Anesthesia and Pain Management

Aidan Magee and Suzanne Crowe

Abstract

Due to developments in surgical techniques and equipment, surgical repairs in smaller infants and young children became feasible in the last decades. This has been linked to new anesthetic drugs and new anesthesia modalities such as regional anesthesia. Increased operative intervention in preterm and low birthweight infants has led to increased demand for postoperative high dependency and intensive care.

The success of major pediatric and neonatal surgery depends on the cooperation between surgeon, anesthetist, and nursing and allied professions to optimize anesthetic and surgical management. Basic techniques for maintaining a favorable physiologic milieu in the face of surgical intervention while at the same time ensuring adequate analgesia and anesthesia is essential. Besides intraoperative management, adequate postoperative care is crucial for the surgical pediatric patient. The best postoperative care should take place in an environment where the healthcare staff are skilled and trained to manage the challenges presented by neonatal and pediatric physiology in the perioperative period.

Keywords

Anesthesia • Analgesia • Cardiovascular monitoring • Cardiovascular monitoring • Perioperative care • Respiratory management • Preterm infant

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Introduction

Historically, the use of anesthetics and analgesics in neonates and infants has been based on extrapolations from studies performed in adults and older children. Over the past 20 years, there has been a growing body of research on the clinical pharmacology and clinical outcomes of these agents in neonates and infants. Developments in surgical techniques and equipment available have facilitated challenging surgical repairs in smaller infants and young children (Smithers et al. 2016; Nose et al. 2016). This has been coupled with new anesthesia modalities, in particular with regard to regional anesthesia, and rapidly metabolized medications such as desflurane and remifentanil (Davidson et al. 2015a; Sale et al. 2006; Sammartino et al. 2011). Increased operative intervention in preterm and low birth-weight infants has increased the demand for postoperative high dependency and intensive care (Brusseau and Koka 2009).

Equally important has been the increased understanding of the need for an efficient smooth-working team. The success of major pediatric surgery depends on maximum cooperation between surgeon, anesthetist, pediatrician, and nursing and allied professions. It is appropriate therefore that everyone involved in the care of the hospitalized child, whether working inside or outside the operating theater, should be familiar with the basic techniques used in maintaining a favorable physiologic milieu in the face of surgical intervention while at the same time ensuring adequate analgesia and anesthesia.

A newborn requires constant vigilance, rapid recognition of the events, and swift intervention during anesthesia. The anesthetic considerations in neonatal surgical emergencies are based on the physiological immaturity of various body systems, poor tolerance of the anesthetic drugs, associated congenital disorders, and considerations regarding the use of high concentrations of oxygen. The main goal is for titration of anesthetics to desired effects while carefully monitoring the cardiorespiratory status (Millar 2005). Advances in neonatology have resulted in the improvement of the survival of the premature and critically ill newborn babies (Eicher et al. 2012; Greenough et al. 2008). Most children with congenital anomalies that can be corrected by surgery are now stabilized and optimized before the procedure. Most of the disorders previously considered as neonatal surgical emergencies in the past no longer require immediate surgery due to new technology and new methods of treating sick neonates (Greenough et al. 2008).

This chapter describes the common neonatal surgical emergencies and focuses on factors that affect the anesthetic management of patients with these disorders. There is a brief review of pediatric physiology and pharmacology relevant to anesthesia. There is an emphasis on preoperative optimization, controlling the operating room environment, and the importance of managing pain to suppress the stress response to surgery.

Most of the current general anesthetics have been associated with anesthetic neurotoxicity in juvenile mammals, and several epidemiologic studies in human infants and toddlers have linked surgery occurring in the first 3 years of life with neurocognitive delays in school-age children (Johnson et al. 2008; Vutskits 2012). These concerns are discussed in this chapter. Practical considerations about pediatric intubation, line placement, and intraoperative fluid management are also reviewed.

Preoperative Optimization

Surgery will be postponed until the infant has grown and gained weight if possible, to reduce morbidity related to gestation and to make surgery
less technically challenging. However, it is not possible to postpone some operations, which are lifesaving for the neonate. Newborns undergoing emergency operations present several difficult challenges for the anesthesiologist. Many surgical emergencies in the neonate are life-threatening and are frequently accompanied by multiple organ system compromise or failure. Communication and cooperation between the entire healthcare team, including the surgeons, anesthesiologists, neonatologists, and pediatricians, are of utmost importance to ensure the best possible care of the child (Taneja et al. 2012). This has implications in terms of operating theater resources, intensive care resources, and the perioperative care of the newborn. Examples of common surgeries include closure of a patent ductus arteriosus and laparotomy for necrotizing enterocolitis in the extremely preterm infant. In the term neonate, release of posterior urethral valves, duodenal atresia repair, and tracheoesophageal fistula or atresia all must be carried out in the first days of life.

The cornerstones of preoperative anesthetic management are a detailed knowledge of the child’s personal and family history, combined with a physical examination. Consideration must be given to the specific surgical procedure to be undertaken and its implications in terms of potential blood loss, monitoring requirements, analgesia requirements, and postoperative care.

The efficient recognition and prompt management of illness in the neonatal period may be lifesaving. The infant’s history includes gestational age, significant events at birth (asphyxia, meconium aspiration, Apgar score), and previous or current mechanical ventilation. The physical examination should pay particular attention to the respiratory and cardiovascular systems. Airway anatomy should be assessed so that potential difficulties with airway management can be anticipated. The physical examination includes hydration status and coexisting diseases.

Laboratory examinations include a recent hematocrit, glucose, and calcium. Glucose metabolism is immature in the newborn period, and the sick infant may develop hypoglycemia rapidly. This is as a result of diminished glycogen stores (inadequate hepatic stores in the premature infant or depletion from catecholamine-stimulated breakdown in stress) or due to hyperinsulinism in diabetic mothers. Infants born with intrauterine growth retardation are also vulnerable to development of hypoglycemia due to reduced hepatic gluconeogenesis. Failure to recognize and treat neonatal hypoglycemia results in seizures and cerebral injury. Neonates who are not fed require maintenance fluid containing dextrose, usually 10%. Blood glucose measurement should be performed regularly as part of normal nursing care. Glucagon and steroid administration is occasionally required to bring the blood sugar level into the normal range (2–6 mmol). Children receiving intravenous dextrose or total parenteral nutrition may experience rebound hypoglycemia if the infusion is stopped abruptly due to increased blood insulin levels.

Hypocalcemia is common in the newborn period, especially in critically ill newborns, infants of diabetic mothers, and infants who have received large volume blood transfusion. Measurements of total serum calcium do not accurately reflect the level of ionized calcium in the blood. Reduced circulating calcium levels can cause seizures, apnea, and low cardiac output as the neonatal myocardium is very sensitive to changes in calcium serum levels. Replacement using intravenous calcium infusion must be carried out using central venous access, as calcium is extremely irritant to small peripheral veins and tissues.

A discussion with parents includes the planned conduct of anesthesia, pain relief, regional anesthesia, postoperative monitoring, blood transfusion, invasive monitoring, and potential admission to the high dependency unit (HDU) or the pediatric intensive care unit (ICU) (Hiller and Krishna 2004).

Postoperative overnight admission and apnea monitoring are required in infants less than 56 weeks corrected gestational age (CGA) and must be planned as part of the surgical admission. Surgical neonates and infants are not generally administered sedative premedication due to the risk of airway compromise. Children older than 12 months may occasionally require a
sedative premedication before separating from their parents.

**Fasting Prior to Anesthesia and Surgery**

Pulmonary aspiration of gastric contents has long been recognized as a cause of morbidity and mortality in patients of all ages undergoing anesthesia and surgery. The incidence of this complication in pediatric anesthesia is reported as 0.02% in one series (Tan and Lee 2016). Of the various preventative measures that have been advocated to reduce the incidence of this complication, the preoperative fast has long since achieved universal acceptance with the result that patients are required to abstain from food and drink prior to induction of anesthesia. Excessive fasting leads to dehydration and hypoglycemia, however, and may accentuate the risk of hypotension at induction of anesthesia. Furthermore, fasting leads to infants and children becoming hungry, thirsty, and fractious. Point-of-care ultrasound examination of the stomach may be useful in demonstrating residual gastric volumes (Van de Putte and Perlas 2014). Current recommendations for infants are a 2-h fast from clear fluids, 4 h for breast milk, and 6 h for formula milk, milk, and solids. Infants and children at particular risk of regurgitation, e.g., pyloric stenosis, intussusception, or perforated appendix, must fast from all oral or nasogastric intake for 6 h (Brady et al. 2005).

**The Operating Theater and Anesthetic Equipment**

The primary objectives of anesthesia are the provision of sleep, analgesia, life support, intensive surveillance, and appropriate operating conditions for the surgery, irrespective of the patient’s age. In order for these to be achieved, it is imperative that both operating theater environmental conditions and anesthetic equipment must be appropriate for infants and children.

Measures must be taken to minimize heat loss, using passive warming by manipulation of the ambient temperature and active warming through fluid warmers, heated mattresses, and forced air warmers. With a large body surface area to body ratio, the neonate tends to lose heat rapidly by conduction, convection, evaporation, and radiation. The newborn has a limited ability to raise its body temperature through heat production from metabolism of brown fat stores and glucose. This inability is exaggerated in the premature infant, who is poikilothermic and vulnerable to cold-induced metabolic acidosis, hypoglycemia, increased oxygen consumption, and weight loss. Critically ill neonates need to be nursed in a warm environment to protect them from the effects of cold stress. Due to the risk of overheating and even burns, the child’s core temperature should be measured and thermostat-regulated equipment employed (Nesher et al. 2001).

**Breathing System**

An appropriate anesthetic circuit for use in infants and children needs to be light, has minimal resistance and dead space, allows for warming and humidifying of inspired gases, and be adaptable to spontaneous, assisted, or controlled ventilation. The most widely used system is the circle system, which allows inspiration and expiration via a dual-limbed length of tubing. Connectors and tubes should also offer minimal flow resistance and dead space. Knowledge of the probable diameter and length of the endotracheal tube appropriate for any given infant is essential. The use of an endotracheal tube (ETT) of too large a diameter may result in tracheal wall damage, while excess length leads to endobronchial intubation. Cuffed ET tubes are now used as standard for managing the neonatal airway and ventilation of the lungs during major surgery (Spitzer and Sims 2016). Facemasks may be used for short surgeries but are limited in use by the neonatal propensity to develop apnea and the need for a tight seal on the face. Laryngeal mask airways (LMAs) are used widely in pediatric anesthesia but less in small infants due to their unreliability in maintaining an adequate and safe airway during surgery and due to their inherent inability to prevent aspiration of gastric contents (Bradley et al. 2013).
Laryngoscopes

Because of the anatomical differences in the infant airway, most anesthetists prefer to use a laryngoscope with a straight blade, lifting the epiglottis up directly to expose the vocal cords. Curved blades are also used, especially in bigger children. The video laryngoscope is increasingly employed in the management of pediatric airways, and it is anticipated that video laryngoscopy will become established as a key tool in achieving intubation efficiently and safely (Lingappan et al. 2015). There should be a “difficult airway trolley” available in every operating department (Calder et al. 2012).

Ventilators

Most children can be ventilated using standard adult ventilators provided the ventilator is of low internal compliance and equipped with pediatric breathing tubes. The ventilator should be capable of delivering small tidal volumes and rapid respiratory rates and have an adjustable inspiratory flow rate and inspiratory to expiratory ratio so that peak airway pressure is kept as low as possible. Pressure-controlled ventilation is frequently used to minimize the risk of pulmonary barotrauma. A suitable temperature-controlled humidifier should be incorporated in the inspiratory limb of the ventilator circuit. The ability to deliver air and oxygen mixtures through the ventilator or the anesthetic circuit should be available.

Anesthesia

Monitoring the cardiorespiratory and metabolic status of small children during anesthesia is usually difficult because the child is not physically accessible. Specific monitoring techniques that provide accurate measurements are discussed. General anesthesia is usually required for surgery; the airway must be secured and anesthesia managed with a combination of inhalational and intravenous agents. Regional anesthesia and opioids may be included to decrease the intraoperative anesthetic requirements and prevent pain in the postoperative period.

Monitoring

The clinical condition of the anesthetized infant can deteriorate more rapidly and with less warning than that of patients of an older age group. It follows that continuous and careful monitoring is required. The monitoring is employed and interpreted by a meticulous and experienced pediatric anesthetist. The incidence of perioperative pediatric cardiac arrest has been linked inversely to the training and experience of the anesthetist in a number of retrospective studies (Zgleszewski et al. 2016).

Cardiovascular Monitoring

1. Electrocardiograph (ECG) is used to detect bradycardia and arrhythmias. Primary arrhythmias are uncommon except in infants with congenital cardiac disease. Bradycardia secondary to hypoxia, hypercarbia, deep anesthesia, and surgical stimulation, e.g., strabismus surgery, is very common and must be responded to immediately as the newborn’s cardiac output is directly related to their heart rate. The neonate cannot compensate for a low cardiac output by increasing their stroke volume, so a sudden decrease in heart rate to 60 beats per minute or less is an indication to initiate chest compressions and resuscitation. The ECG is increasingly important in the context of the enhanced role of regional anesthesia in neonatal practice. Prolongation of the QRS complex is a sign of local anesthetic toxicity and may indicate intravascular injection.

2. Blood Pressure: Routine noninvasive monitoring of blood pressure during anesthesia and surgery is carried out with an automated device, which uses oscillometry. The appropriate cuff size must be used in order to obtain accurate measurements. Direct intra-arterial monitoring is the most accurate measurement of blood pressure and provides “beat to beat”
assessment. Its use is generally restricted to very ill children or those undergoing major surgery. All the proximal and distal arteries of the legs and arms may be used.

3. Central Venous Pressure: Central venous pressure is useful in infants and children who are undergoing major surgery with anticipated large fluid shifts, if significant blood loss and replacement are expected, and during surgery for correction of congenital cardiac disease. The right internal jugular vein is the easiest major vein to cannulate. Monitoring of left atrial pressure and pulmonary capillary wedge pressure is rarely indicated in children and infants.

**Respiratory Monitoring**

1. Pulse Oximetry: Hypoxia is the most common critical incident in pediatric anesthesia. As detection of cyanosis in infants and young children is difficult, the routine use of pulse oximetry is now mandatory. Thermal injury and pressure necrosis have been reported when sensor probes have been applied too tightly.

2. Capnography: The measurement of pCO2 in inspired and expired gases is also mandatory. Capnography is not only a monitor of the adequacy of ventilation but gives warning of disruption in gas supply, inadequate fresh gas supply, and esophageal intubation and is an indirect measure of cardiac output.

**Temperature**

Monitoring temperature is important in pediatrics because of the increased risk of both hypo- and hyperthermia. Common sites for perioperative temperature probes include the nasopharynx, esophagus, bladder, and rectum.

**Neuromuscular Blockade**

Monitoring neuromuscular blockade using a peripheral nerve stimulator is routine practice when non-depolarizing muscle relaxants have been administered.

**Induction and Maintenance of Anesthesia**

The induction agents employed in infants and children are identical to those used in adults. The choice of induction technique depends on the age, size, and physical status of the child. The relative risk of regurgitation and the personal preference of the anesthetist are also considerations. Intravenous induction of anesthesia is often preferable in a critically ill child, to allow slow titration of induction medications, and administration of vasoactive drugs such as atropine, and neuromuscular blockers. Inhalational induction may be preferred in a more stable patient, in an infant with airway concerns, or when securing intravenous access is anticipated to be difficult. The inhalational and intravenous anesthesia agents are summarized in Table 1.

Anesthesia is combined with neuromuscular blockade if muscle relaxation is necessary for tracheal intubation and for optimum operating conditions. Medications available for this purpose are divided into depolarizing and non-depolarizing agents, the difference being how they interact with neuromuscular junction. Depolarizing agents such as succinylcholine provide rapid onset, and short duration muscular blockade, but have many significant side effects. These side effects include hyperkalemia, bradycardia, and the triggering of malignant hyperpyrexia.

Non-depolarizing agents, e.g., atracurium, pancuronium, and rocuronium, produce reliable blockage within 2 min of administration to an infant. Their duration is 20–30 min, and they require reversal with neostigmine when surgery has finished.

Anesthesia is maintained throughout the surgical procedure. This may be done by continuous administration of inhalational agents via the breathing system (Table 1) or continuous infusion of intravenous medication (Table 1). Mechanical ventilation is used to support the infant in all but the shortest of surgeries, due to the rapidity with which the infant’s muscles of respiration tire. A reduction in tidal volume during spontaneous ventilation will cause alveolar collapse, atelectasis, and ventilation/perfusion mismatch. This issue is easily prevented.
by mechanically ventilating the infant lungs with pressure-controlled ventilation. Small increments of positive end expiratory pressure (PEEP) may be added to recruit collapsed lung segments. A mixture of oxygen and air is generally supplied through the breathing system and ventilator. The fraction of inspired oxygen is determined by the anesthetist, taking into account the age of the patient, potential cardiac and/or respiratory morbidities, and the proposed surgical procedure.

Reversal and extubation occur at the end of the surgery. Prior use of neuromuscular agonists requires reversal before safely proceeding to wake the patient. Neostigmine is combined with atropine or glycopyrrolate to offset the bradycardia produced by neostigmine. Residual neuromuscular block may be associated with delayed return of spontaneous respiration and extubation. Delayed emergence may occasionally be attributed to hypothermia, prolonged surgery, acidosis, hypocalcemia, and opiates.

Recovery

Following completion of surgery, the child is transported, fully monitored, to the recovery room. Intubated patients are nursed one to one by trained pediatric recovery nurses. Monitoring of vital signs, adequacy of protective airway reflexes, and correct positioning to prevent airway obstruction, regurgitation, and aspiration are key priorities. The recovery room nurse also monitors the wound site for bleeding, checks the security of the dressings, and administers prescribed pain relief. When infants and children are awake, they may be offered clear fluids or milk to drink. Comfort may be provided by breastfeeding in the recovery room. Exceptions to early feeding should be made following some dental or oral procedures, and when local anesthesia has been applied topically to the vocal cords. In addition to post-discharge instructions provided by the surgical team, parents or guardians need to be given verbal and written instructions regarding postoperative pain relief and what to do if problems arise.

Fluid Balance

Healthy children undergoing minor operations can reasonably be expected to tolerate oral fluids a short time after completion of surgery and do not require intraoperative intravenous fluids. The goal of intraoperative fluid management in those who are dehydrated preoperatively or those who are

| Inhalational agents | Pharmacological effects | Physiological effects |
|---------------------|-------------------------|-----------------------|
| Sevoflurane         | Sedation, anesthesia, rapid emergence | Respiratory depressant, bronchodilator, causes hypotension, bradycardia, decreases cardiac output, increases serum inorganic fluoride |
| Desflurane         | Sedation, anesthesia, rapid emergence | Respiratory depressant, causes hypotension, bradycardia, decreases cardiac output |
| Isoflurane         | Sedation, anesthesia | Respiratory depressant, causes hypotension, bradycardia, decreases cardiac output |
| Halothane          | Sedation, anesthesia | Respiratory depressant, bronchodilator, causes hypotension, bradycardia, arrhythmias, decreases cardiac output |

| Intravenous agents | Pharmacological effects | Physiological effects |
|--------------------|-------------------------|-----------------------|
| Fentanyl           | Analgesia, sedation, anesthesia | Respiratory depressant, bradycardia |
| Propofol           | Sedation, anesthesia | Respiratory depressant, causes hypotension |
| Ketamine           | Analgesia, sedation, anesthesia | Respiratory stimulant, increases airway secretions, causes tachycardia |
| Remifentanil       | Ultrashort acting analgesia, sedation, anesthesia | Respiratory depressant, causes bradycardia |
undergoing major surgery is to sustain homeostasis by providing the appropriate amount of parenteral fluid to maintain adequate intravascular volume, cardiac output, and ultimately, oxygen delivery to tissues at a time when normal physiologic functions are altered by surgical stress and anesthetic agents. The composition of the fluid will vary according to the maturity of the child and the preoperative electrolyte and glucose levels. All infants should have their blood sugar checked following induction of anesthesia and a bolus of 2 ml/kg 50% dextrose administered if the blood sugar is less than 2 mmol/L (R). Surgical stress, opiates, and anesthetic medications stimulate increased release of antidiuretic hormone (ADH), which causes the retention of free water at the renal glomerulus. This may lead to the development of hyponatremia if hypotonic solutions such as 0.45% normal saline are used as intraoperative maintenance fluid. Normal saline 0.9% or lactated Ringer’s solution is now used as standard, with the addition of 5–10% dextrose as necessary (Choong et al. 2006).

Postoperative Pain Management

Pain Assessment

To optimize pain management in the surgical patient, treatment is titrated to their degree of discomfort. The American Academy of Pediatrics has issued the following statement on pain treatment: “To treat pain adequately, ongoing assessment of the presence and severity of the pain and the child’s response to the treatment is essential” (Chou et al. 2016). Self-report remains the “gold standard” for pain assessment. However, as newborns are nonverbal, they require a different method of assessing their pain, usually focusing on posture, cry, and consolability. As they are less able to communicate pain, they may be vulnerable to distress, anxiety, and poor pain management. Pain assessment can be incorporated into routine monitoring as a vital signs measurement so that pain assessment becomes standard practice. A range of validated pain assessment tools for nonverbal children is available (American Academy of Pediatrics Committee on Psychosocial Aspects of Child and Family Health and Task Force on Pain in Infants, Children, and Adolescents 2001). Postoperative pain experienced by the infant is assessed using a variety of validated pain assessment tools, including the FLACC, and the COMFORT-behavior scale (Crellin et al. 2015; Boerlage et al. 2015).

Early recognition is important as it facilitates prompt and adequate management. It may also prevent long-term sequelae (Taddio and Katz 2005). Stress hormone levels have been studied in premature neonates who underwent surgery without perioperative analgesia; levels of cortisol, aldosterone, and other corticosteroids were markedly increased indicating significant stress (Anand et al. 1990; Bouwmeester et al. 2001). In the recovery room and intensive care unit (ICU) setting, stress and agitation resulting from pain and anxiety can lead children to accidentally remove medical devices endangering the child’s safety.

Analgesia

After assessment of pain, the treatment of pain is the next step, and standard treatment is a balanced, multimodal combination, which frequently includes opioids. Treatment with opioids means balancing between effective dosages and preventing oversedation, seeing that opioids have sedative properties as well. Oversedation may lead to longer duration of mechanical ventilation and ICU admission. Inadequate dosages may cause a wide range of endocrine, metabolic, and inflammatory reactions leading to increased sympathetic activity. Besides inadequate pain relief, this may result in prolonged recovery times after procedures, complications, and longer admission duration. Finally, inadequately treated postoperative pain poses a risk for the development of chronic pain.

Current literature lacks systematic data on acute perioperative pain management in neonates and mainly focuses only on procedural pain management. The usual stress response to surgery through hormone release and metabolic modulation is altered in the newborn, which has
implications for cardiovascular monitoring, support, and sedation and analgesia. Intravenous opioids such as morphine or fentanyl as either intermittent bolus or continuous infusion remain the most common modality for the treatment of perioperative pain. Intravenous infusions are administered using the nurse-controlled analgesia system, where small doses of opiate are given following pain assessment and sedation assessment (Czarnecki et al. 2014). Patient-controlled analgesia infusions may be used in older children. Continuous infusions are used only in a high dependency or intensive care environment. Paracetamol has a promising role in decreasing opioid requirement (Padda et al. 1997). Among infants undergoing major surgery, postoperative use of intermittent intravenous paracetamol compared with tramadol resulted in a better recovery profile (Uyasal et al. 2011). Routine use of ketorolac or other nonsteroidal anti-inflammatory drugs (NSAIDs) is not usually recommended in the newborn, but NSAIDs are frequently used to augment analgesia in older children with normal renal function.

The majority of preterm neonates are capable of glucuronidating morphine, but birth weight and gestational and postnatal age influence the glucuronidation capability. Term neonates, infants, and children are able to produce morphine glucuronides. Pharmacokinetic studies have demonstrated that drug half-life and clearance were found to be related to age, but volume of distribution was unchanged. Half-life was estimated to be 9.0 +/- 3.4 h in preterm neonates, 6.5 +/- 2.8 h in term neonates aged 0–57 days, and 2.0 +/- 1.8 h for infants and children aged 11 days to 15 years (Kearns et al. 2003). Longer half-lives mean smaller doses per kilogram are necessary to produce analgesic effects. The rate of morphine infusions need to be reduced in the neonatal and newborn period, particularly if the neonate is jaundiced. There is a large variability associated with infusion rates, which means that infusion rates may need to be adjusted, depending on feedback from pain scores, adjuvant medications, and adverse effects. If the child is feeding, oral morphine may be used instead of intravenous. Combining opiate administration with regular sedation and pain assessment and apnea and oxygen saturation monitoring is recommended.

**Regional Anesthesia**

With the advent of ultrasound and improvements in equipment, the applications of regional anesthesia in the pediatric population have continued to expand. Although frequently used for postoperative analgesia or as a means of avoiding general anesthesia in patients with comorbid conditions, the adjunctive use of regional anesthesia during general anesthesia may effectively decrease the intraoperative requirements for intravenous and volatile agents, thereby providing a more rapid awakening and earlier tracheal extubation and enhanced pain scores (Hamill et al. 2016). More recently, the limitation of the requirements for volatile and other anesthetic agents may be desirable, given concerns regarding the potential impact of these agents on neurocognitive outcome in neonates and infants (Johnson et al. 2008). Several authors have demonstrated the potential utility of combining a neuraxial technique (spinal or epidural anesthesia) with general anesthesia in neonates and infants undergoing intraabdominal procedures (Goeller et al. 2014; Adler et al. 2015).

Regional anesthesia techniques are often combined with light general anesthesia in infants and children. Regional blocks provide prolonged and predictable postoperative pain relief, using local anesthetics. These local anesthesia-based blocks avoid the side effects associated with opiates (e.g., respiratory depression, nausea, vomiting, ileus) and reduce the hormonal stress response to surgery (Abu Elvazed et al. 2016). The regional block usually produces a mixed sensory and motor blockade and may be suitable for use as the sole anesthesia mode, e.g., for inguinal herniotomy (Mueller et al. 2016). There is a greater potential for local anesthetic toxicity in infants as reduced protein binding with alpha (Smithers et al. 2016) acid-glycoprotein means a greater free fraction of the active drug in the bloodstream (Gunter 2002).
Monitoring and secure intravenous access must be in place before performing the local anesthetic block. The skin requires cleaning with 0.5% alcohol containing solution before commencing. Higher concentrations of alcohol in the cleaning solution may result in burns to the fragile neonatal skin or absorption of alcohol into the bloodstream (Sathiyamurthy et al. 2016). Nerves and nerve plexuses are frequently visualized using ultrasound, before specialized needles inject the local anesthetic, or introduce a catheter to administer medication over a longer period of time. The catheter is secured in position on the skin with adhesive tape. The other end of the catheter is attached to a filter to prevent entry of glass particles or bacteria. Dilute concentrations of levobupivacaine are infused continuously over a period of hours to days, depending on individual patient requirements. The rate of infusion of levobupivacaine should be reduced over a period of days to prevent accumulation and a rise in plasma levels (Lerman et al. 2003). Adjunct medications such as clonidine may be added to increase the effectiveness and duration of the regional block (Lak et al. 2012).

Subarachnoid anesthesia is utilized in awake babies for short surgeries on the lower abdomen or perineum, e.g., circumcision and orchidopexy, especially in ex-premature infants (Jones et al. 2015). Avoiding general anesthesia in ex-premature infants is preferable due to their higher incidence of chronic lung disease, oxygen dependency, and apnea. The risk of postoperative apnea with regional anesthesia is decreased but not eliminated (Davidson et al. 2015b).

**Special Considerations in the Premature Infant**

Congenital defects occur more commonly in preterm infants, so that surgery is frequently required. Organs and enzyme systems are immature, and meticulous attention to detail during anesthetic and surgical management is imperative if survival rates are to be high. The large body surface area and lack of subcutaneous fat make maintenance of body temperature very difficult, so that a high neutral thermal environment is essential. Respiratory fatigue occurs very easily and may be exacerbated by residual lung damage following mechanical ventilation, persistent fetal circulation, and oxygen dependency. The response to exogenous vitamin K is less satisfactory than in term infants, and there is an increased risk of bleeding. In addition, anemia is common because of reduced erythropoiesis, a short erythrocyte life span and iatrogenic causes such as frequent blood sampling. Fluid and electrolyte management can be difficult—insensitive losses are high and hypoglycemia and hypocalcemia occur easily, while renal function and the ability of the cardiovascular system to tolerate fluid loads are reduced.

**Anesthesia and the Developing Brain**

Studies conducted over the last two decades on animal models have suggested that inhalational agents, such as isoflurane and sevoflurane, may have a detrimental effect on later development of the infant brain (Johnson et al. 2008). Population-based longitudinal research has not reinforced this hypothesis (Vutskits 2012; Davidson et al. 2016). Concerns exist around the neurological and developmental effects of additional medications such as midazolam, ketamine, and morphine. These concerns must be interpreted cautiously in the light of the requirement for lifesaving surgeries in the newborn period. Parents may ask for further information on the matter and should be provided with balanced, informed advice.

**Anesthesia for Specific Surgical Conditions in the Newborn**

**Esophageal Atresia**

When the diagnosis of esophageal atresia is made (with or without a fistula to the trachea), the blind upper pouch should be continuously aspirated using a Replogle or similar tube. In general, the
operation may be safely delayed pending further investigation – echocardiography is the most important – as there are frequently associated cardiac anomalies. Aspiration pneumonia should be treated, and surgery may then proceed when the infant is in good condition. Pre-thoracotomy fiber-optic bronchoscopy is ideal, as it assists in identifying the location of a fistula, if there is one, or indeed multiple fistulae (Atzori et al. 2006). Anesthesia is similar to that for other neonatal procedures, but special care must be taken to maintain spontaneous respiration until the endotracheal tip is placed below the level of any fistula. This prevents gastric distension, which may induce bradycardia. The fiberoptic is useful in accurately positioning the ETT tip above the carina, but below any anomalous openings to the trachea. Surgical retraction during operative mobilization of the esophagus may compromise either respiratory or cardiac function, so that accurate monitoring is essential. Extubation may be planned shortly after completion of surgery if there has been no contamination of the mediastinum or if the anastomosis is not especially tight. A pleural drain is usually left in place until a contrast study has been performed a number of days later (Kinottenbelt and Skinner 2010). Regional anesthesia using an epidural or paravertebral catheter may assist in early weaning from mechanical ventilation and extubation (Bosenberg et al. 1992).

**Intestinal Obstruction**

The various forms of neonatal intestinal obstruction account for approximately 35% of all surgical procedures in the newborn. The major anesthetic problems are those of fluid and electrolyte imbalance (which must be corrected preoperatively), abdominal distension (causing respiratory impairment by splinting diaphragmatic movement), and the risk of regurgitation and aspiration of gastric contents. Following four-quadrant decompression of the stomach, a modified rapid sequence incorporating a small dose of an intravenous induction agent and a muscle relaxant is performed. The lungs may be ventilated using low pressures (<10cmH2O) until the trachea is intubated. Many pediatric anesthetists do not use cricoid pressure in this context, as it may make intubation more difficult, leading to a need to mask ventilate at higher pressures, for longer, than if the ETT is placed in the trachea without undue delay. Anesthesia is then maintained in the usual fashion. Placement of paravertebral or rectus sheath blocks may facilitate a reduction in opiate needed for postoperative pain relief (Bosenberg 1998).
**Exomphalos and Gastrochisis**

Anesthetic concerns with large abdominal wall defects include heat and fluid loss from the exposed bowel, and the primary closure of the defect, which may impair respiration as the diaphragm, is pushed cephalad. Special care must be taken to keep heat loss to a minimum. Fluid requirements are much greater than in normal neonates, and there is an increased need for electrolyte replacement. Monitoring the changes in peak inspiratory pressures and central venous pressure during primary closure can be useful in advising the surgeon whether primary closure is feasible. A proportion of infants, especially after repair of gastrochisis, require postoperative mechanical ventilation. Large defects may be managed in a staged manner, by placing the external gut into a silo, which hangs above the patient’s abdomen. Gravity assists in the gradual return of the gut to the abdomen. Establishing enteral feed may be slow due to ongoing gut dysmotility, which may persist for a considerable length of time after closure.

**Herniotomy for the ex-Premature Infant**

Improved survival rates in premature and low birth-weight infants have led to increased numbers of them presenting for inguinal hernia repair. While the surgical procedure may be relatively straightforward, these babies represent a considerable challenge for the anesthetist. They must be managed by anesthetists and surgeons with adequate training and experience, in hospitals with appropriate facilities and personnel. Ex-premature infants up to 56 weeks post-conceptual age are at risk of life-threatening apnea after anesthesia and surgery and should have apnea and oxygen saturation monitoring for at least 12 h postoperatively. They are not suitable for day-case surgery. Regional anesthesia techniques such as spinal and caudal anesthesia may be used to augment or replace general anesthesia, but they do not completely remove the risk of postoperative apnea (Davidson et al. 2015b).

**Postoperative Admission to Surgical NICU/PICU**

As each year passes, there are advances in the perioperative management of critically ill children who require surgery. Increased operative intervention in preterm and low birth-weight infants has increased the demand for postoperative high dependency and intensive care. Alternative respiratory and cardiovascular support in the form of extracorporeal life support, inhaled nitric oxide, and high frequency oscillation have expanded the potential to support these severely compromised infants and children.

Differences in physiology and pharmacology in the preterm and term neonate have a direct impact on their capacity to adapt to surgical intervention and to recover in the postoperative period. Pulmonary vascular resistance (PVR) is elevated in the first 10 days of life, which increases the potential to develop right to left shunt through the ductus arteriosus or a patent foramen ovale. This response occurs particularly in response to hypoxia or metabolic acidosis.

There are distinct differences in the coagulation system as plasma levels and activities are low at the time of birth and then increase in the first few months of life. Total body water is higher in the newborn, especially the premature infant, and glomerular filtration rate (GFR) is low in the first few days of life. Thermoregulation mechanisms are poorly developed and require support. The newborn increases cardiac output by increasing heart rate because stroke volume is relatively fixed due to the thin-walled myocardium at birth. The usual stress response to surgery through hormone release and metabolic modulation is altered in the newborn, which has implications for cardiovascular monitoring, support, and sedation and analgesia.

The surgical pediatric patient is best cared for postoperatively in an environment where healthcare staff are skilled and trained to manage
the challenges presented by neonatal and pediatric physiology in the perioperative period.

**Conclusion and Future Directions**

Skilled anesthetic teams with specific knowledge of age-dependent physiology, anatomy, homeostasis, and pharmacological clearance are essential to ensure successful outcome of procedures in pediatric patients. The choice of peri- and postoperative anesthesia and analgesia usually depends on age, size, and physical status of the patient. Research on clinical pharmacology and clinical outcomes in children and infants helped to develop new anesthesia modalities and rapidly metabolizing medications during the last decades, facilitating operations in even preterm and very low weight infants. Further technical and pharmaceutical improvements will allow operations and interventional procedures in the future, which are currently not feasible due to technical or physiological limits.

**Cross-References**

- Congenital Diaphragmatic Hernia
- Esophageal Atresia
- Gastrochisis
- Omphalocele
- Respiratory Physiology
- Specific Risks for the Preterm Infant

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