Anesthesia for Neurosurgery in Infants and Children

Jayant K. Deshpande, M.D. **Nashville, Tennessee**

1. Introduction

Infants and children undergoing anesthesia for neurosurgical procedures present unique challenges for the anesthesiologist. Advances in neurosurgical techniques and technology have changed the face of pediatric neurosurgery and led to improved outcomes for pediatric neurosurgical patients. Basic concepts of neuroanesthesia care are similar in all ages. In this review, we will focus on the important distinctions facing the anesthesiologist caring for infants and children.

2. Intracranial Physiology

The infant skull is not fully ossified and is more compliant (viscoelastic) than the adult skull and has the ability to expand at the open fontanelles and nonfused sutures. The infant may not demonstrate signs typically associated with intracranial abnormalities, because the cranium can substantially expand in response to an expanding intracranial brain mass or process causing hydrocephalus, before coming to clinical attention. Early in the course, infants and young children often do not exhibit the traditional signs of intracranial hypertension such as bradycardia, elevated systemic blood pressure, dilation of the pupils, and papilledema. If present, these signal severe progression with poor outcomes. Neonates and infants may present with increased head circumference, bulging fontanelles, widened cranial sutures, "sundowning" of the eyes, irritability, lethargy, poor feeding, or lower motor deficits.

The limits of cerebral autoregulation may be shifted to significantly lower values (mean arterial pressure (MAP) 20-60 mmHg) in the neonates and infants. The "margin of safety" is narrower as the infant is less well able to compensate for acute hypo- or hypertension. Low MAP presents the risk of ischemia while hypertension in infants may present risk of intracranial hemorrhage. Response to hyperventilation (low PaCO2) in infants may be brisk, with a risk of inducing cerebral ischemia with extremely low PaCO2 (<20 mmHg).

3. Preoperative Considerations and Surgical Preparation

Preoperative preparation of the pediatric neurosurgical patient includes understanding of the underlying neurological pathology and a thorough assessment of any coexisting diseases, medications, intravascular volume status and anesthetic history. Intracranial hypertension may be present and can become lifethreatening. Patients with suspected or verified elevated ICP require careful attention during induction and maintenance of anesthesia to avoid further elevations in ICP. The blood volume may be contracted because of poor intake or recurrent vomiting. Children may have abnormal airways because of associated craniofacial abnormalities. Reactive airway disease, asthma, or recent URI may increase airway reactivity and complicate the perioperative care. Laryngospasm/bronchospasm on induction will lead to an increased PaCO2 and thus elevated CBF and ICP. In many circumstances, an intravenous (IV) induction may be preferable to avoid airway complications. Comorbidities may warrant further investigation. In the child with congenital cardiac disease, it is important to understand the underlying anatomy and physiology. Renal function should be evaluated especially if intravenous dyes are to be used for neuroimaging cases. In patients with epilepsy, anticonvulsant therapy can substantially alter anesthetic drug metabolism.

Preoperative sedation may be indicated to ease the anxiety and fear in children. Anxiety that leads to intense crying or screaming or fighting can cause significant elevations in ICP. Sedation with oral midazolam is preferable as no respiratory depression or change in PaCO2 has reported shown with oral midazolam premedication in children (in doses up to 0.7mg/kg with a max of 20mg).[ref] Intravenous or intranasal midazolam is also acceptable if oral is not tolerated. Other medications such as opioids and thiopental cause respiratory depression and should be used with caution in patients with elevated ICP. Ketamine should be avoided as it increases both cerebral blood flow (CBF) and cerebral metabolic rate and will elevate ICP.

4. Intraoperative Management

The patient's neurological status and coexisting medical issues will guide the choice of anesthetic induction. Typically, infants and children without intravenous access will undergo inhalational induction via face mask. As all volatile anesthetics cause an increase in CBF, (table 3) the anesthesiologist should control ventilation as soon as possible and mildly hyperventilate the patient to decrease PCO2 in order to offset the rise in CBF. Intravenous access then can be placed as needed. A nondepolarizing neuromuscular blocking agent should be administered to facilitate endotracheal intubation. In patients with an indwelling IV cannula, anesthesia can be induced with IV agents such as propofol or thiopental, which lower ICP. If the patient is at risk for aspiration a rapid sequence induction should be performed, preferably using a fast-acting, nondepolarizing neuromuscular blocker.

Positioning

Proper position of the patient for pediatric neurosurgical procedures is imperative to ensure both patient safety and comfort. Generally, patients undergoing neurosurgery are in a supine position with the head of bed elevated. Neck flexion may result in downward migration of the endotracheal tube or occlusion of jugular venous drainage, causing cerebral venous hypertension and increased intracranial volume and pressure. The prone position places raises the risk of eye injury from direct ocular pressure and hypoperfusion. The park bench position is utilized for lateral or midline incisions and when quick access to the patient is needed. Appropriate padding and stabilization is required to prevent stretch, ischemia and pressure injury to the axilla as well as other parts of the body. The sitting position requires careful attention to padding pressure points as well as securing the patient on the bed to ensure patient safety and surgical stability. Venous air embolus (VAE) is a major risk in patients in sitting position or or those with the head of bed significantly elevated. Therefore, additional monitoring is required to detect and treat a VAE.

Maintenance of anesthesia

Maintenance of anesthesia commonly is accomplished with a balanced anesthetic technique of opioiates, volatile anesthetic and neuromuscular blockade**.** Inhalational anesthetics may significantly blunt cerebral autoregulation in a dose dependent manner by producing cerebral vasodilatation, and exacerbate intracranial hypertension. Inhalational anesthetics also alter the evoked potentials that are used in neurological monitoring. These agents are typically avoided or used at low concentration of 0.5MAC or less. Infusions of short-acting opioids such as fentanyl, sufentanil or remifentanil can provide adequate intraoperative analgesia and rapid emergence, permitting postoperative neurological assessment. Neuromuscular blockade is typically used unless the case requires intraoperative assessment of motor nerve function, as in spinal cord or epilepsy surgery.

Fluid management

Fluid management in neurosurgical cases is extremely important and requires good communication between the surgeon and anesthesiologist. Isovolemia is the goal of intraoperative fluid management to avoid hypoperfusion of the brain and other organs. Normal saline (0.9% NaCl) commonly is selected because it is slightly hyperosmolar (308 mOsm) and is thought to attenuate formation of brain edema. In patients with preoperative intracranial hypertension, drugs may help reduce ICP. Hyperosmolar drug therapy with mannitol or hypertonic saline (3% or higher concentration) is commonly used. Loop diuretics, furosemide or bumetamide, may be used to induce a systemic diuresis, decrease CSF production, and improve overall cerebral water transport. These agents should be used with caution to avoid hypovolemia and dehydration.

5. Postoperative care

Postoperative care is determined by the complexity of the surgical procedure and the physiologic alterations that may occur during the operative course. Generally extracranial procedures usually need routine postoperative care. Intracranial procedures and other major neurosurgical cases will require postoperative care in the pediatric intensive care unit (PICU).

6. Selected conditions

Pediatric Brain Tumors

Brain tumors are the most common solid tumors of childhood, and the second most common childhood cancer. Of all childhood brain tumors, two-thirds are located infratentorially, which allows them to substantially progress in size before clinical symptoms are manifested. The location of the tumors varies with age. The younger patients are more likely to have cerebellar and brain stem tumors. With age cerebral/supratentorial tumors become more frequent. Children present with a variety of symptoms and signs depending on the type and location of the tumor. Infants typically display irritability, failure to thrive and macrocephaly, while older children develop headache, nausea, vomiting, seizures, gait disturbances and visual deficits. Anesthetic concerns in these patients include elevated ICP, cerebral edema, intraoperative blood loss, venous air embolus, coagulopathy, loss of protective airway reflexes, metabolic disturbances, and fluid and electrolyte imbalance. The anesthetic plan should be designed to optimize ICP, maintain adequate cerebral perfusion pressure (CPP) and CBF, and allow rapid emergence at the end of the case so that a thorough neurological assessment can be made.

Anti-epilepsy surgery - Children with intractable seizures present for surgical resection of seizure focus, resection of a larger brain area containing a more diffuse epileptogenic region or placement of vagal nerve stimulator. [27] The anesthetic concerns include the possibility of perioperative seizures, altered drug metabolism because of induction of liver enzymes, and interaction of anesthetic drugs with the child's anticonvulsant therapy. In some patients **awake craniotomy** is preferred so that the patient can respond to commands while the specific brain area to be excised is identified. Such cases require a skilled team and a customized anesthetic plan.[28]

Judicious use of regional nerve blocks and intravenous sedatives permit the procedure to be performed safely in most circumstances.

Craniosynostosis and craniofacial reconstruction- Isolated craniosynostosis results in asymmetric skull growth and cranial deformity. Craniosynostosis also may be part of a congenital disease such as Crouzon or Apert syndrome, Pierre Robin sequence or neurofibromatosis. The airway management can be a major challenge in many cases may be even require tracheostomy to secure the airway. Surgery usually is performed early in infancy to optimize chance for normal cranial and psychosocial development. Perioperative concerns include intracranial hypertension, significant blood loss, and airway compromise.

Traumatic Brain Injury

Injuries are the most common cause of pediatric mortality, and traumatic brain injury (TBI) is the leading cause of death in these patients. Due to the larger surface area of the pediatric head, along with weaker neck musculature, TBI can occur even in low velocity conditions. Aggressive treatment of the primary injury, and avoiding and treating secondary injuries are critical to decrease morbidity and mortality. The most common injury is diffuse cerebral swelling with intracranial hypertension, which can result in uncal herniation if not treated. Patients need aggressive management in the pediatric intensive care unit. Patients may require anesthesia care for airway management, surgery for stabilization of fractured skull, facial or cervical bones. Perioperative concerns include a) management of the traumatized airway, with possibility of blood, foreign bodies, or teeth in the airway, b) associated full stomach and chance of gastric aspiration, c) evolving intracranial hypertension because of bleeding and cerebral edema, and d) cerebral ischemia from secondary hypoxia or hypotension. A third or more of these patients may have associated injuries in other organ systems, particularly in the abdomen and long bones. Anesthetic management includes close monitoring to maintain systemic blood pressure at or above normal and avoiding hypoxia. Routine hyperventilation and hypocapnia are not advised as this practice may actually produce cerebral ischemia in certain brain regions.

Children with **epidural hematoma** present a true surgical emergency. Timely evacuation of an isolated hematoma is associated with a good outcome. Delayed treatment can lead to brain ischemia and possibly uncal or transtentorial hernation.

Vascular malformations - Vascular malformations, such as arteriovenous malformations, often present in childhood as acute intracranial hemorrhage. Infants with vein of Galen or other large anomalies may present in congestive heart failure because of high flow through the malformation. Location of the anomaly and type of feeder vessels influence the treatment plan. Open craniotomy procedures have given way to stereotactic surgery or microembolization under fluoroscopy. The procedures may be long in duration and patients may require prolonged neurologic monitoring and care because of the risk of intracranial bleeding or hypertension in the immediate recovery period. Rarely the lesions are so large that extracorporeal circulatory support is necessary for life support during and immediately after the procedure.

Dysraphism

Incomplete closure of the raphe (dysraphism) during fetal development allows neural herniation which persists after birth. Encephalocele is a herniation of the cranial contents (with dura and CSF) out of the skull through a defect. These may be difficult to detect when they occur intranasally or obvious as soft lumps on the head. Myelomeningocele is a herniation of the spinal contents (with dural sac and CSF) through a bony defect in the spine. Either herniation also may contain neural tissue. Myelomeningoceles commonly are detected at birth and are considered urgent surgical cases. The defects need to be repaired within a few days to prevent infection and further damage to the neural tissues. CSF leak or have frank dural rupture may develop, leading to intravascular volume and electrolyte abnormalities which need to be treated preoperatively. Proper positioning during induction and intubation to avoid damage to the exposed spinal contents. Cases are performed in the prone position and careful padding of pressure points is needed to protect these neonates. Patients with dysraphism often develop postoperative hydrocephalus because of disrupted CSF flow and require VP shunt. Associated urologic, orthopedic and neurosurgical dysfunction often require multiple surgical procedures throughout the patient's lifetime.

Latex allergy

Patients with spinal dysraphism are at risk to develop latex allergy. Therefore, from the outset, all patients with neural tube defects should be considered latex sensitive and undergo management in a latex free'latex safe environment. Symptoms of latex allergy range from: mild rash, bronchospasm, generalized urticaria, hypoxemia and hypotension, to frank cardio-respiratory collapse. Treatment of latex allergy will be discussed.

Hydrocephalus

Hydrocephalus is results from obstruction of normal CSF flow. Most children with hydrocephalus will have some degree of intracranial hypertension. Causes of hydrocephalus include intraventricular hemorrhage [IVH], Arnold-Chiari malformation, brain tumor, congenital obstruction, and myelomeningocele. Children typically present with a headache and irritability, but signs and symptoms can progress to lethargy, seizures, vomiting and opthalmoplegia. Surgical treatment for hydrocephalus involves insertion of a drainage system to shunt CSF from the brain to another site in the body. Anesthetic induction is performed to avoid increasing CBF or cerebral metabolic rate. In patients with severe intracranial hypertension, it may be necessary for the surgeon to tap the shunt to remove some of the CSF. These patients should be cared for in a latex free environment.

Spinal Cord Surgery

The two most common neurosurgical procedures on the spinal cord are performed for spasticity related to cerebral palsy, and for correction of a tethered cord. The tethered cord syndrome results from developmental anomalies which entrap the nerves of the cauda equina. The cauda equina migrates rostrally with normal growth from a position of L4 to L1-2. If the nerves are entrapped, they become stretched and create neurological deficits. Surgical correction involves exposure of the cauda equina and release of the tethering anomalies. Intraoperative direct nerve stimulation is utilized to guide release of the tethered cord, and thus muscle relaxants must be avoided.

Surgery for spasticity involves either a dorsal rhizotomy or placement of a baclofen pump. Spasticity from cerebral palsy results in patients with contracture of leg joints and impaired mobility. A dorsal rhizotomy involves a laminotomy in the prone position where specific nerves are targeted after nerve conduction tests are performed intraoperatively. Selected nerve roots are transected to relieve the input to the muscles and decrease the contractures. Neuromuscular blocking agents are contraindicated. The procedure requires prone positioning, necessitating care to avoid pressure injuries to the spastic extremities. In the immediate postoperative period, children may have significant pain requiring analgesia, or muscle spasticity which may be treated with benzodiazepines.

The intrathecal baclofen infusion has provided improvement in some patients with spasticity, reducing the need for these patients to have a dorsal rhizotomy. Patients initially have a 2-3 day trial of intrathecal baclofen infusion. If the spasticity improves, the patients return for placement of a baclofen pump. The procedure is performed with the patient in the lateral position under general anesthesia. The catheter is inserted into the appropriate intrathecal space and tunneled subcutaneously to the site of the pump which is placed either subcutaneously or subfascially in the abdomen. The pump then delivers a programmed amount of baclofen into the intrathecal space to reduce the spasticity.

7. Summary

Anesthesia for infants and children presents some unique challenges because of the difference in the anatomy and physiology at various stages of growth and development. The anesthesiologist must be fully cognizant of these differences in order to conduct a safe and effective anesthetic plan.

8. Selected References

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