANESTHETIC MANAGEMENT OF COMMON PEDIATRIC NEUROSURGICAL PROCEDURES**

**Ventriculoperitoneal Shunt Insertion or Revision**

Ventriculoperitoneal (VP) shunt insertion or revision is probably the most commonly performed pediatric neurosurgical procedure. A shunt is initially placed to palliate disorders that cause hydrocephalus. The proximal end of the shunt is placed within the lateral ventricle of the brain, and the shunt is tunneled underneath the scalp and skin of the neck, chest, and abdomen, where it inserts into the peritoneal cavity to drain cerebrospinal fluid (CSF). Some children may have their shunts terminating into the atrium via one of the great veins of the neck or chest. Children with existing shunts will periodically require revisions because of a variety of reasons that include growth, obstruction, and infection, among others. Occasionally, these revisions will be performed on an emergent basis if the child exhibits signs or symptoms of acutely increased ICP.

There are a variety of causes of hydrocephalus. The most common cause of congenital hydrocephalus is narrowing of the Aqueduct of Sylvius. Acquired hydrocephalus is most commonly a result of intracranial hemorrhage in prematurely born infants. Other causes of hydrocephalus that require shunting include Arnold-Chiari compression associated with myelomeningocele, infections, tumors, and head injury.

Preoperative assessment consists of evaluation of comorbidities and the severity of increased ICP. Premedication with an anxiolytic such as midazolam is usually indicated, but when a child is deemed to have clinically important increased ICP, an intravenous catheter should be placed prior to surgery, and premedication is then carefully titrated under supervision of the anesthesiologist. There is no routine preoperative blood work except evaluation of electrolytes if protracted vomiting is present preoperatively.

Perioperative fluids should consist of normal saline solution or Lactated Ringers solution. Insensible losses usually range from 2 to 4 mL/kg/h. Standard monitors are appropriate. During VP shunts, one intravenous access line is usually sufficient.

In children with preoperative signs and symptoms of increased ICP, a modified rapid sequence IV induction...
is indicated. A moderate amount of opioid is used to facilitate induction and tracheal intubation, but should be tailored toward tracheal extubation at the completion of the procedure. Any of the volatile or IV anesthetic agents is appropriate for maintenance of general anesthesia. N₂O should be avoided if the child has had a craniotomy within the past month, because of the possibility of expanding an existing pneumocephalus. After tracheal intubation, the stomach should be suctioned with a large-diameter (14-French) orogastric tube, and an esophageal stethoscope and temperature probe are recommended.

The surgical procedure for initial insertion consists of two incisions – one on the lateral side of the head, and the other on the skin of the abdomen, with which to retrieve the tunneled shunt and insert it into the peritoneum. Ordinarily the entire unilateral area from the head to the abdomen is prepared and draped (Fig. 30-1). The child lies supine with the head turned away from the operative side. The OR table is ordinarily turned 90 degrees away from the anesthesiologist.

The most commonly used VP shunt is made of Silastic and contains a bubble reservoir with a one-way valve that allows passive flow of CSF out of the brain. With existing shunts that require revision because of malfunction and increasing hydrocephalus, the obstruction can be located either proximally, between the lateral ventricle and the valve, or distally between the valve and the tip of the shunt in the peritoneal cavity.

Postoperative concerns include observation for neurologic changes that may be a signal of impending shunt malfunction, or intracranial bleeding. Opioids are not usually required as pain associated with this procedure is relatively minor. Significant postoperative headache should initiate an investigation of an additional cause.

**Anesthesia for CNS Tumor Resection**

Most intracranial tumors in children are cerebellar and brainstem malignancies of the posterior fossa. Preoperative presentation includes vomiting, headache, and gait and balance abnormalities. Laboratory evaluation consists of hemoglobin, type and screen, and electrolytes, which may be altered by chronic vomiting or hormonal effects of tumors. Preoperative anxiolytic medications are tailored to the condition of the child.

A modified rapid sequence induction is most often chosen for induction of general anesthesia. Some children without preoperative signs and symptoms of increased

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*Figure 30-1*  The patient is prepared for a VP shunt insertion. The head, neck, chest, and abdomen are prepped and draped. The OR table is turned 90 degrees away from the anesthesiologist.
ICP may be admitted to the hospital on the day of the surgery and can undergo mask induction of general anesthesia, with placement of cricoide pressure after consciousness is lost, and rapid placement of an intravenous cannula and administration of a neuromuscular blocker. After tracheal intubation, the stomach should be suctioned with an orogastric tube, and an esophageal stethoscope and temperature probe are recommended. An additional IV cannula is placed, and an arterial line is inserted to monitor blood pressure changes closely and facilitate access to blood for periodic measurement of hemoglobin, electrolytes, and acid–base status. Isotonic IV fluids (e.g., normal saline or plasmalyte) are recommended so as to be compatible with concomitant blood administration. Ventilation is adjusted to maintain the $PCO_2$ in the $35 \pm 5$ mmHg range.

The position of the child will depend on the nature and location of the tumor. It is not unusual for the child to be positioned in the lateral or prone position. Sitting positions are being used with decreasing frequency in children. The child’s head is often secured with a Mayfield or Sugita head frame, or placed inside a horseshoe cushion (Fig. 30-2). Careful attention should be paid to securing the endotracheal tube, and ensuring that there is no excess pressure on the eye sockets or neck.

For virtually all major craniotomies, direct blood pressure measurement by arterial cannulation is recommended. Beat-to-beat arterial pressure is required when there is the possibility of rapid hemodynamic changes that may result from blood loss, venous air embolism, or unexpected effects from manipulation of the cranial nerves in the brainstem. An arterial catheter will also provide a method to easily obtain blood gas samples when using mild hyperventilation, or when the anesthesiologist needs rapid determination of hemoglobin.

Intraoperative risks include the possibility of unpredictable and sudden blood loss (from the area surrounding the tumor, or from a venous sinus tear), brain herniation, venous air embolism, and airway edema. Stimulation of brainstem structures in the posterior fossa may cause sudden hypertension, hypotension and/or bradycardia. Intraoperative adjuvant therapies include antibiotics, mannitol, and dexamethasone, depending on the preferences of the surgeon. Blood loss during tumor removal in small children and infants can be unexpected, rapid, and life-threatening. Prior to beginning a major craniotomy, two intravenous lines should be established in the extremities. Central access is unnecessary, unless dictated by the child’s underlying medical condition. If adequate peripheral access is difficult, the femoral approach to venous cannulation is a feasible alternative, since it avoids the risk of pneumothorax associated with subclavian or internal jugular vein puncture, and will not interfere with cerebral venous return.

Mannitol is often administered during craniotomies at doses that range from 0.25 to 1.0 g/kg. It is almost always used in the setting of increased ICP, but many neurosurgeons will ask that it be administered during routine cases. By transiently raising serum osmolality, mannitol will draw fluid out of the brain and into the circulation. Because of its diuretic effect, urine output will increase for approximately one hour after its administration. It should be given no faster than 0.5 g/kg over 20–30 minutes because of the possibility of hypotension and decreased cerebral perfusion pressure if given at a faster rate. Furosemide (0.25–1 mg/kg) is also useful for decreasing cerebral edema, and has been shown in vitro to prevent rebound swelling due to mannitol. When diuretics are administered, urine output and electrolytes are rendered unreliable for diagnosing hypovolemia, and hormonal imbalances of sodium, such as diabetes insipidus, or syndrome of inappropriate antidiuretic hormone (SIADH) release. Dexamethasone is commonly administered to children to decrease brain swelling associated with intracranial masses, but does not possess acute effects.

Assuming there are no intraoperative events that would warrant postoperative ventilation, tracheal extubation at the completion of the procedure should be planned. The neurosurgeons will want to evaluate the child’s neurological status as soon as possible after regaining consciousness. In fact, the child is often kept in the operating room until a superficial neurological exam is completed. Unexpected deficits may warrant reexploration or immediate head CT scan to detect unanticipated brain herniation or bleeding.

Postoperative considerations include frequent neurological assessments to detect intracranial events, and careful monitoring of cardiopulmonary parameters. Pain control is often easily accomplished as these children rarely have severe postoperative pain. Significant head pain should warrant an investigation for intracranial complications.

Figure 30-2 In preparation for posterior fossa surgery, the patient’s head is stabilized in a Sugita head frame.
Myelomeningocele Repair

Myelomeningocele (also known as spina bifida) is the most common congenital defect of the central nervous system, with a prevalence rate of approximately 4 per 10,000 live births. A myelomeningocele is a fetal malformation involving a posterior protrusion of the spinal cord and meninges through a defect in the spinal column and back, usually at the lumbar level (Fig. 30-3). Because of the risk of meningitis, this is considered a surgical urgency and infants are almost always operated on within 24 hours of birth. Most infants born with myelomeningocele have an accompanying Arnold–Chiari malformation, resulting from downward displacement of the hindbrain into the foramen magnum, and thus receive a VP shunt prior to discharge home in the newborn period.

Preoperative assessment includes careful documentation of all neurologic deficits and a review of other organ systems to rule out additional congenital malformations. Blood work should include a hemoglobin and type and screen. Premedication is not indicated.

Positioning during induction of general anesthesia and tracheal intubation is challenging. A cushion is formed and placed under the back (Fig. 30-4) to prevent contact injury to the dural sac. Alternatively, the infant may be positioned in the lateral position during induction and intubation. The surgical repair is performed in the prone position, with appropriate cushioning that provides ample room for abdominal excursion during ventilation (Fig. 30-5). Avoidance of latex-containing products is begun at birth to prevent eventual development of sensitization.

Typically, two intravenous catheters are inserted for glucose maintenance solution and volume replacement with warmed normal saline or Lactated Ringers solution, up to 25 mL/kg in the first hour and 6–8 mL/kg/h thereafter. Blood loss is usually minimal, unless the skin is undermined and rotation of a myocutaneous flap is required. Therefore, packed red blood cells should be available for the procedure.

Standard monitors are indicated prior to turning the infant prone. The risk of intraoperative hypothermia is significant. A forced warm-air blanket should be placed underneath and around the infant, and all infused fluids should be warmed.

All standard intravenous and inhaled anesthetic agents are acceptable for use during induction and maintenance of general anesthesia, while planning for tracheal extubation at the completion of the procedure. Infants born with myelomeningocele have an increased incidence of an abnormally short trachea. Therefore, the endotracheal tube position and its relation to the carina should be precisely measured to determine the appropriate length of insertion. Regional anesthesia is usually not possible, although reports exist of the sole use of spinal anesthesia, administered by the surgeon throughout the procedure.
As with all neonates, postoperative monitoring for central apnea should be initiated for at least 24 hours following the procedure.

**Latex Allergy**

Latex allergy is the most frequent cause of intraoperative anaphylaxis in children. It occurs in children who have become sensitized to latex by virtue of their frequent exposure to latex-containing medical products, such as rubber gloves and urinary drainage equipment. The most common type of patient with latex allergy is the child with myelomeningocele because of the daily frequent bladder catheterizations. Up to 70% of children with myelomeningocele are reportedly allergic to latex, in contrast to approximately 1–5% in the general population of healthy children. Chronic exposure to latex early in life appears to be an important predecessor to the development of latex allergy.

An intraoperative reaction to latex usually occurs 30–60 minutes after the start of the surgical procedure. It may manifest as a spectrum of clinical findings that range from mild anaphylactoid reactions (e.g., rash) to severe anaphylaxis consisting of bronchospasm and hypotension. It is indistinguishable from other sources of anaphylaxis, and may be difficult to diagnose during a complicated surgical procedure, where these types of clinical findings may be due to any number of causes. Thus, it often becomes a diagnosis of exclusion.

Immediate treatment of anaphylaxis consists of epinephrine and volume replacement while removing the suspected latex-containing products. Histamine-1 and histamine-2 antagonists and steroids are administered as well. Bronchodilators may be included in the treatment regimen if bronchospasm persists.

Prevention of intraoperative latex reactions is accomplished by identifying susceptible patients and maintaining a completely latex-free OR environment. Children with myelomeningocele are automatically considered latex-sensitive from birth, so latex-containing products are not used in their care. Prophylactic medications prior to surgery are no longer used since their use does not necessarily protect against development of a reaction upon exposure. Furthermore, large case series have shown that children with latex allergy will not develop reactions when cared for in a latex-free environment.

**CNS Trauma**

Surgery for pediatric head trauma most often involves evacuation of a subdural or epidural hematoma, or evacuation of an intracerebral hemorrhage that is causing an increased mass effect and increased ICP. Other injuries of the head and neck should be strongly suspected. Cervical spine injuries are almost never ruled out when these children present for emergency surgery, so cervical spine precautions should be observed during induction of anesthesia and tracheal intubation. Clinically important head trauma is usually associated with hypertension and either obtundation or combativeness. When hypotension is present, other injuries causing major blood loss should be sought. The most common sites of significant blood loss in pediatric trauma are the intraabdominal organs, the pelvic bones, and the femur.

Preoperative assessment should include review of the child’s medical history, physical exam with emphasis on airway anatomy and cardiorespiratory status, and review of laboratory tests. If time is available, blood tests should include hemoglobin, platelets, clotting factors, and a type-and-crossmatch. In the event of a severe acute event causing life-threatening increased ICP, these lab specimens can be sent from the operating room, and O-negative blood can be administered if necessary.

At least two large-bore venous cannulas should be placed, preferably in the upper extremities. Lower-extremity and femoral access is acceptable in the absence of intraabdominal trauma, which may include disruption of the inferior vena cava. An arterial line is preferable prior to induction of general anesthesia in cases where there is a reasonable threat of hemodynamic compromise or brain herniation. Otherwise, in most cases, it is inserted after induction of general anesthesia.

Intraoperative fluids should consist of isotonic crystalloid solutions such as normal saline or Plasmalyte, and blood products when indicated. An indwelling urinary catheter is almost always required, and can be removed at the end of the procedure if no longer necessary. Pediatric patients should be maintained normothermic. There is currently no indication for hypothermia in the acute management of pediatric head trauma.

A modified rapid sequence induction is most often performed, using propofol (2–4 mg/kg) or thiopental (4–6 mg/kg) as a hypnotic agent, rocuronium (1.2–1.6 mg/kg) or vecuronium (0.2–0.4 mg/kg) for neuromuscular blockade, lidocaine (1 mg/kg), and fentanyl (1.2–5 µg/kg) as a hypnotic agent, rocuronium (0.2–0.4 mg/kg) or vecuronium (0.1–0.2 mg/kg) for neuromuscular blockade, lidocaine (1 mg/kg), and fentanyl (3–5 µg/kg) or remifentanil (bolus 1 µg/kg over 2 minutes, and followed by a continuous infusion at 0.25 µg/kg/min titrated to hemodynamic values). Unless the patient is severely hypovolemic, ketamine is avoided because of its propensity to increase ICP. If the child has a known full stomach and thus has a reasonable risk of pulmonary aspiration of gastric contents during induction, then a rapid sequence technique is indicated. Cervical spine precautions should be observed during tracheal intubation. This consists of manual in-line neck stabilization by an assistant, and maintenance of the head and neck in a neutral position during all subsequent procedures. During the approximately 1-minute latency period before the neuromuscular blocker takes effect, the child should be moderately hyperventilated with application of cricoid pressure.
Maintenance agents can include any volatile anesthetic agent, avoidance of N₂O if pneumothorax or pneumocephalus is considered, and titration of opioids with the intent of tracheal extubation at the completion of the procedure. In some cases, the neurosurgeon will request an immediate postoperative CT scan; the child should then remain anesthetized until the CT has been completed and the surgeon confirms that it is safe to awaken the patient.

Children with head trauma will almost always be transferred to an intensive care unit postoperatively. Analgesic requirements are relatively low. Bleeding and intracerebral swelling are possible postoperatively; children who manifest acute neurologic changes should receive an immediate head CT and possible reexploration.

### Case

A 9-month-old male infant presents with a 3-week history of an enlarging head circumference, vomiting, and worsening irritability. Pregnancy, birth history, and family history are unremarkable. The infant’s weight is 5.8 kg, and its hemoglobin is 38%. MRI reveals a large posterior fossa mass. Resection of the tumor is planned.

**Is there anything else you need to know before going ahead with general anesthesia?**

Chronic vomiting might lead to a sodium, chloride, or potassium imbalance, and should warrant preoperative electrolytes. If the child was sedated for the brain CT scan or MRI, I would like to know whether the sedation was well tolerated without airway or hemodynamic issues. Preoperative physical exam should be directed toward confirming normal airway anatomy and assessment of hydration status. Lastly, a type-and-cross should be obtained so that blood (red cells) will be immediately available during the surgery. This can be sent shortly after induction of anesthesia, provided the surgeon understands that tumor resection cannot proceed until red cells are immediately available.

**What preoperative orders are appropriate for this infant?**

Attention should be directed toward maintaining preoperative hydration status. An infant with this type of condition is usually admitted to the hospital prior to the day of surgery and will receive intravenous hydration. It is also possible that the infant is admitted from home on the day of surgery if the evaluation was performed as an outpatient. If he isn’t vomiting, routine fasting orders are appropriate, including clear liquids 2 hours prior to the time of surgery. Premedication with an anxiolytic is usually not appropriate for this age group. Preoperative atropine is indicated if halothane is used for induction of anesthesia.

**What monitors and intravenous access lines are appropriate for this case?**

Since large blood loss is a possibility, direct arterial access allows monitoring of beat-to-beat swings in blood pressure and will facilitate blood collection for hemoglobin and blood gas values. Mean arterial blood pressure should be maintained within 20% of preoperative values. A central venous pressure monitor is not usually helpful. Two large-bore intravenous lines in any of the limbs are sufficient. If venous access is unobtainable in the extremities, a femoral venous cannula is a reasonable alternative. Normal saline is appropriate for fluid maintenance and replacement of deficits and insensible fluid losses, which typically average 5–10 mL/kg/h during the case. Esophageal or rectal temperature monitoring is required. Core body temperature should be kept reasonably close to normal using warmed IV fluids and a forced warm-air device underneath and around the child. Capnography should be utilized to keep the PÇO₂ in the low- to-mid-30s throughout the case, unless the surgeon requests otherwise.

**How would you induce and maintain general anesthesia?**

Assuming the infant has a functioning intravenous catheter, any IV hypnotic agent, except ketamine, can be used for induction of general anesthesia. An opioid, such as fentanyl, is usually included, at a dose that will help prevent the hemodynamic changes (and subsequent rise in ICP) during laryngoscopy and tracheal intubation. Lidocaine can also be used for additional protection during airway stimulation. Any nondepolarizing neuromuscular blocker can be used. An assistant should apply cricoid pressure while the anesthesiologist ventilates the infant and intubates the trachea. The endotracheal tube should be well secured to the face, using benzoin if necessary. The surgeon should administer local anesthesia containing epinephrine into the scalp to attenuate acute rises in blood pressure during incision or pin placement, and to mitigate blood loss from the scalp. General anesthesia should be maintained with a moderate dose of volatile agent, with a moderate dose of opioid that can easily be eliminated by the end of the case, so as to facilitate tracheal extubation in the operating room and immediate neurological examination. N₂O is best avoided in these cases. Meticulous attention should be paid to fluid status; urine output should be monitored carefully and hemoglobin testing should occur at least hourly while surgical blood loss is occurring. Transfusion of red cells should occur when the hemoglobin decreases below 7 gm/dL.
During an otherwise stable part of the tumor resection, the heart rate acutely decreases from 120/min to 60/min. What should you do?

There are several causes of sudden bradycardia in this setting. Hypoxemia should always be at the top of one’s differential list and can be immediately ruled out by pulse oximetry. Even if hypoxemia isn’t occurring, the oxygen concentration should be transiently increased to 100% until the bradycardia resolves to maximize oxygen delivery to the brain tissues. Severe hypotension should also be immediately ruled out. Venous air embolism is an important cause of sudden hemodynamic changes during a craniotomy in an infant, even while supine. If this is suspected, the surgeon should flood the field with saline, and carefully search for potentially open vessels through which air is being entrained. Bradycardia is a component of Cushing’s triad and may be a sign of acutely increased ICP. Though possible, this is unlikely after the dura has been opened. The most probable cause of the bradycardia in this setting is the stimulation of the brainstem. The treatment is to temporarily discontinue the surgical stimulation, and administer intravenous atropine if the bradycardia continues or results in hypotension.

What are the important postoperative concerns in this infant?

Unexpected postoperative changes in neurologic exam or mental status are associated with life-threatening intracerebral bleeding or swelling. This is considered a neurosurgical emergency and warrants an immediate CT scan and possible reexploration. If mental status is declining, the patient should immediately receive tracheal intubation and mechanical ventilation; sedatives and paralytics should be administered as needed. Blood should be administered if hemoglobin testing reveals an acute decrease from baseline. Mannitol and furosemide should be considered if acute swelling is occurring.

Case Cont’d

ADDITIONAL ARTICLES TO KNOW
