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REVIEW ARTICLE

Reducing the risk in neonatal anesthesia

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Summary

Neonatal anesthesia is fraught with potential risk for the patient and stress for the anesthesiologist. Where possible, recognition of these risks, avoidance of, and being able to manage them appropriately, must impact positively on perioperative outcomes in this vulnerable group of patients. Good communication with the parents, as well as with other healthcare providers, is crucial to safe and successful anesthetic care.

Introduction

To reduce risk, the cause(s) must be identified (Table 1). With the definition of risk being 'the chance or possibility of danger, loss or injury' (1), assessing risk in pediatric anesthesia depends on the aspect from which you approach the problem—patients and their parents, doctors, hospital managers, policymakers, or insurance companies (2). This discussion will address risk to the patient, a neonate, by being anesthetized at this early age. What are the risks associated with neonatal anesthesia? Being aware of these risks, paves the way toward reducing them (3). They include prematurity, the presence of congenital lesions or syndromes, disease processes particular to neonates (necrotizing enterocolitis, patent ductus arteriosus), a narrow margin for error—especially with drug administration and dilution, correct placement of the endotracheal tube, and difficulty with vascular access. Infants of <1 month of age are well recognized as having the highest incidence of adverse events, both in the operating room and in recovery (4). Lack of adequate training of practitioners and cultural attitudes to the treatment and survival of sick neonates will not be addressed. Anesthesia-induced neurotoxicity as a consequence of being exposed to anesthetic agents at this young age (5), and whether or not, at this stage, this is clinically relevant (6), is covered by another review in this journal. Regardless of the type of surgery planned, safe neonatal anesthesia can only be performed with an insightful understanding of the physiological and anatomical changes taking place in the transition from fetal to neonatal life (7). For the premature infant, immature organ systems and their even smaller size aggravate these problems. Among those questions most frequently asked by pediatric anesthetists (6,) many relate to neonates. These include the pharmacology of drugs in newborns, in particular, pharmacokinetics, pharmacodynamics, safety, and side effects (8).

Pharmaceuticals for the neonate

Neonates are recognized as being the age group with the greatest gap in pharmacological understanding, and this includes the role of TIVA (6). Practitioners worldwide take the responsibility for routinely using many medications off-label in their daily clinical practice, and most medications for this age group are prescribed in this way. Clinical trials are increasingly difficult to perform, and most clinicians rely on case reports and expert opinion for guidance in neonatal prescribing. Off-label use may include using the agent for an unregistered indication, route of administration, dose, and/or age group of the patient. For most

Table 1 Risk factors in neonatal anesthesia

Apnea
Anatomy/airway/anesthesia/analgesia/awareness
Breathing and oxygenation: beware high FiO_2
Circulation: Transitional circulation, PHT, immature myocardium, impact of anesthetic agents on cardiovascular stability, parasympathetic dominance
Congenital anomalies and syndromes: Comorbidities of cardiac defects and difficult airway
Disability: neurological immaturity, focal neurological deficits
Drugs: Pharmacology in neonates, off-label use of medications, dilution errors
Environment: temperature, transport, minimal handling
Fluids: do not tolerate rapid infusion of fluids
Glucose: hypoglycemia
Hematology: coagulation
Hypos and hypers: glucose, calcium, potassium, sodium, temperature, hemoglobin
Peri/intraventricular hemorrhage (PVH, IVH)
Pain
Prematurity: immature organ systems, small size, young age
Sepsis, small size
Types of surgery: emergency
Vascular access: arterial or venous

anesthesiologists in clinical practice, it is a relief to know that 'Off-label pharmacological use is ubiquitous, legal and ethical' (9).

In an analysis of critical incidents relevant to pediatric anesthesia, medication issues predominated, with the duplication of dosing between the operating room and the wards being the most common in this study (10). This emphasizes the need for good documentation and communication between these two areas of perioperative care. Drug substitution and dosage errors in pediatric anesthesia in general have been found to be more common than in a comparative adult population (11). Avoiding errors when diluting drugs, and making mistakes when administering them, requires on-going vigilance and meticulous attention to detail. Further errors include the administration of incorrect medications, dose, schedule, and infusions rates, with failure to follow protocols, inattention, and poor communication compounding the problems (12). These risks can be reduced by ensuring that ampoules do not look similar or have the same writing, that pharmacy be tasked with preparing dilutions, by the use of calculators for working out minute pediatric doses, cross-checking drugs and doses with colleagues or nursing personnel, using international color-coded labels for groups of drugs, or the use of computer-generated drug charts for certain specialties, for example cardiac anesthesia.

After the administration of potent opioids via dedicated lines, and to avoid complications of late-onset re-sedation in recovery or the ward, it is crucial that these lines are flushed and cleared of any medication (while the baby is still being monitored closely) prior to the baby's discharge from the theater.

There is an increasing awareness of the possibility and probability of opioid withdrawal in neonates when these critically ill children have received continuous infusions for a prolonged period (13). Pain in these babies has, for many years, been ignored, but increasingly, in both the perioperative and intensive care settings, practitioners are providing good pain relief. With the use of ultra-short acting medication such as remifentanil or fentanyl, as well as the traditional longer acting opioid morphine, the need for weaning patients off these medications should be factored into their treatment regimen. Monitoring for signs and symptoms of withdrawal, and anticipating the onset of these, will allow for timeous management strategies to be employed.

Syndromes and congenital anomalies

Syndromes, chromosomal anomalies, and congenital disorders are frequently exposed in the neonatal period. A syndrome is a group of symptoms that consistently occur together or is a condition characterized by a set of associated symptoms (1) (Table 2). A symptom is a physical or mental feature regarded as indicating a condition or disease (1). Congenital heart disease is the commonest congenital anomaly, at 1 : 125 live births. These are often associated with some form of airway abnormality. If one abnormality is present, the anesthesiologist should search to find another. Dysmorphic features may provide an external indication of internal anomalies, and a cardiological consultation, with preoperative echocardiography, may be warranted. In our unit, the following babies would be echoed prior to

Table 2 Definitions

Neonate	First 28 days of life, regardless of gestational age
Prematurity	Infants born at <37 completed weeks gestational age
	Low birth weight (LBW): <2500 g
	Very low birth weight (VLBW): <1500 g
	Extremely low birth weight (ELBW): <1000 g
	Further arbitrary division on gestational age: 35–37 weeks, 30–34 weeks, 27–29 weeks, and <26 weeks.
SGA	Small for gestational age: <10% of weight for gestational age at birth
LGA	Large for gestational age: >10% for weight for gestational age at birth
Syndrome	A group of symptoms that consistently occur together, a condition characterized by a set of associated symptoms
Symptom	Physical or mental feature regarded as indicating a condition or disease
Postconceptual age	Gestational age + postnatal age
Apnea	Cessation of breathing for >20 s, or >15 s with bradycardia

anesthesia: any cyanosed infant, one with a murmur, those with well-recognized associations, for example duodenal atresia and Down's syndrome, and, because of the common association with cardiac anomalies, those patients with airway or ear abnormalities.

Metabolic abnormalities, more commonly referred to as 'Inborn errors of metabolism', in this age group are individually rare but collectively much more common. Mass screening of the following occurs in many countries: hypothyroidism, hyperphenylalaninemia, galactosemia, and maple syrup urine disease. An inborn error of metabolism should be in the differential diagnosis of any critically ill neonate—whether or not he/she requires surgery. Hypocalcemia may be part of syndromes, for example Di George syndrome, or occur after the administration of citrated blood products. Hypoglycemia, if not diagnosed timeously, may have catastrophic immediate and long-term consequences. Although not routine for mass screening in the neonatal period, the following may have implications for the pediatric anesthetist: glucose-6-PD deficiency, the genetic muscle disorders, for example Duchenne's muscular dystrophy, hemoglobinopathies, adreno-genital syndrome, and cystic fibrosis.

Risk of morbidity and mortality is highest in children under 1 year of age, those with comorbidities, and those undergoing emergency surgery (14). Because of the dangers inherent in neonatal anesthesia, most operations are avoided during this period; thus, surgery performed on neonates is often emergency surgery. For those babies whose differences are obvious—as in many of the syndromes with gross airway anatomical abnormalities, the challenges are no surprise. Those with anomalies of a covert nature, a critical event in the perioperative period may be the first indication of that pathology. Anesthetic concerns relate mostly to the airway and cardiovascular systems, but some of the metabolic and neuromuscular disorders may have life-threatening reactions with anesthetic agents. Many excellent textbooks on the subject are now available (see suggested reading), and the internet provides a rapid reference to most of the abnormalities likely to be encountered. These should be consulted prior to starting the anesthetic on a syndromic baby. As more genetic bases for syndromes become available, there is a move away from eponymous names for syndromes. Negative anesthetic information (i.e., no known anesthetic implication) is as valuable as a list of anticipated problems.

Transitional circulation

The neonatal circulation is a dynamic state which may revert to a transitional circulation at any time, particularly when subjected to a variety of biochemical or physical challenges.

To understand the cardiovascular changes which occur at birth, knowledge of the fetal anatomy and physiology is essential. Unique characteristics of the myocardium and the specific blood flow pathways differentiate the fetus from the neonate and also the older child and adult. These are further altered by congenital anomalies that may be present. Echocardiography findings enable us to understand fetal and neonatal cardiovascular physiology and anatomy in both normal and diseased states (15).

In the first weeks of life, the pulmonary circulation remains very sensitive to PaO_2, $PaCO_2$, asphyxia, acidosis, hypothermia, hypo- or hyperglycemia, hypocalcemia and sepsis, and any of these may cause an increase in pulmonary vascular resistance (PVR), thus re-opening any of the transitional circulation shunts (except obviously not the placenta as it is no longer there) resulting in persistent pulmonary hypertension of the neonate (PPHN). Other conditions that predispose to PPHN include meconium aspiration, asphyxia, hypoxia, sepsis, and congenital diaphragmatic hernia (16). In the perioperative period of a sick neonate, any one or more of these factors may be present. During anesthesia, difficulty in maintaining the airway, with consequent hypoxia, hypercarbia, and acidosis, may cause the patient to revert to a transitional circulation, and it may take time for this to revert back to normal. Monitoring oxygen saturations on the right arm (preductal saturations) as well as on either leg (postductal) may provide the diagnosis as, with reverting to a transitional circulation, the preducal saturation will be higher than the postductal measurement.

The incidence of patent ductus arteriosus (PDA) in premature infants (prems) is common. The PDAs of prems do not close that easily because they have less ductal muscle, the subendothelial cushions that obliterate the lumen when the ductus constricts are absent, and the internal elastic lamina is intact (17). Patency in these babies is more likely to be due to the relaxing effects of the endogenous prostaglandins than to a lack of response to the contracting influence of oxygen. The impact of anesthetic agents on the reactivity of the PDA may cause a significant drop in diastolic pressure, causing noteworthy ST-segment depression.

Prematurity

Age is an important risk factor in anesthesia. With newborns encompassing an ever-smaller and more premature patient profile, the risks associated with providing perioperative care, analgesia, and sedation in these babies increase. Their 'small size' is no longer a baby of <2 kg, but one that is a mere few hundred grams, and the age of 36 weeks is positively 'old' compared with 24 weeks. Some things do, however, stay the same. Small size, immature organ systems, congenital anomalies, fragility with handling, increased oxygen, and glucose requirements each contribute to high-risk anesthesia. Definitions are covered in a number of texts (16,18,19) (Table 2). Regardless of the gestational age, a neonate is defined as a baby in the first 28 days of life (19).

Perioperative risk factors for premature infants include the following: apnea (central, obstructive, mixed, or respiratory muscle fatigue), anemia, respiratory distress syndrome, chronic lung disease, retinopathy of prematurity, bronchopulmonary dysplasia, sepsis, hypoglycemia, and an increased sensitivity to pain (20–22). Each of the risk factors for neonates (Table 1) is compounded by decreasing gestational age.

Apnea of prematurity is a well-recognized complication in the postoperative period. It is made worse by sepsis, anemia, hypoxia, metabolic abnormalities, hyper-or hypothermia, hypoglycemia, intracranial hemorrhage, heart failure, vagal dominance, and medications such as opioids and prostaglandins. Treatment options include stimulation, bag-mask ventilation, nasal CPAP, ventilation, or use of respirogenic agents such as caffeine or aminophylline (16).

Those babies with congenital heart disease (CHD) may be pink (normal oxygenation), blue (cyanosed), or gray (shocked) (23), may present with well-recognized signs and symptoms of heart failure, or may present the diagnostic dilemma of a baby with myocarditis or an abnormal left coronary artery off the pulmonary artery (ALCAPA). Many of these will require anesthesia for interventions of a palliative or curative nature. The neonatal myocardium has many significant differences from the older child and adult which are of a cyto-architectural, physiological or functional, and biochemical nature (17). This immature myocardium has fewer contractile elements with fewer mitochondria in a relatively disorganized pattern. Less sarcoplasmic reticulum (SR) with poorly formed T-tubules compares unfavorably with well-developed SR and T-tubules in adults (17). The neonatal myocardium depends on extracellular calcium for contractility, and this has considerable clinical significance. Another significant difference is the cellular source of energy: adults myocardial cells rely on free fatty acids for their energy, whereas immature cells use carbohydrates. This provides better tolerance to ischemia, with rapid recovery of function. The consequence of this, for anesthetists, is that the immature myocardium is less compliant and shows limited cardiac output improvement with increased preload. It does not tolerate a high afterload, requires normal serum levels of calcium, and is sensitive to calcium channel blockers. The parasympathetic system predominates until about 6 months of age, and neonates develop global rather than focal ischemia—unless the coronaries are involved in the pathology, for example ALCAPA. Table 3 provides a summary of cardiovascular physiology of the neonate.

Pulmonary hypertension (PHT) is a major risk factor for neonatal surgery. Whether this is part of a return to transitional circulation or as a consequence of a congenital abnormality, its presence requires meticulous preoperative planning and treatment. Persistent pulmonary hypertension is a significant cause of morbidity and mortality in neonates, especially in premature infants. This is a reversible condition but, uncontrolled, may cause severe and unrelenting respiratory failure and right ventricular dysfunction. Prevention of pulmonary hypertension is key to successful intraoperative management, and successful treatment involves strategies to decrease PVR and provide inotropic support for the right ventricle.

Top tips for anesthetizing extreme premature infants

- Minimal handling: use fingertips gently, not your whole hand

Table 3 Summary of cardiovascular physiology of the neonate

Blood volume of 90–100 ml kg^{-1}
Noncompliant myocardium ∴ small fixed stroke volume (1–2 ml kg^{-1}) and a rate-dependent cardiac output.
Bradycardia results in ↓ CO.
Sparse sympathetic innovation to neonatal myocardium and vagal tone predominates.
Immature baroreceptor response ↓ ability to compensate for hypotension with ↑ HR.
Normal heart rate 140 ± 20 $b.min^{-1}$, BP ± 70/52
Mean blood pressure = gestational age in weeks
Has high cardiac output (180–240 mls kg^{-1} min^{-1}) and low systemic vascular resistance.
CVS adapts poorly to changes in intravascular volume ∴ hypovolemia → ↓CO, ∴ ↓ BP and hypotension.
Heart rate, and to a lesser extent blood pressure, are good indicators of intravascular volume.
Baroreceptor reflexes are absent in anesthetized infants.
Ventricles: Dominant RV at birth. At 6 months RV: LV = 1 : 2. ECG: RV dominance.
Hypoxia → bradycardia, ↓ CO, and vasoconstriction.
Higher hematocrit, ↑ blood viscosity.
↑ Metabolic rate: oxygen consumption is 6–9 mls kg^{-1} min^{-1}. Ill neonate ↑to 20 ml kg^{-1} min^{-1}
Transitional circulation and reactive pulmonary vasculature.
Fetal hemoglobin: Hb 18–20 g dl^{-1}. (↓ at 2–3 months).
Erythropoietin disappears shortly after birth and reappears at 2–3 months

CO, cardiac output; BP, blood pressure; RV, right ventricle; LV, left ventricle; $b.min^{-1}$, beats per minute.

- Meticulous attention to pressure complications: blood pressure cuff, saturation probes, the back of the head, and heels, nasogastric tube traction on the nose
- Meticulous drug administration: choice of medication, dilutions, fluid flushes
- Minimize FiO_2: aim for saturation of 88–95%
- Near infrared spectroscopy (NIRS) is a very useful tool for monitoring cerebral or visceral organ perfusion, oxygenation, ventilation, and hemoglobin
- Balance risk of invasive monitoring with the risk of a compromised limb. Sympathectomy of a limb with critical ischemia from an arterial line, using a local anesthesia block, may be beneficial
- Good pain control: neonates in pain and distress will not grow, not to mention the long-term consequences of untreated pain
- Ventilation intraoperatively: minimum FiO_2, minimal peak inspiratory pressure, 3–5 cms PEEP, i:e ratio of 1 : 1,40–60 breaths per minute, permissive hypercapnia
- Postoperative ventilation: very ill infant, high-dose opioid anesthetic, muscle weakness
- Patience with vascular access
- Be fully prepared with all consumables and equipment that may be needed
- Neonatal anesthesia is best provided by two anesthetists working together.

Airway, breathing, and oxygenation

Good airway management is crucial to success in anesthesia, intensive care, and during resuscitation. A difficult airway may be evident from the initial attempts to hold the head for induction, with the large occiput, especially in prems, causing the head to roll from side to side. This also increases head and neck flexion which, together with an anterior larynx, makes intubation more difficult. Good positioning may be all that is needed to improve visibility. Face masks may be ill-fitting, making bag-mask ventilation problematic. The presence of a nasogastric or nasojejunal tube compounds the problem, and whether to remove the tube or not is the question. Except in the moribund baby, intubation should always be performed with analgesia sedation or general anesthesia. Awake intubation is not advised as this may result in raised intracranial pressure, raised blood pressure, apnea, desaturation, and airway trauma.

Laryngeal mask airways may not seat well and are frequently the source of laryngospasm and loss of the airway during surgery. They are, however, useful in the neonate with a difficult airway.

Rapid sequence induction (or that all-encompassing term ‘modified rapid sequence’) for premature infants and neonates is potentially problematic. Cricoid pressure is difficult to apply. It distorts the anatomy, and exactly how much pressure should be applied, and when to apply it is uncertain (24). Changing endotracheal tubes requires precision and care, as adverse events are common at this time. If a bougie has been used, and the baby decompensates immediately thereafter, a pneumothorax should be high on the list of differential diagnoses. Firm securement of the endotracheal tube may be difficult, as many strapping materials cause damage to the fragile skin of the face.

Laryngospasm is a common adverse event in pediatric anesthesia, but although it is a cause of major morbidity, it is not a reported cause of death (3). However, it should never be underestimated, and protocols, especially in training institutions, should be in place for its eventuality.

Traditionally, more oxygen was better. Now, as we have become increasingly aware of the potential damage of delivering a high inspired oxygen (FiO_2) in many neonates, this may not hold true (22). The impact of excessive oxygen is felt largely on the brain (increased incidence of periventricular hemorrhages and adverse neurological outcomes), eyes (retinopathy of prematurity), and lungs (bronchopulmonary dysplasia). High oxygen levels affect intra- and extracardiac shunting by altering pulmonary vascular pressures, and this can be used to manipulate flow. Left to right shunt flow will be increased, and with an abnormal left coronary artery from the pulmonary artery (ALCAPA), coronary steal may occur. For babies with cyanotic CHD, increased levels of oxygen radicals are produced.

Anesthetic management should aim at providing a minimal FiO_2 to maintain oxygen saturation of 88–95%, minimal peak inspiratory pressures, positive end-expiratory pressures of 3–5 cm H_2O, inspiratory to expiratory ratio of 1 : 1 at a rate of 60 breaths per minute, and to allow permissive hypercapnia (18).

Coagulation

Hemostatic mechanisms are immature but are functionally balanced in the healthy neonate, with no tendency toward coagulation or thrombosis (25). Plasma clotting factors are inconsistently different from the older child or adult. Vitamin K-dependent factors are low at birth, and preoperative vitamin K supplementation is necessary prior to surgery. Factors II, VII, IX, and X and the contact factors (XI and XII) are 50% lower than adult levels at birth. Factor VII rapidly increases after birth, II and VII remain low for most of childhood, and IX can be as low as 15% of adult levels until 9 months of age. Fibrinogen, Factors V, VIII, and XIII are normal at birth, whereas Von Willebrand factor (VWF) levels are increased at birth and are normal at about 2–6 months of age (26). All of these differences, plus any comorbidities present, for example congenital cyanotic heart disease or sepsis, require hematological investigations prior to any surgical procedure. These screening laboratory tests for hemostasis may, however, have different values between neonates and adults (24). Recent recommendations for standardization of all diagnostic laboratories testing for hemostasis in pediatrics have been published (27). Reference ranges should be specific for age, the type of analyzer, and the reagent.

Platelet number and volume are similar between neonates and adults. Neonatal platelets do not respond normally to agonists, and their fibrinogen binding sites are not fully developed. This continues for the first 2–4 week of life (25). Despite this, conventional tests do not show platelet dysfunction, probably due to high VWF levels and a higher hematocrit. Neonatal bleeding may be due to congenital bleeding disorders, asphyxiation, cyanotic CHD, disseminated intravascular coagulation, or sepsis. Iatrogenic causes should be ruled out.

Sepsis

Providing anesthesia for a sick neonate may be an uncomfortable challenge. Many pathophysiological responses of normal neonates are altered, for example cerebral autoregulation in sick neonates and prems is lost, and cerebral perfusion is directly related to arterial pressure (28). Altered coagulation, depressed immunity, easily traumatized tissues, the tendency to intra- and periventricular hemorrhages, and immature organs systems increase the possibility of adverse events. Invasive monitoring may be preferred, but arterial and venous central lines are often difficult and run the risk of severe complications. In the face of possible immune-compromise, strict aseptic techniques are essential. Regional anesthetic options may be limited by coagulopathies, with thrombocytopenia being common. Electrolyte imbalances require correction, especially hyponatremia, hyperkalemia, and hypocalcemia. Early judicious use of inotropes may be necessary.

Near infrared spectrometry (NIRS) may act as a global indicator of the interventions that will influence cerebral oxygenation during anesthesia, but there are few studies in premature infants on this subject (22). Certainly in clinical practice, it is a very useful tool to detect the impact of overventilation with hypocapnia, anemia, hypotension with poor cerebral perfusion, and vascular compression of vessels perfusing the brain. This is especially valuable in very small babies and where no invasive monitoring is possible. It is the practice in our unit to use NIRS with all neonatal and cardiac anesthesia, and in those surgical procedures involving the neck, where obstruction of major vessels is reflected in a drop of the NIRS reading.

The risks of transporting the hemodynamically unstable neonate with respiratory disease who is intubated and being ventilated need to be balanced against the benefits of surgery performed in the operating room. The pros and cons of this are addressed in this journal. Whether the neonate is being transported from a peripheral hospital to a specialist center or transferred from the intensive care unit to the operating room, airway catastrophes and circulatory instability are possible. Risks of hypoglycemia, hypocalcemia, hypothermia, and fluid overload are a reality, with exposure to inappropriately high inspired oxygen almost certain.

However, the risks of unplanned extubation at any stage of this journey are very high, especially so on transfer to and from the incubator and the operating table, and the consequences are dire. After arrival in the operating room, a goal-directed check of the airway—especially of the endotracheal tube—is needed, with documentation of the findings.

An operating room ideally suited to neonatal surgery, with point-of-care investigations and a blood bank on the premises, may not be available to all practitioners. A local anesthetic technique in an operating room used for adult surgery, with minimal neonatal monitoring, may be the only option. The anesthetic choice, whether inhalational, total intravenous, or regional, will depend on the hemodynamic stability of the baby, the procedure planned, the comorbidities that the baby has, and whether or not options exist for postoperative ventilation.

Technical factors

Size matters! The smaller the baby, the more technically difficult everything becomes: from vascular access, intubating conditions, and handling, to find the correct-sized equipment for that infant. Even today, much of the equipment required for safe perioperative care is not suitable for tiny babies. Especially in intensive care, pressure sores from pulse oximetry probes necessitate regular changing of these sites.

The use of ultrasound for vascular access has made a significant difference to the ease, speed, and safety of acquiring venous access in these patients. Although not yet standard of care in all units, this technology is to be encouraged in all centers caring for infants and children. Surgical central venous catheters are now also placed under ultrasound guidance. In many of the bigger units, interventional radiologists, anesthetists, and surgeons team up to provide a vascular access service.

Hypothermia is a well-recognized risk factor in neonatal anesthesia. Its prevention is mandatory, and in transporting the baby to the operating room, measures such as the use of incubators or kangaroo care by the mother are successful tools. A warm, dry baby will reduce the possibility of hypothermia.

Types of surgery performed

Any of the various surgical specialties may be implicated, both for elective and emergency operations (19). With a systemic approach to the emergencies, these would include some of the following:

Abdominal: General nonsubspecialty surgery: Necrotizing enterocolitis (NEC), intestinal atresias, bowel obstruction, bowel perforations, strangulated inguinal hernia, malrotation or midgut volvulus, tracheaesophageal fistula or esophageal atresia, congenital diaphragmatic hernia, anorectal anomalies, omphalocoele, and gastroschisis.

Airway: Ear nose and throat (ENT): choanal atresia, an obstructed airway (congenital or acquired), vocal cord palsy, foreign body, and masses, for example cystic hygroma.

Cardiac: open heart surgery (e.g., obstructed total anomalous pulmonary venous drainage), placement of a systemic to pulmonary shunt, and coarctation of the aorta.

Neurosurgery: myelomeningocele, congenital hydrocephalus, and tumors.

Urological: extrophy of the bladder, pelviureteric junction obstruction with hydronephrosis, cloaca.

Laparotomy for NEC encompasses many of the challenges faced during most surgeries for neonates and premature infants. These are usually premature babies, often extremely ill, coagulopathic, and septic. Raised intra-abdominal pressure will impact negatively on renal function, and bowel and lower limb perfusion. Inhalational anesthetic agents may result in a drop in blood pressure, especially once the baby is being ventilated. Despite the concerns about the long-term neurocognitive consequences of ketamine in this age group, this may be a safer option in providing more stable hemodynamics. If postoperative ventilation is available, high-dose opioid anesthesia is a consideration. In the very ill, coagulopathic baby, neuraxial regional anesthesia may not be possible, but local anesthetic wound infiltration, or wound catheter infusion is possible.

Warning signs and solutions

Signs: poor perfusion, 'monitor failure'-abnormal oxygen saturations and blood pressure measurement failure, drop in endtidal CO_2, cyanosis, and bradycardia are all indicators of impending doom (29).

Solutions: knowledge, high index of suspicion, monitoring, protocols, for example for laryngospasm and insertion of central vascular lines (3), and meticulous attention to detail. The use of oxygen saturation monitors and capnography and the discontinuation of the use of halothane have had an impact on morbidity and mortality in neonatal anesthesia (14).

Conclusion

Reducing the risk of neonatal anesthesia requires recognition of the risk factors, where possible preventing their occurrence, and being able to manage the consequences of the problem. Anesthesia and surgery is necessary for many of these babies, but their perioperative care may be considerably safer with knowledge, preparation, and planning for any eventuality. Awareness of the potential impact of even very small changes from ideal physiological parameters in the neonate may reduce morbidity and mortality. Meticulous attention to detail of all aspects of perioperative care, constant vigilance, rapid recognition of changes in vital parameters, and the ability to intervene quickly is the cornerstone to successful neonatal anesthesia.

There are many strategies and work groups all over the world which each have the same aim: to provide safe anesthesia to children (30), and, in particular, the vulnerable neonatal group. With the recognition of risk factors, the reporting critical adverse events in the perioperative period, and the development of planning strategies to avoid or to be able to manage these effectively, anesthesia to neonates and premature infants will meet this target. Knowledge and anticipation of potential pitfalls take the unpredictability out of neonatal anesthesia.

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Conflict of interest

No conflicts of interest declared.

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