REVIEW

Anesthesia for intracranial surgery in infants and children

Craig D. McClain and Sulpicio G. Soriano

Purpose of review
Age-related differences in the surgical lesions, anatomy and physiological responses to surgery and anesthesia underlie the clinically relevant differences between pediatric patients and their adult counterparts. Anesthesiologists need to be aware of the unique challenges in the anesthetic management of the pediatric neurosurgical patient.

Recent findings
Neurosurgeons with subspecialty training in pediatrics have driven advances in intracranial surgery in infants and children. Subspecialization in pediatric neurosurgery and critical care has resulted in more favorable outcomes. Innovations in tumor, epilepsy and endoscopic and cerebrovascular neurosurgery are constantly being adapted to the pediatric patient. The highly specialized nature of these and other pediatric neurosurgical procedures prompt calls for similarly trained anesthesiologists for management of these infants and children.

Summary
The aim of this review is to highlight the impact of these techniques on the intraoperative management of the pediatric neurosurgical patient. These issues are essential in minimizing perioperative morbidity and mortality.

Keywords
childhood tumors, epilepsy surgery, neuroanesthesia, pediatric anesthesia

INTRODUCTION

Childhood intracranial lesions are different from adults'. Brain tumors are the most common solid malignancies in pediatric patients [1], and the histology and location of these tumors are significantly different from adults. Infants and children with medically intractable seizure disorders are increasingly benefiting from epilepsy surgery [2]. Finally, advances in diagnosis and interventional neuroradiology have increased survival of infants and children with neurovascular lesions. The highly specialized nature of these and other pediatric neurosurgical procedures prompted calls for like-minded and trained perioperative team for management of these infants and children [3]. This notion has been supported by reports noting that subspecialzation in pediatric neurosurgery and critical care has resulted in decreased morbidity [4▪,5]. The developmental stage impacts the anesthetic management of infants and children undergoing intracranial neurosurgery. Age-dependent differences in anatomy, cerebrovascular physiology and neurologic lesions distinguish neonates, infants and children from their adult counterparts. The goal of this review is to highlight these age-dependent differences and their effect on the anesthetic management of the pediatric neurosurgical patient.

PREOPERATIVE PREPARATION AND INTRAOPERATIVE MANAGEMENT

The preoperative assessment of the pediatric neurosurgical patients requires a focused approach on areas unique to this surgical cohort. Childhood tumors present with a variety of signs and symptoms that may affect the conduct of anesthesia [6]. These

Department of Anesthesiology, Boston Children's Hospital and Harvard Medical School, Boston, Massachusetts, USA

Correspondence to Sulpicio G. Soriano, MD, Boston Children's Hospital, 300 Longwood Avenue, Boston, MA 02115, USA. Tel: +1 617 355 6457; e-mail: sulpicio.soriano@childrens.harvard.edu

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KEY POINTS

- A thorough preoperative organ system-based evaluation of the pediatric patient is essential to minimize perioperative morbidity.
- Neonate and infants are at risk of intraoperative cerebral hypoperfusion due to inadequate systolic blood pressure and inadvertent hypocarbia.
- New innovations in surgical approached and intraoperative technology are constantly being adapted to pediatric neurosurgical patients.

include lethargy, seizures, cranial nerve palsies, focal muscle weakness, hypothalamic-pituitary axis hormonal deficiencies, nausea and vomiting (Table 1) [7]. A complete history and physical examination should reveal these symptoms and provide a framework for the well tolerated conduct of anesthesia. Pediatric patients have a higher risk for perioperative respiratory and cardiovascular morbidity and mortality than adult cohorts [8]. The systemic effects of general anesthesia and the physiological stress of surgery impact this vulnerable group. Therefore, a thorough review of the patient's history can reveal conditions that may increase the risk of adverse reactions to anesthesia and identify patients who require more extensive evaluation or whose medical condition needs to be optimized before surgery.

The age of the patient has a major impact on the conduct of anesthesia. The level of anxiety and the cognitive development and age of the pediatric patient dictate the type of sedation and induction medications. Children between the ages of 9–12 months and 6 years may have separation anxiety and may need orally or intravenously administered benzodiazepine. Parental presence during induction of anesthesia is common and a viable alternative to ease both patient and parental anxiety but requires full engagement of the operating room team. Obtunded and lethargic patients should have a rapid anesthetic induction in order to minimize cerebral hypoperfusion and pulmonary aspiration.

Anesthesia can be induced with sevoflurane, nitrous oxide and oxygen by mask in neurologically stable patients. Although some neuroanesthesia practices avoid the use of nitrous oxide, its brief use during induction of anesthesia should not be clinically significant. More importantly, intracranial hypertension may be exacerbated by hypercarbia and hypoxia, which may occur if the airway becomes obstructed during induction. Patients with lethargy or nausea and vomiting are at risk for aspiration of gastric contents and will benefit from a rapid-sequence induction of anesthesia with succinylcholine. Contraindications to the use of succinylcholine include malignant hyperthermia susceptibility, muscular dystrophies, burns and recent denervation injuries.

Table 1. Coexisting conditions that impact anesthetic management

Condition	Anesthetic implications
Congenital heart disease	Hypoxia Arrhythmias Cardiovascular instability Paradoxical air emboli
Prematurity	Postoperative apnea
Gastrointestinal reflux	Aspiration pneumonia
Upper respiratory tract infection	Laryngospasm, bronchospasm hypoxia, pneumonia
Craniofacial abnormality	Difficult tracheal intubation
Denervation injuries	Hyperkalemia after succinylcholine, Resistance to nondepolarizing muscle relaxants Abnormal response to nerve stimulation
Epilepsy	Hepatic and hematological abnormalities Increased metabolism of anesthetic agents Ketogenic diet
Arteriovenous malformation	Congestive heart failure
Neuromuscular disease	Malignant hyperthermia Respiratory failure Sudden cardiac death
Chiari malformation	Apnea Aspiration pneumonia
Hypothalamic/pituitary lesions	Diabetes insipidus Hypothyroidism Adrenal insufficiency

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The most important tenet in neuroanesthesia is to preserve neurological function [9▪▪]. As the lower limit of cerebral autoregulation pediatric patients is unknown, they are at risk for cerebral hypoperfusion, especially when they are deeply anesthetized during periods of massive blood loss [10]. The most frequently used technique during neurosurgery consists of an opioid (i.e., fentanyl, sufentanil or remifentanil) and low-dose isoflurane or sevoflurane. Dexmedetomidine can be used as an adjunct. It does not significantly affect most intraoperative neurophysiologic monitoring and reduces opioid requirements. The use of adjuvant infusions of dopamine to provide vasoactive support is beneficial during hemodynamically tenuous intervals. Patients on chronic anticonvulsant therapy usually require a larger dose of neuromuscular-blocking agents and opioids because of induced enzymatic metabolism of these agents. The use of neuromuscular-blocking agents should be discussed with the surgical and neuromonitoring teams, if assessment of motor function is planned.

Hemodynamic collapse due to massive blood loss or venous air embolism looms as a catastrophic complication for any major craniotomy. Large-bore intravenous access and arterial blood pressure monitoring are, therefore, essential for these procedures. Should initial attempts fail, central venous cannulation may be necessary. Femoral vein catheterization avoids the risk of pneumothorax and does not interfere with cerebral venous return. Furthermore, femoral catheters are more easily accessible to the anesthesiologist. Routine insertion of central venous catheters is not a reliable measure of preload and is not routinely indicated for this reason alone [11▪].

Patient positioning requires a careful preoperative planning to allow adequate access to the patient for both the neurosurgeon and the anesthesiologist. The prone position can lead to decreased lung compliance, venocaval compression and bleeding due to increased epidural venous pressure. Supportive lateral rolls can alleviate these problems by minimizing abdominal and thoracic pressure. Elevating the head facilitates venous and cerebrospinal fluid drainage from the surgical site. However, this increases the likelihood of venous air emboli (VAE). Maintaining normolemia minimizes this risk. Early detection of a VAE with continuous precordial Doppler ultrasound may allow treatment to be instituted before large amounts of air are entrained. Should a VAE produce hemodynamic instability, the operating table must be placed in the Trendelenburg position in order to improve cerebral perfusion and prevent further entrainment of intravascular air. Special risks exist in neonates and young infants as right-to-left cardiac mixing lesions can result in paradoxical emboli. Significant rotation of the head can also impede venous return via compression of the jugular veins and can lead to impaired cerebral perfusion, increased intracranial pressure and venous bleeding. Obese patients may be difficult to ventilate in the prone position and may benefit from the sitting position. In addition to the physiological sequelae of the sitting position, a whole spectrum of neurovascular compression and stretch injuries can occur.

Massive blood loss should be aggressively treated with crystalloid and blood replacement, as well as vasopressor therapy (e.g., dopamine, phenylephrine, epinephrine and norepinephrine). Isotonic saline is generally chosen as an intraoperative maintenance fluid because it is mildly hyperosmolar and should minimize cerebral edema. However, rapid infusion of more than 60 ml/kg of isotonic saline may cause hyperchloremic acidosis. Patients with diabetes mellitus, total parenteral alimentation and premature and small newborn infants may require glucose-containing intravenous fluids. Transfusion of 10 ml/kg of packed red blood cells increases hemoglobin concentration by 2 g/dl. Pediatric patients are susceptible to dilutional thrombocytopenia in the setting of massive blood loss and multiple red blood cell transfusions. Administration of 5–10 ml/kg of platelets increases the platelet count by 50 000–100 000/mm^3. The routine use of the antifibrinolytic agent, tranexamic acid, in surgical procedures with excessive blood loss, such as posterior spine fusions, cardiac surgery and craniofacial reconstructive procedures, has been shown to decrease blood loss in pediatric patients [12▪▪]. In the case of severe cardiovascular collapse, some pediatric centers have rapid response extracorporeal membrane oxygenation teams that can provide rescue therapy when the crisis is refractory to standard cardiopulmonary resuscitation algorithms. However, the use of anticoagulation in the setting of ongoing bleeding may be problematic.

ANESTHETIC MANAGEMENT OF SPECIFIC NEUROSURGICAL PROCEDURES

A majority of brain tumors in pediatric patients are located in the posterior fossa. These tumors have a mass effect and often obstruct cerebrospinal fluid flow, which can lead to hydrocephalus and intracranial hypertension. If the patient is symptomatic, measures to reduce hydrocephalus and intracranial hypertension include intravenous steroid therapy and a ventricular shunt or external ventricular drain in severe cases. Brain stem tumors may impinge upon the respiratory control centers and cranial nuclei. These structures are also vulnerable to surgical manipulations and dissection. Stimulation of the nucleus of cranial nerve V can cause hypertension and tachycardia. Irritation of the nucleus of the cranial nerve X may result in bradycardia and vocal cord paralysis. Continuous observation of the blood pressure and ECG are essential to detect encroachment upon these structures. Elevation of the bone flap can result in sinus tears, massive blood loss and/or VAE. Inadvertent entry into the straight and transverse sinus can precipitate massive VAE.

Damage to the respiratory centers and cranial nerves can lead to apnea and airway obstruction after extubation of the patient's trachea.

Supratentorial tumors are more common in infants and adolescents. Infants predominantly have embryonal tumors; whereas craniopharyngiomas occur more frequently in toddlers and children and may be associated with hypothalamic and pituitary dysfunction. Steroid replacement therapy with either dexamethasone or hydrocortisone may be required as the integrity of the hypothalamic-pituitary-adrenal axis may be disrupted. Perioperative diabetes insipidus can lead to electrolyte and hemodynamic derangements due to excessive fluid loss through polyuria. Laboratory studies should therefore include serum electrolytes and osmolality, urine-specific gravity and urine output. Diabetes insipidus is marked by a sudden polyuria (> 4 ml/kg/h), hypernatremia and hyperosmolarity. Initial management consists of infusion of aqueous vasopressin (1–10 mU/kg/h) and judicious fluid administration that matches urine output and estimated insensible losses.

Advances in intraoperative MRI provide the opportunity to define the margins of tumors during the surgical section. This provides the opportunity to conservatively resect the lesions without causing iatrogenic damage to normal tissue or residual tumors in single operative session. However, this combined surgical and imaging procedure is associated with prolonged anesthesia times and hazards in a MRI environment [13▪]. Ongoing investigations are examining the efficacy and cost-effectiveness of this hybrid environment.

Epilepsy surgery poses several anesthetic management issues [14]. General anesthetics can compromise the effectiveness of intraoperative neurophysiologic monitors that guide the resection of the epileptogenic focus. High levels of volatile anesthetics and neuromuscular blockade may also suppress cortical stimulation. Nitrous oxide can precipitate pneumocephalus after a recent craniotomy (up to 3 weeks later) and should be avoided until after the dura is opened.

A variety of techniques have been advocated to facilitate intraoperative assessment of motor-sensory function and speech, including awake craniotomies. In the 'sleep-awake-asleep' technique the patient undergoes general anesthesia for the surgical exposure. The patient is then awakened for functional testing and general anesthesia is reinstituted when patient cooperation is no longer needed. Most cooperative patients will tolerate sedation with propofol or dexmedetomidine. Propofol does not interfere with the electrocorticogram, if it is discontinued 20 min before monitoring in children undergoing an awake craniotomy [15]. Supplemental opioids are administered to provide analgesia. It is, however, imperative that candidates for craniotomy under local anesthesia or sedation be mature and psychologically prepared to participate in this procedure.

Cerebral hemispherectomy for the management of medically intractable seizures has evolved over the last decade, with a trend from anatomic (total) toward minimally invasive functional resections [16,17]. Significant intraoperative blood loss and hemodynamic instability of both techniques have an impact on the anesthetic management of these patients [18,19]. Coexisting comorbidities, concurrent anticonvulsant therapy and evolving coagulopathies must also be of concern to the anesthesiologist [14]. Tranexamic acid has been recently shown to attenuate massive blood loss in a variety of surgical procedures in infants and children [20,21] and has been empirically administered in surgical procedures associated with massive blood loss [12▪▪].

The primary goal of the anesthesiologist during cerebrovascular surgery is to optimize cerebral perfusion while minimizing the risk of bleeding. Large arteriovenous malformation may be associated with high-output congestive heart failure requiring vasoactive support. Hypertensive crisis after embolization or surgical resection of the arteriovenous malformation should be rapidly treated with vasodilators. These lesions are often managed by combined neurointerventional and neurosurgical approach, which start with endovascular occlusion of the lesion followed by surgical resection and ending with a postoperative angiography.

The goal of anesthetic management of patients with moyamoya syndrome is to optimize cerebral perfusion with aggressive preoperative hydration and maintaining normotension or mild hypertension during surgery and the postoperative period [22]. Intraoperative normocapnia is essential because both hypercapnia and hypocapnia can lead to steal phenomenon from the ischemic region. Intraoperative electroencephalogram monitoring may be utilized during surgery to detect cerebral ischemia. Optimization of cerebral perfusion should be extended into the postoperative period by maintaining euvolemia and using sedatives and opioids to prevent hyperventilation induced by pain and crying.

Technological advances in endoscopic surgery have provided minimally invasive approaches to the surgical management of central nervous system lesions. Endoscopic-guided biopsies of deep-seated brain lesions have been adapted to pediatric patients [23]. Endoscopic third ventriculostomies have been proposed as a viable and efficacious alternative to ventricular shunts. Despite the relative safety of this procedure, hypertension, arrhythmias and neurogenic pulmonary edema have been reported in conjunction with acute intracranial hypertension due to lack of egress of irrigation fluids and/or manipulation of the floor of the third ventricle.

CONCLUSION

The anesthetic management of infants and children for intracranial surgery is based on age-dependent factors that are unique to the neurosurgical lesions and the anesthetic approach to these patients. Advances in subspecialty training in pediatric neurosurgery mandate that anesthesiologists be well versed in this evolving field [24■■]. Thorough preoperative evaluation and open communication among members of the healthcare team are essential for minimizing perioperative morbidity and mortality.

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Conflicts of interest

There are no conflicts of interest.

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