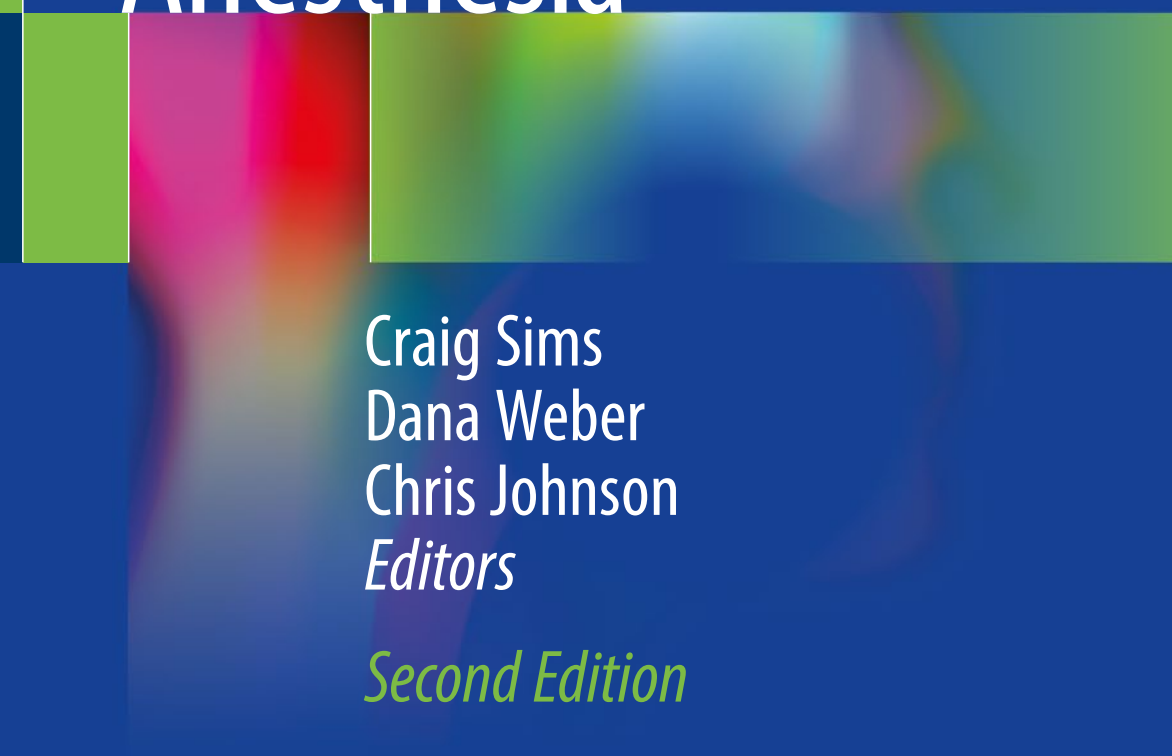
A Guide to Pediatric Anesthesia



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Editors

Second Edition

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Ten Current Issues in Pediatric Anesthesia and Where to Find Them

1. **Emergence Delirium**
   Young children sometimes wake from anesthesia crying and unhappy. There are many reasons for this, although sevoflurane dysphoria is commonly blamed. See Chap. 2.
2. **The Uncooperative Child**
   Many children become anxious during induction of anesthesia, and their anxiety may cause them to become uncooperative. There are many ways to reduce children's anxiety. See Chap. 3.
3. **Videolaryngoscopes**
   Many types of videolaryngoscopes are now available in sizes suitable for children. Their use is being informed by new studies, including the PediRegistry study of difficult airway management in children. See Chap. 4.
4. **Reducing Perioperative Respiratory Complications**
   Respiratory complications are the leading cause of morbidity in pediatric anesthesia, and there has been a surge in studies looking at the risk factors for them and how to modify the risk. See Chap. 11.
5. **Shorter Fasting Times for Clear Fluids**
   It is now realized clear fluids leave the stomach quickly, and allowing them up to 1 h or less before anesthesia has become common. See Chap. 5.
6. **Neurotoxicity of Anesthetic Agents**
   There is laboratory evidence that many anesthetic agents, including volatiles, affect the developing brain of neonates. See Chap. 2.
7. **The Airway**
   Many anesthetists do not like caring for children because of difficulties managing the pediatric airway. See Chap. 4 for many practical tips.
8. **RSI and Cricoid Pressure**
   The adult technique of rapid sequence induction is dangerous if directly applied to young children. There are calls to abandon the technique and cricoid pressure altogether. See Chap. 1.

9. **Reducing Pain and Distress During Procedures**
   Holding a child down to perform a procedure is becoming less and less acceptable. Many techniques and drugs are now used to make procedures more comfortable and less distressing for the child, parents, and staff. See Chap. 27.
10. **Hypotonic IV Fluids for Children**
    Hypotonic, dextrose-containing solutions have been traditionally used for IV fluids in children. The risk of hyponatremia from these fluids is so high that salt-rich fluids are recommended nowadays. See Chap. 5.

Useful Formulae in Pediatric Anesthesia

Weight

Body weight for infants = (age in months/2) + 4 kg (APLS)

Body weight for children 1–10 years = (age + 4) × 2 kg (UK Resuscitation Council)

Body weight for children older than 10 years = age × 3.3 kg (large variation in normal adolescent weight however) (APLS)

Blood Pressure

Expected systolic blood pressure for children older than 1 year = 80 + (age in years × 2) mmHg.

Fluids

Maintenance fluid rate in mL/h: (4:2:1 rule)

4 mL/kg first 10 kg weight + 2 mL/kg next 10 kg weight + 1 mL/kg for rest of weight (e.g., for a 19 kg child: (10 × 4) + (9 × 2) = 58 mL/h).

Minimum 10% dextrose infusion for neonate day one (4 mg/kg/min) in mL/h = 2.5 × weight in kg (e.g., 3 kg neonate needs at least 7.5 mL/h 10% dextrose)

ETT Size

Uncuffed ETT size for a child over 2 years: Age/4 + 4 = ETT size (inside diameter, mm) (modified Cole formula)

Cuffed ETT size for a child over 2 years: Age/4 + 3.5 = ETT size (ID, mm) (Motoyama formula)

ETT Depth

Position at vocal cords = ID size of ETT (e.g., 4.5 ETT should be 4.5 cm at vocal cords)

Oral ETT length (at lips in cm) = age/2 + 12

Nasal ETT length (at nostril in cm) = age/2 + 15 (and diameter of correct-size nasal ETT same as oral ETT for children)

Neonates: Oral ETT length (at lips in cm) = weight(kg) + 6

Neonates: Nasal ETT length (at lips in cm) = (weight(kg) × 1.5) + 7

Suction Catheter for ETT

Size of suction catheter for ETT (in French Gauge) = 2 × size of ETT (ID)

Urinary Catheter

Urinary catheter size (FG) = 2 × size of ETT (ID)

CVC

Depth for central line placement in right IJV = 10% of height (e.g., 8 cm in an 80 cm long child)

Contents

An Overview of Pediatric Anesthesia

1

Craig Sims and Tanya Farrell

'Pediatric' or 'child' applies to someone aged less than 18 years. The American Academy of Pediatrics defines 'pediatric' as less than 21 years, while some centers use 16 years. An infant is a child aged between 1 and 12 months. The term 'neonate' applies to the first 4 weeks of life. Children make up a quarter of the population in most Western countries and a higher proportion in developing countries. Pediatric anesthesia is very common—5.5% of children have an anesthetic each year, and about half are preschool age. The commonest indication for anesthesia is ENT surgery, but children often need anesthesia for procedures such as scans and dental treatment that an adult would tolerate without anesthesia.

Pediatric anesthetists have several special attributes described by the late Dr. Kester Brown: they have expertise in caring for neonates and infants during anesthesia and surgery; they understand the anesthetic implications of congenital disease and disability; and they have knowledge of the psychological, physiological, pharmacological and anatomical differences with age.

1.1 Safety of Pediatric Anesthesia

Anesthesia for children has become very safe. Parents can be reassured that the profession has taken many steps over the years to reduce risk. These steps include analysis of past incidents (anesthesia was the first specialty to perform incident monitoring), embracing new monitoring technologies, improved specialist training and taking

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advantage of safer drugs. The overall mortality from anesthesia alone in a healthy, older child is approximately 1 in 50,000 to 1 in 100,000. Tertiary pediatric centers report overall mortality at 24 h after anesthesia and surgery at about 13 per 10,000 anesthetics. Anesthesia-related mortality in this group is reported as 0.7 per 10,000.

Morbidity is common with anesthesia in children. More than half of critical incidents are respiratory incidents and are mostly airway related such as laryngospasm, bronchospasm, hypoxia, and hypoventilation. The risk increases with decreasing age, because of smaller airway diameter and a predisposition to develop apnea and airway obstruction from airway irritation (Fig. 1.1). Infants and young children also desaturate rapidly. Children 3 years and younger have a higher risk than older children. Infants are particularly at risk, with critical incidents four times more likely compared to older children. Surveys show critical incidents (again most commonly respiratory) occurring in 3–5% of infants. Risk is also increased by underlying pathology including congenital disease, the urgency of the procedure, and the hospital setting (Table 1.1).

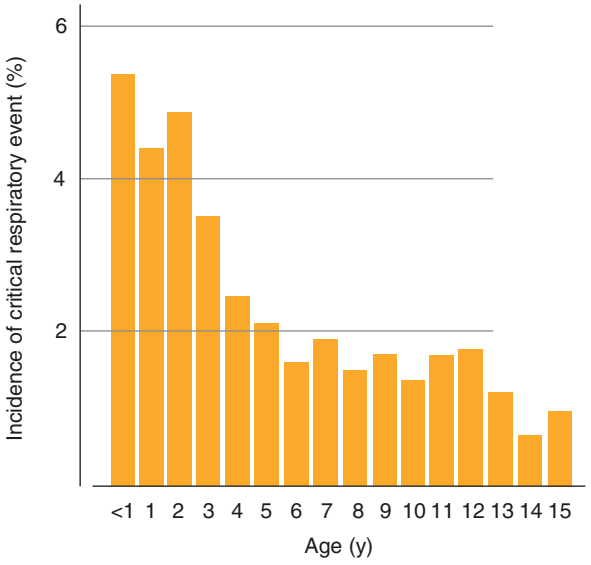

Fig. 1.1 The incidence of critical respiratory events (those requiring immediate intervention and that led (or could have led) to major disability or death) during anesthesia in children of different age groups. Based on data from APRICOT study, Lancet Respir Med 2017; 5:412–25

Table 1.1 Patient, surgical and anesthetist factors that may increase the risk of anesthesia in children

Factors increasing risk of morbidity and mortality			
	High risk	Medium risk	Low risk
Age	Neonates, infants	1–3 years	>3 years
ASA status	3–5	2 (includes recent URTI)	1
Surgery	Cardiothoracic, neurosurgery, scoliosis surgery	Airway and dental surgery	Peripheral, minor surgery
Emergency surgery	Increases risk		
Experience of the anaesthetist	Increased risk with small case load of children of similar age to patient		

Keypoint
Most critical incidents are respiratory and airway related. Proficiency in airway management is the cornerstone of safe pediatric anesthesia practice.

The risk of morbidity is lower if the anesthetist is experienced and has a large pediatric case load (Table 1.2). Although there are no formal requirements for anesthetists caring for children, it is generally agreed that practitioners anesthetizing children aged 3 years and less should regularly anesthetize this age group, and anesthetists caring for children aged less than 1 year should regularly anesthetize infants. Neonatal anesthesia should be performed by those who have a fellowship in pediatric anesthesia.

Keypoint
Children aged less than 3 years, and especially aged less than 1 year are at a higher risk from anesthesia than older children.

1.2 Organization of Services

If you are anesthetizing a child in a non-pediatric hospital it is important to make sure it is safe to do so. Several factors determine if a child can be safely cared for at a particular facility. Broadly, there are factors relating to the patient and the type of surgery planned (Table 1.3), and factors relating to the hospital such as the level of staffing, equipment and facilities (Table 1.4). An older child undergoing day stay surgery has different health facility requirements compared with an infant with coexisting medical problems requiring overnight admission after surgery.

The Australian and New Zealand College (ANZCA) guideline PS29 (2019) and the United Kingdom College guidelines (2018) discuss staffing for the care of children in non-pediatric hospitals. These policies particularly apply to infants and neonates because of their greater risk. Anesthetists looking after children should have

Table 1.2 The pediatric caseload of the anesthetist affects the rate of complications

Number of anesthetics given per year	Complications
1–100 children	7/1000
100–200 children	2.8/1000
More than 200 children	1.3/1000

Based on Auroy and Ecoffey, Anesth Analg 1997

Table 1.3 Patient factors to consider in determining level of staff and facilities needed to safely care for children

Patient factor
Age of child, esp. if <12 months
Type of surgery
ASA status/General health of the child
Overnight admission
Emergency procedure

Table 1.4 Summary of requirements to safely anesthetize children (based on ANZCA PS29 and RCOA guidelines)

Organization of services	
Staff	Experience and case load to maintain competency in relevant ages and case mix of: anesthetist assistant recovery ward nurses
Equipment	In addition to equipment and facilities needed to safely anesthetize adult patients: Size-appropriate breathing circuit, airway equipment and monitoring Anesthetic machine and ventilator suitable for ages of children being anesthetized Suitable fluid administration devices (may include burette) Resuscitation drugs and equipment (including defibrillator and pads suitable for children) Ability to control temperature of OR Beds and cots suitable to contain child and prevent falls
Facilities	Ability for parents to accompany child to theater and be present in recovery Separated areas from adults-wards, OR, PACU Accommodation for parents if overnight admission Links to tertiary pediatric centers for advice and transfer of patients if postoperative problems occur Pharmacy knowledgeable in pediatric doses Acute pain service, HDU/ICU if relevant to case-mix
Governance	Local hospital group with oversight of scope of practice and suitability of staff involved Local protocols and regulations for selection of patients and aspects of their care Gradual implementation of any changes and ongoing quality assurance

training in the relevant age group, and should not anesthetize children if they are not comfortable to do so due to either lack of recent experience or inadequate case load. Having a second anesthetist to help should be considered for infants and children ASA3 status or higher. The anesthetic assistant and perioperative staff should have training in the care of children. Not all children can be cared for in tertiary children's hospitals, so most countries have networks in which information, guidelines and training are exchanged between central specialist and peripheral general hospitals. As part of this, there is generally a lead consultant to oversee provision of pediatric anesthetic services in general hospitals.

1.3 Preoperative Assessment

As in adults, assessment of children before anesthesia includes a history and examination, aiming to assess previous anesthetic problems and the severity of co-existing diseases. It is also an opportunity to establish rapport with the child and parents, assess the child's behavior and reassure the parents with your manner and professionalism. Most children are healthy and active, although there is always the possibility of an unrecognized abnormality or syndrome. Some children have dysmorphic

Table 1.5 Facial dysmorphic features that may indicate a congenital syndrome

Dysmorphic feature
Widely spaced eyes (hypertelorism)
Beaked or other nose abnormality
Low hairline on forehead
Low slung or malformed ears
Craniosynostosis
Microcephaly

features suggesting an underlying syndrome (Table 1.5). If a child has one congenital malformation it is more likely that there will be another. Common conditions to specifically ask about include preterm delivery, recent upper respiratory tract infection, obstructive sleep disorder, developmental concerns and bleeding disorders.

Examination needs to take into consideration the modesty of the child, particularly with school-aged children and adolescents. Examination may occasionally reveal a previously unrecognized heart murmur (see Chap. 20, Sect. 20.3.1), signs of asthma or URTI (see Chap. 11, Sects. 11.2 and 11.3), or loose teeth. The most important aspect of airway assessment is mandibular size (see Chap. 4, Sect. 4.2). Investigations such as hemoglobin, CXR and urinalysis are not routinely performed in healthy children undergoing minor surgery. Hemoglobin is not tested because significant anemia is rare in children and mild anemia does not affect the decision to proceed with anesthesia. Some centers use the Sickledex test in patients at risk of sickle cell anemia.

Pre-anesthetic clinics are not always used for healthy children. Clinics are unlikely to reveal significant medical problems, are inconvenient for the family, and do not influence the most likely reason for cancellation of surgery, which is a viral illness just before surgery. Assessment is commonly by a telephone interview before admission and review by the anesthetist on the day of surgery. However, this approach reduces the time available for informed consent for anesthesia.

1.3.1 Loose Teeth

Children lose deciduous teeth from 5 years of age. A very loose tooth may dislodge and be aspirated during anesthesia and is sometimes removed (with parental permission) after induction. The tooth needs to be very loose before trying this, and usually has no visible root (it is resorbed). If the tooth is not very loose it can be surprisingly difficult and unpleasant to remove, and the gum may bleed. A tooth that is not on the verge of falling out can be watched carefully during airway manipulation and checked at the end of the case to make sure it has not been dislodged.

1.4 Consent

The legal age for consent is usually between 16 and 18 years, depending on the jurisdiction. Consent for a child is therefore obtained from the parent or legal guardian. However, there is growing recognition of the rights of younger people. It is

usual to at least obtain the *assent* (permission) to proceed with anesthesia and surgery in older school aged children, even though they may not be able to give legal consent. Further complicating this area is the increasing recognition by courts of children's abilities to make their own decisions about treatment. Some health areas have policies in place that allow children as young as 14 years to consent to treatment. However, these policies are not a replacement for laws and it is still usual to obtain parental consent when the child is younger than 16–18 years.

Young people at 16 years of age have the legal ability in most countries to make decisions about their own care, and they must be presumed to be competent to make such decisions unless it can be shown otherwise. A valid refusal of surgery by a child who is competent should usually be respected. Legal advice should be sought if the procedure is felt to be in their best interests despite their refusal, especially if the refusal of treatment could result in death or serious harm.

Children younger than 16 years can consent if they demonstrate Gillick-competency. The Gillick competency test establishes the legal principles to decide a child's ability to make health care decisions. The Gillick case considered consent for prescription of the oral contraceptive to a 16 year old girl, and whether or not a parent's permission was required. The findings of this case have been used to determine consent issues in general. For a child to be deemed competent to decide about their healthcare they must have the ability to understand the factual, moral and emotional consequences of their decision. Competence is not reliant on a fixed age, and competence for one situation does not imply competence for all. The child's age is still considered—the younger the child, the less likely the child can understand the implications of their decision and be considered Gillick-competent.

Keypoint
Although some adolescents are mature enough to consent to anesthesia and surgery, it is wise to obtain the parent's consent in most perioperative situations.

In certain life-threatening circumstances, society allows the wishes of a child or the parents to be overridden. This is firstly because a child is unlikely to competently rationalize life and death decisions, especially when they are so easily influenced by authority figures. Secondly, society is unwilling to allow any person to make life and death decisions for someone else, including one's own child. Hence laws make it possible in an emergency to override the wishes of a person aged less than 18 years. The exact legal mechanisms for this vary between jurisdictions, and the involvement of the hospital's medical administrator is usual. These emergency provisions only apply if the procedure is critical and life-saving—a blood transfusion in severe hypovolemic shock may be permitted, but not force feeding an anorexic child who is not critically ill. As a practical matter, it is best to negotiate a compromise before proceeding to the courts for permission. Consent to treatment is

more likely to be given when the child's and parent's wishes and concerns are considered.

Fortunately for pediatric anesthetists, consent issues are usually resolved by the time a child presents for surgery. However, consent issues for anesthetists may arise at the time of induction—is it reasonable to proceed when the child withdraws their hand from the IV cannula, or pushes away the facemask? Children older than about 8–10 years who are developmentally normal probably should not be restrained. Fear is often a large part of the child's refusal, and this can be allayed with discussion, parental involvement, involvement of play therapists in children having many anesthetics, and pharmacological premedication if agreed. Younger children are probably not able to understand the importance of their treatment and it may be reasonable to restrain the child and proceed if other strategies fail. Supervising the parent to help restrain a younger child can help parents to accept this course of action. Although restraining a 2 or 3 year old child is straightforward and not uncommon, restraining a young school-aged child is unpleasant for the child, parent and staff, and should be avoided as much as possible by paying attention to the behavioral management aspects of the child. The age beyond which restraint is not reasonable depends on many surgical, patient, practical, societal and reality factors. A great deal of judgement is involved from case to case. Sometimes during induction, a decision must be made quickly to take one path or another before the child's cooperation deteriorates further.

1.4.1 Blood Transfusion in a Jehovah's Witness Child

A blood transfusion critical to survival of the child (usually as determined by more than one doctor) can be given legally without the consent of the parents. In fact, doctors have a legal obligation not to allow a child to die by withholding treatment. In the elective situation, children older than 14–16 years may be able to refuse a transfusion themselves, but the legality of this would need to be determined before proceeding with surgery.

When a child's parents refuse permission for a blood transfusion, they are usually only trying to do what is best for their child. Indeed, anesthetists should be trying to minimize blood transfusion in every child-there are many risks of transfusion, and children have a long life ahead for these risks to become apparent.

Confrontation over this issue can be minimized by listening to the parents, telling them all the things that you will do to try and avoid blood products, and telling them that you are legally obliged not to let their child die. There is no need to force parents to explicitly agree with this plan and thus refute their own beliefs. There is also little to be gained from a confrontation with parents who are under stress about their child's anesthesia and surgery when the likelihood of transfusion is extremely low. As medical providers, the legal obligation is straightforward and most parents are aware of this. Ongoing argument serves only to put parents and sometimes the child under further stress.

1.5 Intravenous Access

A short 24G or 22G cannula in the dorsum of the hand is the commonest method of securing IV access in children. The finer 24G cannula may be more difficult to insert, but it is less likely to be felt by the child. The lack of feeling may allow a second attempt to insert the IV if the first attempt failed. The 24G cannula is the usual size for neonates and small infants, but in older children it tends to kink when the child moves post op.

1.5.1 Positioning of the Awake Child for IV Access

Tapes and equipment should be prepared before inserting the cannula to facilitate quick fixation, as the child may move and dislodge the cannula. If the child lies on the bed, blankets can be placed to hide their hand and restrict movement. Younger children can also sit across the parent's lap, with the child's arm brought under the parent's arm (Fig. 1.2). This position hides the hand from the view of the child and parent and helps to keep the hand still by placing the child at a mechanical disadvantage.

1.5.2 Assistance

A good assistant is vital to maximize the chances of successful venipuncture. Just using a tourniquet for a young child is unlikely to work. It is important that the assistant holds the child's hand and arm correctly, aiming to distend the veins and prevent withdrawal of the child's hand. The assistant needs to hold the forearm tight enough to act as a tourniquet, but not so tight that the hand turns white from arterial compression. The assistant also gently retracts the child's skin up the limb, which helps to fix the vein. The assistant's other hand can be placed across the child's elbow joint, which helps prevent sudden limb movement if the child feels the needle (Fig. 1.3). The anesthetist can stabilize their own arm by resting their elbow on something to compensate for sudden movements by the child.

1.5.3 Tips for Venipuncture

If no veins are visible, using the index finger to very gently feel the dorsum of the hand may detect the faint bulge of an underlying vein. It is best to try this before using antiseptic, as this makes the skin very slightly sticky and much harder to feel subtle variations. Sometimes a faint blue tinge can be seen as an indication of a vein. The child's feet can also be used for induction. IV insertion in the foot, however, is more painful than in the hand. An IV can be left in the foot for post op use depending on the child's age, length of stay and postoperative ambulation.

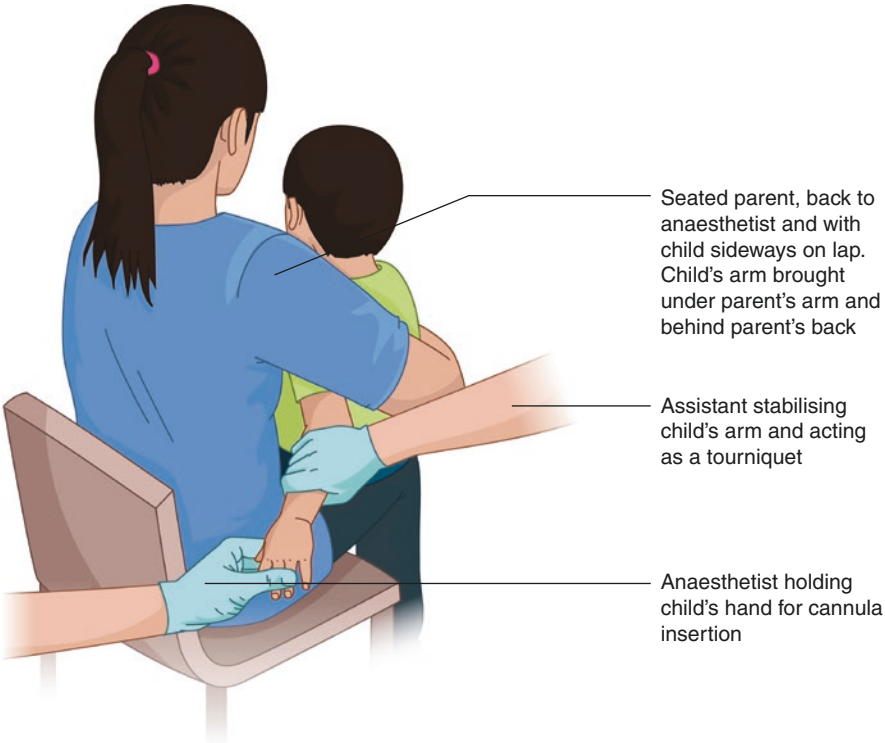

Fig. 1.2 Positioning the clingy or uncooperative toddler for insertion of an IV. All equipment, including tape, is prepared beforehand. The child sits sideways across the seated parent's lap and is distracted with stickers or a toy. The parent's arm hugs the child's back and the child's arm is brought under the parent's arm. An assistant stabilizes the child's arm and squeezes it as a tourniquet. The anesthetist holds the child's hand and stabilizes it for insertion of the cannula

Some veins are constant in position and can be accessed on the basis of landmarks only. These sites are:

1. The long saphenous vein just in front of the medial malleolus—feel for the groove in the malleolus that contains the vein.
2. Between the fourth and fifth metacarpal bones on the dorsum of the hand;
3. The cephalic vein on the lateral aspect of the forearm—it tends to be in line with the skin crease between the thumb and index finger, 1–3 cm proximal to the wrist.

Injection of air bubbles is always avoided in children as they may have undiagnosed congenital heart disease or a patent foramen ovale allowing bubbles to cross into the arterial circulation. Care to remove air bubbles is required every time a venous line is used.

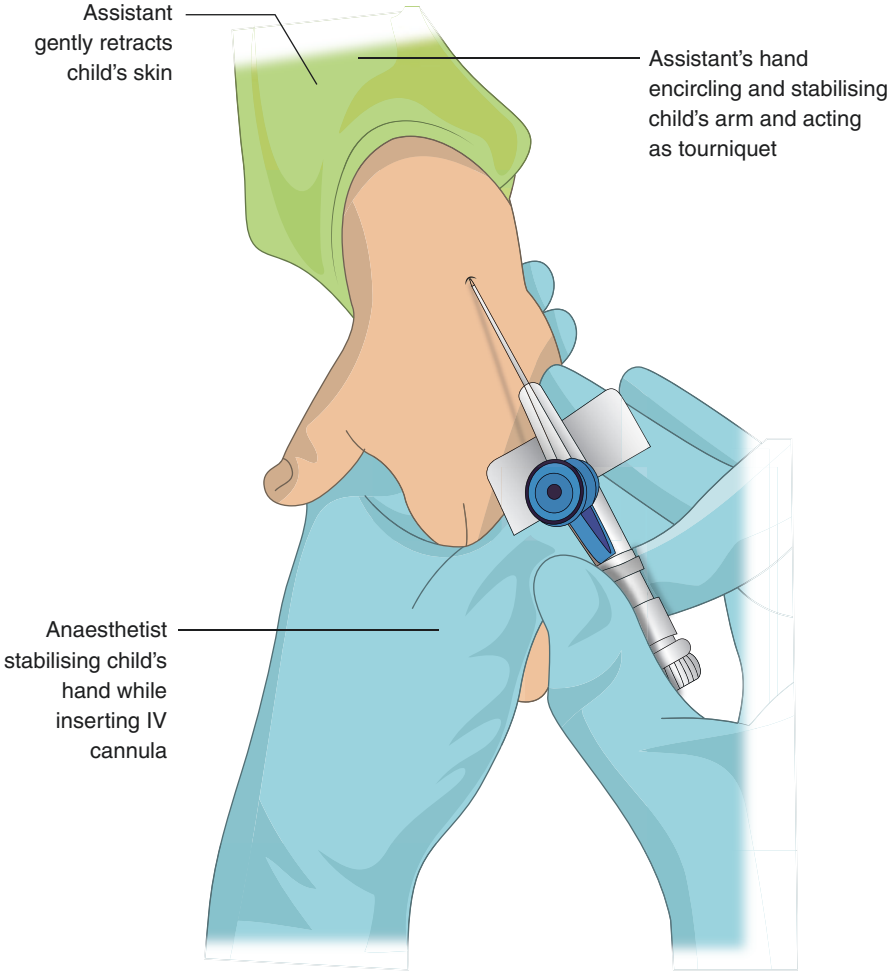

Fig. 1.3 The assistant's hand encircles the child's forearm. It acts as a tourniquet, retracts the skin on the dorsum of the hand, and prevents the child pulling away

1.5.4 Equipment to Find Veins

Transillumination with visible light can help find veins in some neonates. Several devices use near infrared light to highlight veins. These are sometimes useful for superficial veins, but do not necessarily increase the rate of first attempt success. They have not been rigorously studied and are difficult to recommend. Ultrasound is useful for vascular access, but not so much for superficial, collapsible veins on the dorsum of the hand. Nevertheless, in difficult cases it can help identify veins in the cubital fossa, forearm or saphenous vein. Some have suggested using a thin gel pad

between the probe and skin to increase the distance between the probe and vein, and to reduce compression of the vein by the probe.

1.6 Induction

Both inhalational and intravenous induction are suitable for children, and there is often an institutional preference for one or the other. There are advantages and disadvantages to each induction type (Table 1.6). IV induction became more popular after the introduction of topical anesthetic creams. However, an IV can still be sited using nitrous oxide/oxygen and distraction. Possibly the greatest advantage of the IV induction is that IV access is present from the outset, and IV inductions have a lower incidence of adverse respiratory events compared to inhalational induction.

Some children still hate needles even though they may be old enough to understand the anesthetic cream will work. Inhalational induction requires skill in distraction and behavioral management to enable the child to keep the mask on long enough for the volatile agent to work. Parental presence at induction is standard in most pediatric hospitals and is discussed in the Chap. 3.

During induction, there is a period in which the child can be distracted and kept calm, but after which stress and fear can make the induction increasingly difficult. It is important to be organized with an induction plan, to brief your assistant before starting and make sure that all equipment is ready to use.

1.6.1 Inhalational Induction

Sevoflurane is the only available inhalational agent suitable for induction. A routine induction includes 66% nitrous oxide in oxygen for 20–40 s, followed by 8% sevoflurane. The timing of nitrous administration is critical—if too short, the child may reject the mask when sevoflurane is started, and if too long the child will either lose interest and cooperation or become dysphoric from the nitrous oxide. Induction is possible without nitrous, but it is more likely that the mask will be rejected. If the T-piece is used for induction, it is best to give the child a few breaths at 0.5% sevoflurane before increasing to 8% (the fresh gas flow enters T-piece very close to the facemask, and the sudden smell of 8% sevoflurane may be noticed by the child). In a circle circuit, sevoflurane washes into the circuit more slowly and can be started at

Table 1.6 Advantages and disadvantages of IV and inhalational induction

IV induction	Inhalational induction
IV access present	No needle
Less cooperation from child required	Gradual loss of airway
Less excitatory movement	No pain from propofol
No smelly gas	Faster wake up than after IV induction
Less pollution	Parent can see what is happening to child

8% after nitrous oxide has been given as before. There is no need to incrementally increase the sevoflurane during induction as this slows induction and increases excitatory phenomena. The child's cooperation is needed for a calm inhalational induction, and techniques to help achieve this are discussed in Chap. 3, Sect. 3.4.

Keypoint
There is no need to incrementally increase sevoflurane concentration during gas induction—this slows induction and increases the incidence of excitatory phenomena. The incremental technique is a hangover from the technique of halothane induction.

Some airway obstruction is common after consciousness is lost due partly to excitatory phenomena that occur with sevoflurane (see Chap. 2, Sect. 2.6.5), and partly due to loss of upper airway tone. CPAP and gentle jaw thrust are used to overcome this. Nitrous oxide can be eliminated at this stage if desired and sevoflurane given in 100% oxygen. An oral airway should not be inserted at this stage. It is important to maintain the sevoflurane at 8% until a deeper level of anesthesia is reached and this partly obstructed, excitatory stage has ended. Listening to the heart rate and observing tidal volume will also give a guide to depth and the need to reduce the sevoflurane concentration. Cardiovascular depression occurs with high concentrations of sevoflurane, but in these early stages of inhalational induction it is the airway that will cause problems, not hypotension.

1.6.2 Intravenous Induction

IV access is obtained and anesthesia is induced with propofol. Co-induction techniques using benzodiazepines and opioids are uncommonly used in children because it is less important in children to blunt the hemodynamic responses to induction and intubation, and the priority is often to induce an upset child as quickly as possible. Preoxygenation and application of monitors before induction are omitted in many centers to reduce the child's anxiety.

1.6.3 Rapid Sequence Induction

The classic rapid sequence induction technique used in adults is not suitable for children. Children quickly become hypoxic during apnea, and although preoxygenation can reduce this, children may be difficult to preoxygenate correctly. The consequence of these factors is a hurried, 'crash' intubation with the risk of morbidity. Children must be gently mask- ventilated between induction and intubation. Cricoid pressure protects the stomach from inflation during mask ventilation. If mask

ventilation cannot be achieved during cricoid pressure, the pressure is reduced or it is removed completely if ventilation is still difficult.

Keypoint
The adult technique of RSI with apnea before intubation is a dangerous technique in children. RSI in children includes gentle mask ventilation before intubation.

The technique of RSI is now questioned as it prioritizes aspiration over everything else and increases other risks. These risks include hypoxia, awareness, hemodynamic changes, and a hurried, traumatic intubation that may be more stressful and difficult than it might otherwise have been. The role of cricoid pressure is also questioned, as there is no clear evidence it is of benefit. It is difficult to perform correctly, and anatomical variations mean even properly performed cricoid might not compress the esophagus. Young children have a soft, compliant trachea and cricoid pressure can obstruct their airway. As a result, cricoid pressure is often omitted in neonates and infants, and some anesthetists also omit it in older children. Head-up tilt and the child's lower esophageal sphincter tone are relied on instead of cricoid pressure. Cricoid pressure is still strongly recommended in children with intestinal obstruction.

Keypoint
Cricoid pressure is often omitted in neonates and infants because it compresses and obstructs the soft trachea. Its role in older children is also being questioned. Cricoid pressure is still recommended in children with intestinal obstruction.

Classic rapid sequence induction includes intubation within 1 min of induction. In children, 'rapid' does not need to be so rapid because there is mask ventilation and no period of apnea to manage. Whether intubation is performed within 1 min or a longer period becomes less important. Some authors argue it is more important to check there is complete muscle relaxation before intubation, rather than intubating within an arbitrary time. As a result, the rapid onset of muscle relaxation becomes less important. Although suxamethonium may be used for rapid sequence induction in children, non-depolarizing relaxants are commonly used—they have a relatively fast onset in children and ventilation with volatile anesthetic agents before intubation enhances their effect. The high doses of relaxants used in adults is not necessary in younger children.

Finally, use of a rapid sequence induction does not mandate a cuffed ETT. Either a cuffed or uncuffed ETT may be chosen for children with full stomachs—uncuffed ETTs have a long history of safe use in children in this situation. If suxamethonium

has been used to facilitate intubation with an uncuffed ETT that then needs to be changed because of excessive leak, consider giving a long-acting relaxant before the tube change. Many would re-apply the cricoid pressure during the tube change if it was used for the initial intubation.

1.7 Maintenance

The choice of technique during maintenance follows the same principles as with adults. The choice of airway management and type of ventilation depends on a variety of patient, procedure and anesthetic factors. Neonates and small infants are commonly intubated and ventilated for all but the briefest case. Otherwise great care must be taken with the issues of rebreathing, respiratory muscle fatigue, and loss of a clear airway. Furthermore, as the patient is so small, the surgical field is close to the airway and it is difficult to instrument the airway during surgery if problems arise.

Another important difference between children (especially preschool age) and adults is that more care is required during maintenance to ensure calm and safe emergence. Pain and delirium are two important reasons for children waking upset and distressed, and these can be minimized during maintenance. Unlike adults who may suffer in silence from inadequate analgesia, children will let everyone know if they are uncomfortable or distressed.

1.7.1 Hypothermia

Hypothermia during anesthesia is common in both children and adults. Children, however, are more at risk—they have a large surface area relative to body weight, so heat production is relatively low compared to environmental losses. Infants and neonates also have reduced ability to generate heat because of absent or reduced shivering. A child's head is large in proportion to the rest of the body, and the head is a site of significant heat loss if it is not covered.

Most heat is lost through the skin via radiation and convection. Losses are minimized by keeping the child covered, warming the OR (typically to about 21 °C for children, higher for neonates) and using a forced air warmer.

Conductive heat loss may be large if gel pads are placed under the child to prevent pressure injuries. These gel pads are made of dense visco-elastic polymer with a large thermal mass and will draw heat from the child. They should either not be used, or pre-warmed with a forced air warmer. Only about 10% of heat loss is through the airway, and passive humidification is adequate in pediatric anesthesia. Equipment to keep children warm during surgery is discussed in the Chap. 5.

1.8 Recovery

The facilities required for pediatric recovery are the same as for adults and are covered in professional and College guidelines. Staff should have experience in pediatric recovery and receive ongoing training in resuscitation. Staffing numbers in

pediatric recovery need to be higher as even an awake child needs to be watched closely. For example, a child may try to climb out of their cot or bed. As in theater, pediatric recovery requires the full-size range of airway and resuscitation equipment.

Parents are usually allowed into recovery. This requires staff to escort them into recovery, having enough room around the bed space for them, and a method to ensure privacy for other patients. Most centers wait until the child is awake and not at risk of airway problems before allowing the parent in.

1.8.1 Common Recovery Problems

1.8.1.1 Emergence Delirium and Agitation

Children will soon let everyone know if they wake up sore or unhappy. Anesthetists looking after children are careful to ensure good analgesia on awakening. Children can be agitated when they wake up for many different reasons, however pain is the most important one to exclude before considering other causes (Table 1.7). Agitated children cry and are unhappy, but are consolable, recognize their parent and can usually communicate. This is quite different to a child with delirium.

Emergence delirium is a drug-induced disorientation. The reported incidence varies enormously because of differences in definition, but is typically up to 18% in children 3–7 years old. The child cries or screams, may be hallucinating, is uncooperative, inconsolable and thrashes around. The child often does not appear to recognize their parent. This scenario is different to children who are agitated children for other reasons—they cry and are unhappy, but are consolable, recognize their parent and can usually communicate. Delirium begins as the child awakens and usually lasts less than 30 min, although it can be longer. It is common in preschool-aged children, especially preschool aged boys, after anesthesia with sevoflurane and desflurane. Other risk factors are listed in Table 1.8. Midazolam may cause emergence delirium in some children, particularly when used at higher doses in young children for short procedures, when the child is still affected by midazolam at the time of wake-up.

The Cochrane review found four effective ways of reducing emergence delirium: propofol, fentanyl, dexmedetomidine and clonidine. Propofol anesthesia is the most

Table 1.7 Causes of a child waking agitated and crying after anesthesia

Cause of agitation at awakening
Pain; full bladder
Unfamiliar surroundings; feeling unwell or out of sorts; parent not present
Hungry; bad taste in mouth
Hypoxia
Delirium
Difficult induction; child's temperament

Although the terms 'emergence delirium' and 'emergence agitation' are often used interchangeably, emergence delirium tends to refer to the anesthesia-induced disorientation, and agitation to a broad group of causes for an unhappy child at wake-up

Table 1.8 Signs indicating a child is likely to have emergence delirium, and factors making emergence delirium more likely to happen after anesthesia

Signs of emergence delirium	Risk factors
No eye contact Non-purposeful movement Unaware of surroundings or parent Restless, inconsolable	Patient: Preschool age, especially boys Child's temperament, particularly anxiety
	Surgery: ENT and ophthalmology
	Anesthesia: Emergence from sevoflurane or desflurane Rapid awakening Midazolam in some children

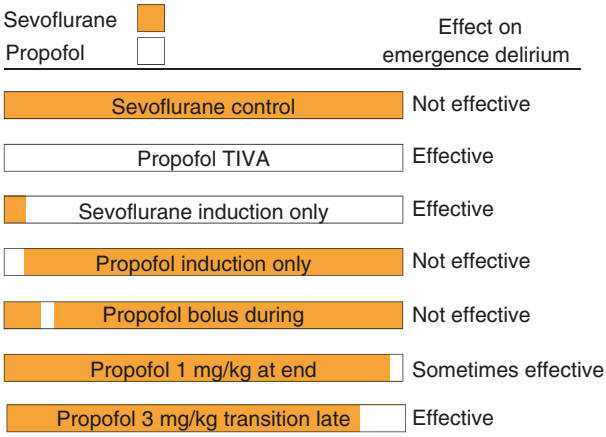

Fig. 1.4 The effect of propofol on emergence delirium when used alone or in conjunction with sevoflurane anesthesia. From D Costi, Australian and New Zealand College of Anaesthetists Annual Scientific Meeting, Adelaide 2015

effective way of preventing emergence delirium. The greater the proportion of anesthesia that is propofol, the better the effect (Fig. 1.4). Fentanyl is effective and worth giving to at-risk children, even if a regional block is adequate for analgesia. Any increased risk of PONV from fentanyl can be effectively reduced. Dexmedetomidine is expensive, making clonidine an attractive alternative. Clonidine however, is not effective in reducing emergence delirium after tonsillectomy or adenoidectomy.

Treatment begins with eliminating other causes including hypoxia (although it can be difficult to get accurate oximeter readings on a thrashing child) and pain. Reassure the parents who are usually very distressed at seeing their child behaving like this and ensure that the child avoids injury. Most children just need observation and time to settle, but others benefit from intervention. Consider small doses of propofol 0.5–2 mg/kg (ensuring equipment is available in case of apnea), IV clonidine (0.5–1 μg/kg), or fentanyl 0.5–1 μg/kg. Ketamine or dexmedetomidine may also be effective, but midazolam is not. It often helps if the child sleeps again for 10 or 15 min and re-awakens gradually. Sedation calms the child but also gives the recovery staff and parents time to regroup from what can be a very harrowing experience.

1.8.1.2 Oxygen Dependence

A proportion of children require oxygen to maintain their oxygen saturation at 96% or above. Oxygen is given by facemask or with a mask nearby ('blow-by' oxygen). Most children won't tolerate nasal prongs. Small infants can be given oxygen using a nasopharyngeal catheter and flow rates of 1 L/min or less. Prolonged oxygen dependence after anesthesia is abnormal and a cause needs to be determined. The commonest reason is a resolving URTI where the child has some underlying pneumonitis and simply needs time to wake up, cough, clear secretions and re-expand their lungs. However, causes such as aspiration and other pulmonary events need to be borne in mind and excluded if appropriate. A CXR will help if the child looks unwell or if oxygen is still required for more than an hour or two. Routine chest X-rays are not taken because of concerns about radiation exposure.

1.8.2 Discharge from Recovery

This is usually based on criteria or a scoring system rather than time. Scoring systems such as the modified Aldrete or Steward scores are commonly used. These measure several parameters to give a score, and discharge occurs when a certain score is reached. In general, the score ensures the child is conscious, maintaining their airway, has acceptable oxygen saturation, good pain control, and is not agitated.

1.9 Complications

This section deals with some of the causes of morbidity after anesthesia in children.

1.9.1 Postoperative Nausea and Vomiting (PONV)

PONV is a common problem in children, as it is in adults. Several factors indicate the child is at increased risk of PONV (Table 1.9). There is no evidence nitrous oxide increases PONV in children.

Children under 3 years of age are at low risk of PONV and are not usually given prophylactic antiemetic therapy (Fig. 1.5). However, PONV is a common problem after this age. The incidence is the same in boys and girls until puberty, after which it is higher in girls. There are several procedures with a particularly high incidence of PONV. These include strabismus repair (up to 70% PONV incidence if no antiemetic given), umbilical hernia repair, prominent ear correction, middle ear surgery, and procedures longer than 30 min. An important reason for PONV in all types of surgery is too much opioid relative to the amount of pain.

Antiemetic drugs are discussed in Chap. 2, Sect. 2.13. The Association of Paediatric Anaesthetists of Great Britain and Ireland have released guidelines for

Table 1.9 There are several indicators a child has an increased risk of PONV and may require more than a single antiemetic

Risk factor	
Anesthetic	Volatile agents Excess opioids relative to level of pain
Patient	Age 3 years and older History of motion sickness or PONV Post pubertal female
Procedure	Longer than 30 min Strabismus correction Umbilical hernia repair Orchidopexy Prominent ear correction Tonsillectomy

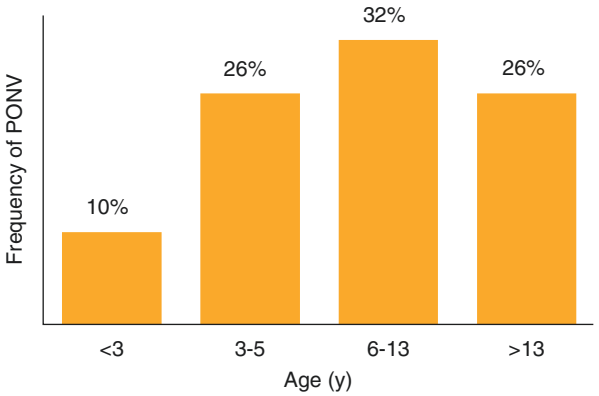

Fig. 1.5 PONV rates in children of different ages. Data from Bourdaud et al. Pediatr Anesth 2014;24:945–52

the PONV management. It recommends ondansetron 0.15 mg/kg when there is a risk of PONV, and ondansetron in conjunction with dexamethasone 0.15 mg/kg when there is an increased risk of PONV.

1.9.2 Post Extubation Stridor

A croupy cough or inspiratory stridor is uncommon if care is taken with ETT size selection. However, these symptoms occasionally occur and are due to edema at the cricoid ring which narrows the airway and causes turbulent or obstructed airflow. It is more likely in small children (who already have a small diameter airway), children with a recent URTI (where there may already be some inflammation and edema of the upper airway), or if an oversized ETT was used (ie no leak at 20 cmH_2O pressure or cuff too large to gently pass through cricoid ring). Observation alone may be appropriate if there is no significant obstruction. IV dexamethasone would be appropriate if obstruction is mild and not accompanied by increased work of breathing or oxygen dependence, or if there is concern that obstruction may worsen.

Dexamethasone may work much quicker than expected by its mechanism of action—oral prednisone reduces symptoms of croup in the emergency department in under 30 min. Nebulized adrenaline (epinephrine) is given if obstruction is significant (Table 1.10). Racemic adrenaline was incorrectly believed to cause less arrhythmias and is no longer used. A 1% adrenaline (epinephrine) solution for nebulizers is now used. If this is not available, the 1:1000 (0.1%) IV form of adrenaline can be used. If treatment with adrenaline is required, overnight admission for observation should be considered.

1.9.3 Venous Thromboembolism (VTE) and Deep Vein Thrombosis (DVT)

VTE is rare in children, possibly due to their high levels of the thrombin-inhibitor alpha-2 macroglobulin, which only reduces to adult levels during adolescence. Seventy percent of VTE's occur in neonates and teenagers. Sick neonates in ICU who have a central venous catheter are at high risk for venous thromboembolism, but also for complications from thromboprophylaxis. Factor V Leiden and deficiencies of the regulatory proteins C, S, or Anti-Thrombin III do not appear to be important until puberty. Teenagers 13 years and older are at increased risk of DVT, especially if they have malignancy, are undergoing major surgery of the pelvis or lower limbs, or have a past history of VTE. Additional risk factors are listed in Table 1.11. Mechanical prophylaxis is suggested if one or more of these factors are present in a teenager, and pharmacotherapy (in the absence of contraindications) in

Table 1.10 Treatment of post extubation croup in recovery

Treatment for post extubation croup
Dexamethasone IV 0.5–0.6 mg/kg
Nebulized adrenaline (epinephrine)—two types available:
1. L-isomer adrenaline 1% nebulizer solution 0.05 mL/kg diluted with normal saline to 4 mL
OR
2. Adrenaline 1:1000 (IV preparation) 0.5 mL/kg (maximum 5 mL), use undiluted in nebulizer bowl

Table 1.11 Adolescents 13 years and older are at increased risk of VTE and DVT

Risk factor	
Patient	Underlying cancer, sepsis or systemic medical comorbidity Personal or strong family history VTE Severe trauma or burns
Procedure	Surgery and anesthesia longer than 90 min Major pelvic or lower limb procedure Reduced mobility 3 or more days postop

Additional risk factors are listed above. Mechanical DVT prophylaxis is suggested if one or more of these factors are present in an adolescent, and pharmacotherapy (in the absence of contraindications) in adolescents with more than two of these factors

teenagers with more than two of these factors. Anti-embolic and compression stockings are used for DVT prevention in children at risk and large enough for them to fit, usually about 40 kg. Low molecular weight heparin (enoxaparin) 0.75 mg/kg (maximum 20 mg) twice a day is given to children older than 6 months by vertical subcutaneous injection in the lower abdomen. This is preferably given 2 h before surgery, but otherwise after induction. The adult dose of 40 mg once a day can be used in children heavier than 40 kg. Factor Xa levels and platelet count are checked on day one if heparin is continued postop. Heparin induced thrombocytopenia is less common in children than adults.

1.9.4 Aspiration

Aspiration is rare but slightly more common in children than adults. The incidence in children is about 1 in 2–3000. Children have less sequelae than adults, and even when there are chest X-ray changes, usually improve very quickly without specific therapy. Reflux symptoms are common in infants and young children, but are not necessarily an indication for a rapid sequence induction. Medications to reduce the risk of aspiration are not usually used in children because of the rarity of aspiration and sequelae. A child who aspirates a small amount is usually oxygen dependent for a period after anesthesia and is admitted for observation.

1.9.5 Awareness

Awareness in children (0.5–1.0%) is quite different to adults (0.1–0.2%). It is more common, may occur in non-paralyzed children without signs of inadequate anesthesia, and does not seem to cause distress or post-traumatic stress disorder. The reason for the high incidence of awareness in children is not known. There is concern that it may reflect problems in the questionnaire methodology used in studies of awareness—children may be more suggestible and more likely to report memories on repeated questioning. They may also have a diminished ability to encode and consolidate memory, making it difficult to differentiate true memories from actual events and dreams.

1.9.6 Laryngospasm

Laryngospasm most commonly occurs at induction and emergence, but occasionally in recovery. All pediatric recovery areas should have the equipment, training and procedures to deal with this. It can be prevented by having all children awake on arrival in recovery. However, the rapid awakening required to achieve this may

not always be practicable and may increase the likelihood of emergence agitation. Laryngospasm is discussed in detail in the Chap. 4, Sect. 4.11.

Note
Always remember to let the child's parent know about any intraoperative problems—it is unprofessional and unfair for the parent to find out later from nursing staff and increases the likelihood of a complaint.

1.10 Day Surgery

At least half of all procedures in children are performed as day cases, although the proportion at any given center varies with its case mix.

1.10.1 Suitability for Day Surgery

As with adults, suitability for day surgery depends on the type of procedure and the requirements for postoperative observation, care and pain control, underlying medical conditions, age of child, ability of the parent to care for the child and the location of the child's home relative to the hospital. Not all infants are suitable for day surgery: Former preterm infants whose postmenstrual age (PMA) is less than 52–60 weeks and term infants who are less than 44 weeks PMA are at risk of apnea after anesthesia and must be admitted for observation (see Chap. 14, Sect. 14.4.4). Children at risk of malignant hyperthermia who have been given a trigger-free anesthetic are suitable for day surgery.

1.10.2 Discharge Criteria

Discharge occurs when a set of criteria are met. The exact criteria vary between centers, but all aim to allow time to detect any complications that may cause problems at home after discharge (Table 1.12).

If the child was intubated, some centers include a minimum time to stay to observe for post extubation stridor. However, stridor usually develops within the first hour after extubation and most centers do not alter their criteria for discharge according to anesthetic technique. Voiding of urine is not usually required, even if the child had a caudal block. Two adults are recommended to accompany the child home in the car—the child may be sleepy, is likely to be in the back seat or even a rear-facing seat, and it is difficult for the driver to closely observe the child. Patients who live in the country or regional areas distant to the hospital may still be able to

Table 1.12 Discharge criteria after anesthesia

Criteria for discharge after anesthesia in children
Awake, not dizzy
Observations, including oxygen saturations, satisfactory
Pain controlled, with no intravenous analgesics recently (usually within last 60–90 min)
No nausea and vomiting. Tolerating, (or likely to tolerate) oral fluids
No croup or upper airway obstruction
Parent or carer willing to take child home, preferably by car or taxi
Instructions (preferably written and procedure specific) about postoperative care (surgical and anesthetic) including a contact if problems

undergo day surgery. This depends on institutional preferences, surgical procedure and how well the child recovers early on. Well children who have undergone short procedures or scans with a very low risk of complications and a good early recovery may be allowed to return to the country if it is not too late in the day. However, nausea and vomiting during a long car journey home is a concern of this approach.

1.10.3 Problems After Day Surgery

About 1% of children require unplanned hospital admission after day surgery, although the exact number varies according to the case mix of the center. The unplanned admission rate is used to audit the effectiveness of the day surgery unit's preparation and selection processes. The main reasons for admission are shown in Table 1.13.

1.10.3.1 Postoperative Fever

Fever on the night after surgery is not uncommon, although the incidence depends on the definition of fever used and the patient population. It is common for no definite cause to be found, but it is important to make sure the fever is not due to an infection. A persistent fever (not just a spike) needs examination and investigation. Possibilities to consider in the child with a fever postoperative are listed in Table 1.14.

Table 1.13 Reasons for unplanned overnight hospital admission after day surgery

Reasons for admission
Nausea and vomiting
Uncontrolled pain
Drowsiness or dizziness
More complicated surgery than planned
Family request

Table 1.14 Causes of fever after anesthesia and surgery in children

Cause of postoperative fever
Chest infection
Other infection
Unrelated viral illness
Inflammatory reaction to surgery
Malignant hyperthermia

An inflammatory reaction to surgery is thought to be the most common reason for postoperative fever. However, the chest is a likely source in a child with a pre-existing URTI or after an undetected endobronchial intubation. Atelectasis alone is no longer thought to cause fever. MH is rare and may cause a high fever up to 10 h post op in susceptible patients.

1.11 Vaccinations Before and During Anesthesia

Parents sometimes ask for their child to be given their vaccinations during anesthesia to avoid them feeling the needle. They may also ask if their child's vaccination can go ahead in the days before surgery. Anesthesia, stress and trauma modulate the immune system and may influence the effectiveness of the vaccination. However, there is no clear evidence on this topic. Most countries have routine immunization schemes which include several vaccinations within the first year of life and many anesthetic procedures are performed in this age group without apparent sequelae. Vaccinations can cause systemic effects such as fever, rash, malaise and myalgia for several days afterwards. If the child is vaccinated just before surgery, these symptoms may be confused with an URTI and delay surgery. Alternatively, if the child is vaccinated during anesthesia, these symptoms may be confused with a febrile reaction or illness secondary to anesthesia and surgery. For these reasons, it is suggested to schedule or even delay (if possible) surgery so it does not affect the child's immunization schedule. Surgery is delayed 48 h if possible after vaccination with inactivated viruses. These include influenza and polio, which may cause systemic symptoms as above. Some in the UK suggest no delay after vaccination with live attenuated viruses (measles/mumps/rubella, chickenpox), but others in Australia suggest 3 weeks. It is preferable not to vaccinate during anesthesia and surgery, but if the child is otherwise unlikely to be vaccinated, it would seem best to go ahead so the child does not miss out.

Review Questions

1. A healthy but anxious 4 year old girl has anesthesia for myringotomy and tubes. She was given oral paracetamol as a premed. She had an inhalational induction, but did not willingly accept the mask at induction. After induction she was given sevoflurane 2% in nitrous oxide/oxygen for surgery and transferred to PACU. She woke soon after crying and thrashing. Why might she have woken like this? Could anesthesia have been different to prevent this outcome?
2. Justify your use of perioperative antiemetics in children.
3. A 2 year old child requires anesthesia for myringotomy and tube (ear grommets) insertion. What risks would you discuss with the parent?
4. A 12 year old girl is brought to theatre to have her broken arm treated. She is frightened, crying, and refuses to let you look at her hand to insert an IV for induction. What will you do?

5. A 15 year old has refused consent for open reduction of her forearm fracture. She was told there was a risk of nerve damage from the surgery, and is concerned this will stop her playing her much-loved musical instrument. Do you have to accept the child's refusal? Can you seek consent from the parent instead? What would you discuss with the child?
6. An 18 month old boy has woken after anesthesia for laparotomy for intussusception and has a croupy cough and hoarse cry. What is the likely cause, and how will you decide if treatment is required? What are the treatment options?
7. You are asked to anaesthetize a 5 year old at a day surgery unit where you have not worked at before. How will you decide if is safe to anaesthetize the child there?
8. You are called to the day surgery ward to see a 2 year old who has a fever 1 h postop. She had a 2 h orthopedic procedure with an uneventful GA. The esophageal temperature at the end of anesthesia was 37.4°, and it was 37.7° when discharged from PACU. Why might this child have a fever and what will you do?

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Pharmacology of Anesthetic Agents in Children

2

Craig Sims and John Thompson

As children grow, absorption, distribution and clearance change because anatomical and physiological processes mature. Many drugs are poorly studied in children. Data is often extrapolated from adults as there are financial and ethical problems with clinical pediatric studies. These problems often mean newer drugs are not approved for use in children. Fortunately, the pharmacokinetics of many drugs commonly used as part of anesthesia have been studied, though less so their pharmacodynamics. This chapter focuses on the pharmacological differences between children and adults.

2.1 Factors Affecting Dosage in Children

Size and age are the most important determinants of drug dose in children. Size is most commonly dealt with by weight-based dosing but age affects organ function and body composition, which require more complex adjustments to dosage.

2.1.1 Size

Children can be less than a kilogram or more than 100 kg. There are three alternatives to allow for this. The first is weight-based dosing (mg/kg, up to a maximum equal to the adult dose). This is simple, accurate enough for most drugs and

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commonly used in anesthetic practice. Size and metabolism are not linearly related however, and the other two methods of dosing try to allow for this. Body surface area is one method. This requires complex calculations and is used for drugs with low therapeutic margins such as chemotherapy agents. The other alternative is to scale the dose using a non-linear, allometric power technique. Allometric scaling describes the nonlinear relationship between size and organ function. It also requires complex calculations and is not used clinically.

2.1.2 Age

Pharmacokinetic and pharmacodynamic differences between children and adults are maximal in the first 2 years of life, making neonates and young infants at high risk of side effects.

2.1.3 Pharmacokinetic Changes

The pharmacokinetics of drugs change with age due to several factors (Table 2.1). The two most important are differences in body composition and immature metabolic pathways.

Changes in body composition affect the physiological spaces into which drugs distribute. The high proportion of total body water (TBW) and extracellular fluid (ECF) in neonates (75% and 50% of body weight respectively) are the major factors, along with changes to fat, muscle, plasma protein levels and regional blood flow differences.

Keypoint
Neonates are 'wet' and 'skinny' at birth, increasing the apparent volume of distribution for many drugs.

Table 2.1 Pharmacokinetic differences in neonates and infants that affect their response to drugs

Absorption
Slow gastric emptying until 6–8 months and reduced gastric acidity in infancy
Thin neonatal skin, increasing absorption of EMLA and chlorhexidine antiseptic
Volume of distribution increased
Increased total body water (mostly as increased ECF)
Decreased fat and muscle as a proportion of body weight in neonate; increased and more sustained peak concentration of drugs that redistribute into fat and muscle
Decreased albumin (and affinity), decreased alpha-1 acid glycoprotein
Clearance
Decreased metabolism in neonate, especially if preterm. Varies with different P450 isoenzymes. Most conjugation enzymes also decreased
Renal function immature during first 6 months, adult level by 1–2 years

ECF extracellular fluid

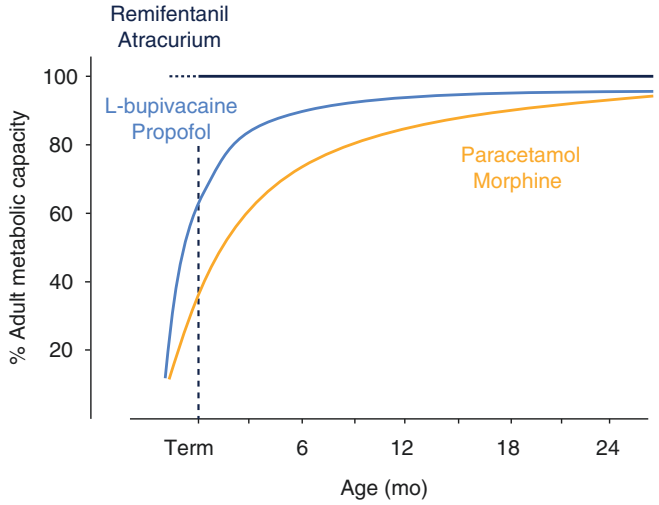


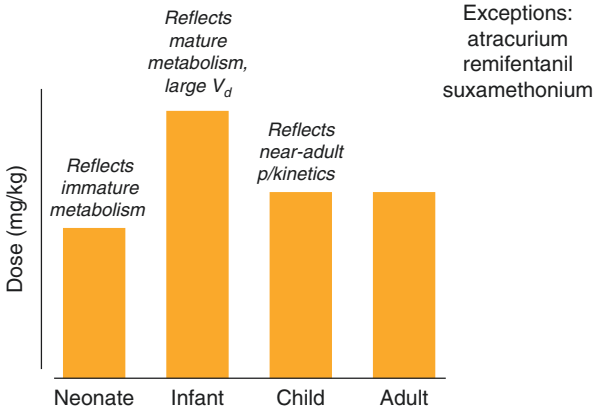
Fig. 2.1 Maturation of clearance, expressed as a percentage of adult capacity. Glucuronide conjugation, responsible for paracetamol and morphine metabolism, matures slower than the cytochrome P450 isoenzymes responsible for L-bupivacaine metabolism. Cytochrome P450 isoenzymes also contribute to the metabolism of propofol during infancy, whereas propofol undergoes glucuronide conjugation in older children. Blood and tissue esterases which metabolise remifentanil and atracurium are fully active in term, and probably preterm, infants. Adapted from Anderson, Eur J Anaesthesiol 2012;29: 261–70

Metabolic pathways are immature at term. The activity of most enzymes responsible for drug metabolism is low at birth and increases after birth, but may take 2 years to reach adult levels (Fig. 2.1). Drug metabolism begins developing even before birth, making the post menstrual age (PMA) more important than the age since birth for determining metabolism in former preterm children. Esterases are an exception to this pattern of development, and are fully developed at birth. As metabolism matures, clearance also increases and is highest at 1–2 years of age (Fig. 2.2). Clearance peaks at this age because of a mathematical artefact caused by expressing clearance in terms of weight. Clearance and weight are not linearly related (doubling weight does not double clearance), and there comes an age when clearance has increased more than weight. Renal excretion also develops with age. At term, the glomerular filtration rate (GFR) is about one quarter that of an adult, and reaches adult levels by 1–2 years.

These pharmacokinetic changes combine to affect drug doses in different ways as age increases. For the first several months of life, and especially the first 3 months, reduced metabolism is the most important factor determining dose. Doses are therefore generally lower in neonates and infants. With age, metabolism matures, clearance is relatively high, but body water volumes are relatively large too. Doses expressed in mg/kg are then even higher than in adults (Fig. 2.3).

Fig. 2.2 Schematic representation of weight-based clearance of many drugs during childhood. Clearance is generally lower in neonates compared with adults due to reduced metabolism, then increases in toddlers and decreases gradually during childhood to the adult level. Although the shape of this curve is helpful in the clinical setting, it is an artefact caused by the weight-based calculation of clearance

Fig. 2.3 The dose in mg/kg of many drugs is larger in infants and young children



Keypoint
The speed of maturation of metabolism varies between children and increases inter-individual variability of drug effects in children.

Note
The doses of three anesthetic drugs do not change with age because they are metabolized by esterases which are fully active at birth: suxamethonium, remifentanil and atracurium.

2.1.4 Pharmacodynamic Changes

The neuromuscular junction is not fully developed in neonates, affecting muscle relaxant action. The CNS is not fully developed, affecting the MAC of volatile agents. Although end-organ maturation has an effect on the action of other drugs, it is the pharmacokinetic changes that are most important beyond infancy.

Keypoint
In general, drugs have longer duration of effect in neonates. Children aged 1–2 years need higher doses in mg/kg, and these doses are shorter in effect. The dose and effects of drugs in children beyond 2 years age gradually change to adult levels during childhood.

2.1.5 Pharmacogenomics

Genetic influences on drug metabolism is another factor affecting drug dosage. Genetic polymorphisms affect how a drug is used in an individual child, or what drug-drug interactions might occur. Phenotyping will become more available for children requiring treatment with drugs dependent on polymorphic enzymes for metabolism. The recent understanding of genetic influences on codeine metabolism has led to its removal from pediatric practice. Another example is the metabolism of tramadol.

2.2 Licensure of Drugs in Children

Many drugs commonly used in the care of children are not recommended for use in children by the drug's manufacturer (Table 2.2). This off-label use has occurred due to the pharmaceutical companies balancing the costs of research and licensure against potential market increase in a small market segment. Strict adherence to the licensure would severely restrict access to safe and useful agents for children. The defensibility of using drugs off-label relies on following contemporary practice and using drugs that are supported by evidence. Related to licensure, many useful drugs

Table 2.2 Commonly used drugs and minimum age recommended by manufacturer

Drug	License age
Propofol	Over 3 years
Fentanyl	Over 2 years
Remifentanil	Over 1 year
Oxycodone	Adults
Ropivacaine	Term neonate
Atracurium	Over 1 month
Ondansetron	Over 2 years
Dolasetron, Tropisetron	Adults
Sugammadex	Over 2 years

do not have a commercially made oral liquid preparation. Work-arounds include preparation by a compounding pharmacy or using the IV preparation orally, both with uncertain bioavailability. Various strategies are used to improve taste and tolerability of oral preparations.

2.3 Drug Errors

Drug errors are common in pediatric anesthesia. The dose has to be calculated and taken from an adult-sized ampoule. Pediatric doses may not be a whole number and misplacing decimal places and trailing zeroes are risks. Medication errors are twice as common in children compared with adults, most commonly at the prescribing stage. The commonest error is a dosing error, and the commonest (and classic pediatric error) is a ten times overdose. Drug infusions are a high risk for errors because of the complexities of variable weight and concentration. Oral drugs have the added risk of different strengths (such as paracetamol elixir 120 mg or 250 mg per 5 mL). Finally, small amounts of drug remaining in a three-way tap, injection port or IV line can be enough to cause serious complications in children. A running IV does not remove residual drug traces, and each injected dose must be followed with a saline flush through the same injection site. Techniques to reduce errors specific to children are listed in Table 2.3.

2.4 Local Anesthetic Creams

Local anesthetic creams are used to reduce the pain of venipuncture. However, children still often fear needles and do not believe the cream will work. EMLA® is a eutectic mixture of lidocaine, prilocaine and excipients. It takes 45–60 min to work, although a longer duration is more effective. The larger the needle, the more likely it is to be felt. The cream continues to penetrate deeper and work better for at least

Table 2.3 Reducing drug errors in children

Techniques to reduce drug errors in children
Have another person in theater check unusual doses, unusual drugs, or difficult calculations
Have another person in theater check the preparation of infusions
Label drugs carefully. Do not rely on color of a drug or memory
Avoid diluting drugs if possible, or always use the same or a standard dilution for each drug
For drugs that are not titrated to effect such as antibiotics, draw up only the dose to be given
Cross check by comparing the dose with an adult dose—"If an adult dose is for 50 kg and the child is 10 kg, how does the dose I'm about to give compare?"
Prescribe practical doses for postop use that are not complex for staff to calculate (such as 110 mg of paracetamol rather than 113 mg); or use increments of dose that match the strength of the drug preparation—paracetamol 24 mg/mL for example
Write 'micrograms' in full to prevent one thousand times overdose from misreading abbreviation
Flush the IV injection point after every dose of drug

the first few hours, though the skin can become 'soggy' if the cream is left on more than 3 or 4 h. It works for 1–2 h after removal, depending on duration of application. It vasoconstricts micro vessels which may make larger veins more obvious against a pale background. Prilocaine toxicity (methemoglobinemia) is a concern in neonates. Absorption of EMLA through their thin skin is increased, and methemoglobin reductase activity is reduced. During the first 3 months, application to only one site for up to 1 h in a 24 h period is recommended.

Tetracaine (amethocaine) gel ('Ametop' or 'AnGEL' cream) is faster in onset (30 min) and penetrates better than EMLA for IV insertion. It vasodilates microvessels and makes the skin red. Local skin reactions are rare, but more common than after EMLA. It should be left on no longer than 60 min and continues to work for 2 or 3 h after removal. Four percent of lidocaine cream (LMX-4) also takes 30 min to have a similar efficacy to EMLA.

2.5 IV Induction Agents

2.5.1 Propofol

Propofol is particularly useful in children because it suppresses airway reflexes and reduces emergence delirium.

2.5.1.1 Pharmacokinetics

Children have a central volume of distribution almost twice that of adults and an increased rate of clearance (Table 2.4). They need larger doses to achieve the same plasma concentrations as adults, mainly because of increased distribution from plasma to peripheral compartments. After its administration, more propofol remains in the body for any given plasma concentration, increasing the context sensitive half time and slowing recovery. Rapid awakening is not a feature of TIVA with propofol in children. Neonates and infants have lower clearance of propofol as glucuronidation, which is the major metabolic pathway for propofol metabolism. The immature glucuronidation is partially offset by the faster maturing P450 system. However, neonates remain at an increased risk for accumulation during either intermittent bolus or continuous administration of propofol.

2.5.1.2 Clinical Use

The induction dose is often stated as 2.5–3.5 mg/kg in unpremedicated children. However, doses of 4–5 mg/kg are routinely used in younger children to reduce spontaneous movements and facilitate instrumentation of the airway (Table 2.5).

Table 2.4 Pharmacokinetic data for propofol at different ages

Age group	Vd (L/kg)	Clearance (mL/min/kg)
Neonates	5.6	20
Child <3 years	9.5	53
Child >3 years	9.7	34
Adult	4.7	28

Table 2.5 Summary of IV induction agent doses

	Age group	
Agent (dose mg/kg)	Neonates	Infants and children
Propofol	3	3–5
Thiopentone	3	5–7
Ketamine	1–2	1–3

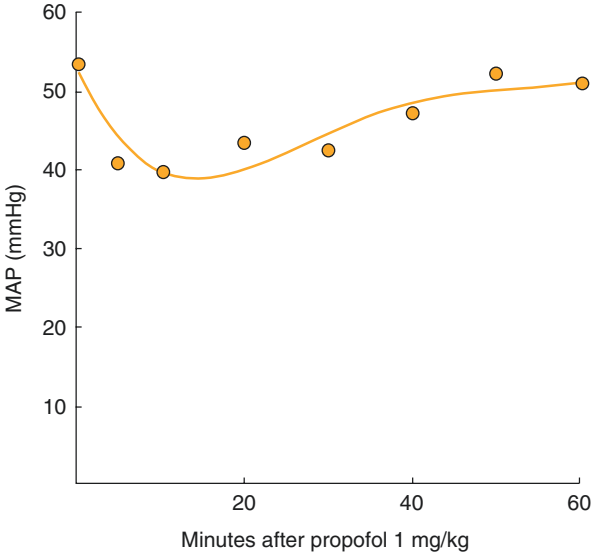


Fig. 2.4 A propofol bolus may cause a prolonged fall in blood pressure in neonates. Based on Welzing et al., Pediatr Anesth 2010;21: 605–11

Lower doses are required in neonates, after sedative premedication, and if there is hypovolemia. Many children have food allergies to eggs and although propofol can still be used, more information should be sought if the history is of anaphylaxis to egg. Stinging with injection is a problem in children, as small veins on the dorsum of the hand are commonly used for induction. Lidocaine 0.2 mg/kg for every 3 mg/kg of propofol is effective. Propofol induction in children causes more hypotension than thiopentone, but propofol causes less hypotension in children than in adults. However in some neonates a bolus dose causes significant hypotension lasting up to an hour (Fig. 2.4). Propofol causes apnea of more than 20 s in up to 50% of children and depresses pharyngeal and laryngeal reflexes (making a bolus of 1–2 mg/kg useful to avert coughing or laryngospasm). A propofol bolus or transition technique at the end of sevoflurane anesthesia, or TIVA are effective methods to prevent emergence delirium (see Chap. 1, Sect. 1.8.1).

2.5.1.3 Propofol Infusions in Children

Propofol infusions reduce airway responsiveness, emergence delirium and nausea and vomiting in children. Children do not usually wake quickly after propofol anesthesia due to the high doses needed and long context-sensitive half time. They tend to sleep for a period in recovery but then usually wake in a calmer and less

distressed manner if analgesia is adequate. Starting an infusion at some point after an inhalational induction is quite acceptable, and most of the benefits of propofol are still gained. The propofol dose is reduced by the concomitant use of remifentanil or alfentanil, and to a lesser extent by nitrous oxide (Table 2.6).

2.5.1.4 Target Controlled Infusions (TCI)

There are two TCI models licensed in some countries for children—the Paedfusor and Kataria. Both have minimum age and weight settings and target plasma rather than effect site concentration. Age however is ignored as a variable by both models, although the Paedfusor does adjust assumed volumes when the when age is more than 12 years. In general, TCI pumps give children a bolus dose about 50% higher and a maintenance rate 25% higher compared to adult TCI models.

TCI propofol is a useful technique in children, but the algorithms can't entirely allow for the marked inter-individual variability of propofol in children and for the pharmacokinetic changes over a broad range of ages. These issues and some practical points are given in Table 2.7.

2.5.1.5 Manual Propofol Infusions

Manual infusions of propofol are commonly used because they can follow a manual IV induction or inhalational induction. The doses are much higher than in adults.

Table 2.6 Initial target propofol concentration in adolescents during maintenance with propofol given with analgesic agents

Intraoperative analgesic	Target concentration propofol (μg/mL)
Propofol alone	4–6
Remifentanil or regional block	3–4
Nitrous oxide	4–5

Titration of dose according to observed anesthetic depth is critical. Adapted from McCormack, Curr Anesth Crit Care 2008;19:309–14

Table 2.7 Problems and practical points of propofol TCI in children

Propofol TCI in children	Comments
Problems	Pump algorithms use averaged pharmacokinetic variables. Titration of the dose is still needed to allow for interindividual differences
	Target concentration in children is probably the same as in adults, but it is not known why this is the case when MAC for volatiles varies with age
	Induction slower than manual propofol bolus which may prolong induction process in unhappy or uncooperative child
Practical points	If gas induction, start TCI target 1–2 μg/mL then increase as sevoflurane washes out. Closely observe depth of anesthesia and watch for hypotension
	Always add an analgesic component to reduce propofol dose: An effective regional block; remifentanil infusion; alfentanil infusion if short anesthesia; even just nitrous
	If propofol used alone, need target about 6 μg/mL or more to prevent involuntary movement. Huge dose and PACU recovery is prolonged
	Wake-up concentration reported as 1.3–1.8 μg/mL

Table 2.8 Macfarlan manual infusion scheme for propofol to achieve plasma concentration of 3 μg/mL in children aged 3–11 years

Infusion rate	Time			
	First 15 min	15–30 min	30–60 min	Thereafter
Propofol (mg/kg/h)	15	13	11	10 and titrate
Propofol (μg/kg/min)	250	220	180	170 and titrate

Doses can be titrated lower with concomitant use of opioid, regional block or nitrous oxide

One technique is the MacFarlan scheme, in which a 2.5 mg/kg induction dose is given followed by an infusion with the rate decreased at 15 min intervals (Table 2.8).

2.5.1.6 Propofol Infusion After Inhalational Induction

Manual propofol infusions can be started after an inhalational induction, but either a small bolus or high initial infusion rate is needed to replace the volatile agent. TCI propofol after inhalational induction is started at a low target, then progressively increased as the volatile concentration falls. This approach avoids a large initial bolus which would cause hypotension. It is kinetically imprecise to change from a volatile to an IV technique because the volatile concentration in the brain is falling while the propofol concentration is rising, but is a practical solution to the problem. The anesthetic depth must be closely watched, and erring on the 'too deep' side while avoiding hypotension seems wise.

2.5.1.7 Propofol Infusion Syndrome

Propofol infusion syndrome consists of metabolic acidosis, myocardial failure and rhabdomyolysis and has a mortality of 50%. The likely mechanism is disruption of mitochondrial fatty-acid oxidation, either by an unidentified metabolite or an underlying neuromuscular defect. It is triggered by the combination of high metabolic energy demand, low carbohydrate availability and high lipid availability. It is more common in children than adults, possibly because of their lower carbohydrate stores. The syndrome is associated with prolonged, high-dose propofol infusion in young children—more than 5 mg/kg/h for longer than 48 h. However, several large series have found prolonged propofol infusions to be safe, and children may need an underlying genetic predisposition to develop the syndrome. The development of lactic acidosis may be a warning sign, and dextrose-containing IV fluids may reduce the risk of the syndrome. Nevertheless, prolonged sedation of children in ICU with propofol is contraindicated, and it is probably best to limit the duration of anesthesia in children using a propofol infusion to less than 6 h and to reduce the dose of propofol with the concomitant use of remifentanil.

2.5.2 Ketamine

Ketamine is best reserved for special situations in children. Its strengths are preservation of airway tone, functional residual capacity of the lungs and cardiovascular stability. A dose of 1–2 mg/kg IV gives 5 min of anesthesia for short procedures. An

intramuscular dose of 3–5 mg/kg is an alternative. When used as an induction agent, there is no clear 'drop off point', and the eyes often remain open. Oral secretions are increased and some anesthetists routinely give an antisialogogue.

Its use in theater is restricted to situations where cardiovascular depression from propofol is a concern (particularly in shock states, cyanotic congenital heart disease or pulmonary hypertension). It is also used by some for upper airway procedures, although apnea, coughing, airway obstruction and laryngospasm can occur. It is also useful for anesthesia in children with anterior mediastinal masses as it preserves the functional residual capacity of the lungs.

Outside the OR environment, it is used for short, painful procedures such as burns dressings because the relative preservation of airway tone may improve safety, although some would argue against this. The airway can still be lost during ketamine anesthesia, and there is concern about its use by non-anesthetists such as physicians providing sedation or anesthesia in the emergency department. In intensive care, it is useful for induction of the septic or shocked child.

The quality of recovery is often not good, and many anesthetists consider it a poor alternative to modern agents. Recovery is slow, and hallucinations, agitation and behavioral disturbances are a significant problem, although they are not as common in children aged 5 years or younger (5–10%) compared to adults (30–50%). Nausea and vomiting are also common after ketamine anesthesia. Other uses include premedication of autistic or combative patients, as discussed in Chap. 3, Sect. 3.3.3.

2.6 Inhalational Agents

Inhalational agents are widely used in children. Pharmacokinetic differences facilitate inhalational induction, a technique that is very commonly used.

2.6.1 Speed of Induction

Inhalational induction is faster in children than in adults. The reasons for this are: firstly, alveolar ventilation is high relative to FRC in children (5–1 in neonates, 1.5–1 in adults) so that the alveolar concentration reaches the inspired concentration quickly. Secondly, a higher proportion of the cardiac output goes to the brain so that the brain concentration reaches the alveolar concentration quickly. A third reason is that volatile agents have lower tissue/blood solubility in neonates compared with adults. Although this difference was significant for halothane, it is not an important factor with modern insoluble agents such as sevoflurane.

2.6.2 MAC

The minimum alveolar concentration (MAC) at which 50% of patients do not move in response to incision changes with age. MAC is highest at age 1–6 months and

then decreases with age (Fig. 2.5). MAC is lower in neonates compared to both children and adults. MAC is probably even lower in preterm neonates, but this has only been studied with isoflurane. The mechanism for MAC changing with age is not known, but may be due to changes in regional blood flow or receptors. Sevoflurane differs from the other agents because its MAC is similar (not lower) in both neonates and infants.

2.6.3 Nitrous Oxide

Nitrous oxide is still commonly used in pediatric practice. It facilitates inhalational induction and intubation under deep volatile anesthesia (Table 2.9) and it is a potent analgesic for suppressing responses to intense stimulation during surgery. This is especially useful if postoperative pain is not expected to warrant opioids. Although nitrous oxide probably increases respiratory morbidity in adults, the ENIGMA trial

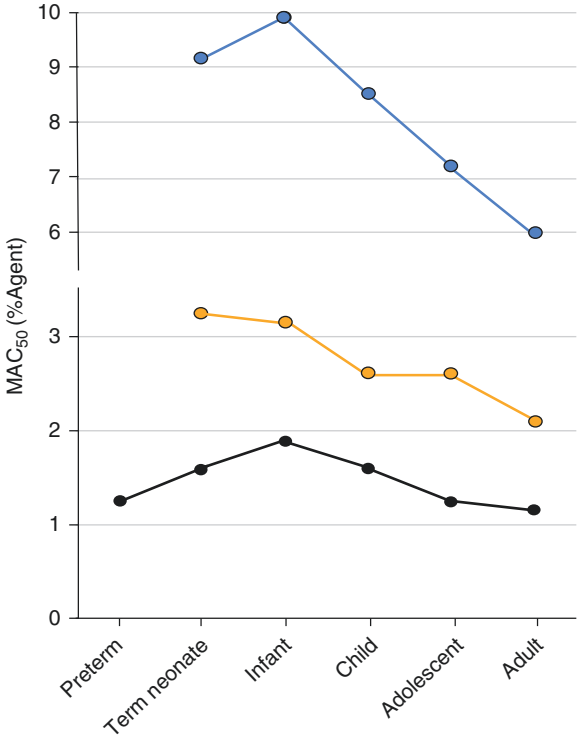


Fig. 2.5 MAC for volatile agents at ages ranging from preterm neonates to adults. Note that generally MAC is highest in infants and decreases with age. Sevoflurane is different because MAC is not lower in neonates compared to infants

Table 2.9 Effect of nitrous oxide on MAC for intubation in children

	MAC for intubation sevoflurane (%)
MAC in oxygen	2.7–3.2
MAC in 60% N2O	1.6

results cannot be translated directly to children—adults often have co-morbidities, while most children have healthy lungs and do not develop respiratory effects. Finally, there is no evidence that nitrous oxide added to volatile agents increases nausea and vomiting in children.

2.6.4 Neurotoxicity of Anesthetic Agents

Studies in young animals consistently show anesthetic agents cause neuronal apoptosis (programmed cell death). All commonly used anesthetics including inhalational agents, nitrous oxide, ketamine, propofol, barbiturates, and benzodiazepines have this effect. Exceptions are opioids, dexmedetomidine, clonidine, and xenon. The applicability to humans of these animal studies is not certain.

Subsequent human studies have not consistently shown an effect of anesthesia at a young age on later neurodevelopment—some studies have found an association while others have not. However these studies are difficult to interpret. They are retrospective and aim to detect an effect from a brief exposure to anesthesia amongst all the confounding factors that could affect development during a child's life, including the reason the child required surgery and anesthesia. Also, such studies can only detect an association, not causality. Further complicating the issue is a debate that careful control of respiratory, hemodynamic and metabolic variables might be more important than choice of a particular anesthetic agent in avoiding neurodevelopmental changes after anesthesia.

In response to these animal and human studies, the FDA issued a warning in 2016 to US physicians that anesthesia lasting more than 3 h in children younger than 3 years old may affect subsequent neurodevelopment. However the assertions of the warning have not been accepted by anesthetic associations outside the US.

More recently, results of the first prospective randomized trial became available. Infants were randomized to spinal or general anesthesia for herniotomy, and children's development followed for 5 years (the GAS study). This study found general anesthesia did not affect developmental outcomes. The weakness of the study however, was that anesthetic exposure was less than 1 h. Another recent prospective study compared the development of twins, one of whom had received a GA and one of whom had not (the MASK study). This study also found general anesthesia did not affect developmental outcomes.

Parents may raise the issue of potential toxicity prior to surgery and this should prompt a discussion of the points above. At present, there is no good evidence anesthetic agents affect neurodevelopment of humans. There is currently no need to change practice or delay surgery, but children should not have surgery during infancy if it can be avoided (although there is no evidence for a 'safe' age with no risk, young infants are undergoing rapid brain development, and all risks from anesthesia are higher in the first year). Furthermore, delaying surgery to avoid an

ambiguous and unknown risk of neurotoxicity must be balanced against the added real risk of delaying treatment.

Tip

What to say to a parent who asks if anesthesia will damage their child's brain?

There is animal work suggesting anesthesia affects brain development, but it is not clear how this research applies to children.

There is no evidence a single short GA affects brain development in humans.

Avoiding or delaying surgery and anesthesia may have a much greater risk.

There may be a possibility some brain delays occur in very specific areas and under very specific circumstances, but it is not known if this is due to anesthesia or the reason the child is having surgery, and it has to be balanced against the need for the procedure.

There is no evidence to suggest a specific 'safe' age with no risk.

2.6.5 Sevoflurane

Sevoflurane is widely used because it causes minimal irritation to the airway during induction and maintenance and is the only agent suitable for inhalational induction. It causes less cardiovascular depression and is a safer agent than halothane which was used in the past. It reduces laryngeal and pharyngeal muscle tone which contributes to upper airway obstruction, but also facilitates insertion of an oral airway or LMA.

Inhalational induction with sevoflurane using a circle circuit is achieved by giving the child 66% nitrous oxide in oxygen for 20–30 s, then 8% sevoflurane. Gradually increasing the sevoflurane concentration is a hangover from the halothane induction technique which slows induction and increases the incidence of excitatory phenomena. However, when the T-piece is used for induction, the sudden odor of 8% sevoflurane can cause mask rejection, and a couple of breaths at 0.25–0.5% before turning to 8% is better accepted. The inspired concentration should be kept at 6–8% until excitatory phenomena and respiratory obstruction have reduced.

2.6.5.1 Excitatory Phenomena with Sevoflurane

A series of excitatory phenomena occur during inhalational induction with sevoflurane, including movements of the limbs, upper airway obstruction and hypertonicity of the trunk. They are a common and normal part of inhalational induction. Their incidence is reduced with premedication but increased if sevoflurane is incrementally raised during induction. Sevoflurane often causes seizure-like EEG changes at concentrations over 4%, and may rarely cause overt seizures in children who have a reduced seizure threshold. The seizures usually occur during induction shortly after consciousness is lost, when brain concentration of sevoflurane is highest.

Emergence delirium describes a condition in which children wake after anesthesia crying or screaming inconsolably, thrashing their limbs and appearing disorientated. However it can be difficult to determine if the child's behavior is due to pain (see Chap. 1, Sect. 1.8.1). Emergence delirium is more common after sevoflurane and desflurane than after other agents. The incidence is highest in preschool aged boys and when children awake quickly after sevoflurane. Various strategies have been tried to reduce it, including giving clonidine and opioids during anesthesia, or giving propofol towards the end of anesthesia. There is no evidence changing to isoflurane after sevoflurane induction reduces emergence delirium, whereas changing to propofol is effective.

2.6.6 Isoflurane and Desflurane

Isoflurane and desflurane are pungent and irritant to the upper airway and will cause coughing, breath holding or laryngospasm if used for inhalational induction. Using isoflurane for anesthesia maintenance does not reduce the incidence of emergence delirium. The tachycardia that occurs in adults when desflurane is rapidly increased in concentration is less of a problem in children and easily blunted with opioids. The airway irritation caused by desflurane has prevented it from having a major impact in pediatric anesthesia.

2.7 Fentanyl

Fentanyl is commonly used in pediatric anesthesia, although perhaps not as often as in adult practice where it is used for hemodynamic stability. The clearance of fentanyl is higher in infants and children compared to adults, while it is reduced in neonates (reflecting reduced hepatic metabolism) and in cyanotic heart disease (reduced liver blood flow). However the volume of distribution is much higher in neonates than adults and the plasma concentration after a single bolus dose is a lower than in adults. As a result, neonates may tolerate high doses with less respiratory depression than in adults (Fig. 2.6). However fentanyl has a reduced clearance in this age group, and it accumulates with repeat doses. It is popular as an anesthetic agent in neonatal and cardiac anesthesia, but in children it is generally used for its analgesic properties. It is useful as an analgesic component to anesthesia, particularly if neither nitrous oxide nor a regional technique is used. An intraoperative bolus has a short duration and does not provide adequate postoperative analgesia after many types of surgery. However, fentanyl 1–2 μg/kg reduces the incidence of emergence dysphoria after sevoflurane, albeit increasing the incidence of PONV. Intranasal fentanyl is used for procedural pain in the emergency department, and fentanyl infusions are used as an alternative to morphine for postoperative opioid infusions (see Chap. 9, Sect. 9.3.3).

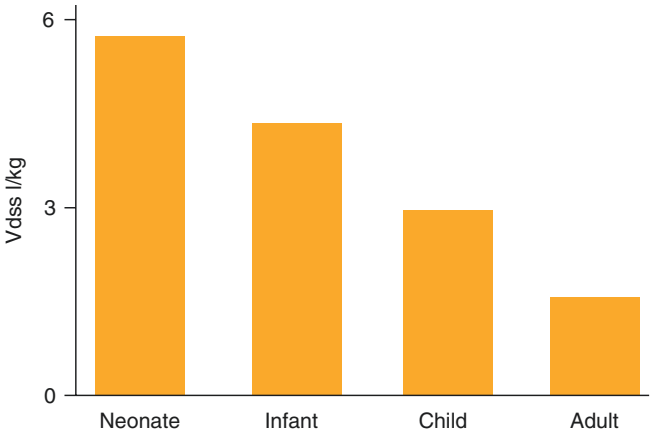


Fig. 2.6 Volume of distribution at steady state (Vdss) for fentanyl at different ages. A bolus dose is distributed into a relatively large volume in neonates, and blood concentration is lower. Neonates can tolerate relatively high doses without respiratory depression. Clearance however is lower in neonates, prolonging the duration of any fentanyl given. Based on Johnson et al. Anesthesiology 1984;61: A441

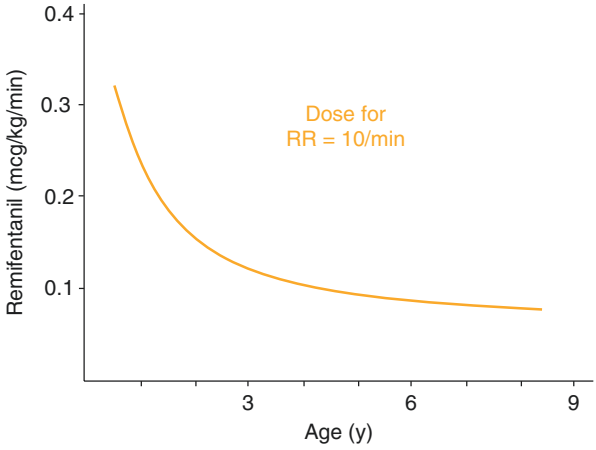


Fig. 2.7 Remifentanil dose required for respiratory rate of 10 breaths/min at different ages. Spontaneous respiration is maintained at higher doses of remifentanil in infants and young children than older children. (Based on Barker et al., Pediatr Anesth 2007;17:948–55)

2.8 Remifentanil

Remifentanil is unique among opioids because the non-specific esterases responsible for its metabolism are fully active at birth. It has an increased volume of distribution in infants and children, but also a higher clearance so that elimination half-life is similar at all ages. Remifentanil is the only opioid with a clearance that is higher in infants than children. As a result of these pharmacokinetic differences, infusion rates that would cause apnea in adults are possible in spontaneously breathing children (Fig. 2.7). Children aged 3–11 years require about twice the infusion rate of

adults during anesthesia to block the response to skin incision. The usual dose in controlled ventilation is 0.2–0.5 μg/kg/min, and doses as high as 0.3 μg/kg/min are tolerated during spontaneous ventilation in infants. A remifentanil bolus of 1–3 μg/kg has been used to facilitate intubation without muscle relaxants in children, although bradycardia is a concern with these doses. There is no TCI model for remifentanil in children.

Keypoint
Remifentanil is unique among opioids. The enzymes that metabolize it are fully active at birth, and its dose is higher in neonates than children—the opposite to every other opioid.

2.9 Muscle Relaxants

The role of muscle relaxants in pediatric anesthesia has changed over the years—intubation is less common since the LMA has been widely used and can be achieved with a combination of volatile agent, propofol and opioid in young children. Volatile anesthesia either alone or in combination with remifentanil can prevent involuntary movement, and muscle relaxation is not needed to be able to ventilate children. Nevertheless, relaxants retain a role in many cases.

2.9.1 Pharmacokinetic Changes

The volume of distribution of relaxants is higher throughout childhood compared with adults due to children's larger ECF volume. Clearance is also higher throughout childhood compared to adults. As a result, children require higher doses in mg/kg compared to adults, and these doses have a shorter duration. The ED95 for most relaxants is higher in children compared to adults (Table 2.10). The onset of relaxants is faster in children compared to adults because of the relatively high cardiac output in children (Table 2.11).

Table 2.10 Approximate ED95 doses of muscle relaxants in children

	ED95 dose (μg/kg)		
	Infants	Child	Adult
Suxamethonium	700	430	270
Atracurium	165	200	220
Rocuronium	240	400	350

Note the higher doses in children compared to adults

Table 2.11 Onset time of muscle relaxants in children

	Onset time (min)		
	Infants	Child	Adult
Suxamethonium	0.6	0.7	0.9
Atracurium	1.2	1.7	2.2
Rocuronium	1.1	1.3	1.6

Note the faster onset due to increased cardiac output

Table 2.12 Neonates are sensitive to non-depolarizing relaxants

Differences of relaxants in neonates
Low proportion of muscle (10% body weight compared to 33% in child)
Neuromuscular junction is immature until 2 months of age – Less acetylcholine (ACh) is released with each action potential – ACh vesicles deplete during tetanic stimulation and muscle fade is normal – Full blockade is reached with only 40% receptor occupancy in neonates, compared to 75% in adults
Metabolic enzymes immature
More type II slow fibers resistant to blockade in respiratory muscles

2.9.2 Relaxants in the Neonate

Neonates are sensitive to non-depolarizing relaxants and have a reduced margin of safety. There are several reasons for this (Table 2.12). The dose of most non-depolarizing relaxants is lower in neonates. Both vecuronium and rocuronium have a longer duration of action in neonates. A typical dose of rocuronium in neonates is 0.3–0.4 mg/kg. Most relaxants in neonates last longer. This general rule holds true except for two important relaxants that have a shorter duration in neonates than children: suxamethonium and atracurium, which are both metabolized by esterases that are fully active at birth.

Keypoint
Muscle relaxants have a faster onset and shorter duration in children. Neonates are sensitive to non-depolarizing relaxants but resistant to suxamethonium. Pharmacokinetic changes result in doses of relaxants being the same at all ages.

2.9.2.1 Volatile Agents Potentiate Relaxants

As in adults, the dose and duration of relaxants are affected by the use of volatile agents. However, healthy children are better able to tolerate brief, high concentrations of volatile agents that can greatly improve the effect of small doses of relaxants. For example, 0.3 mg/kg of rocuronium or 0.3 mg/kg of atracurium given with sevoflurane are effective for intubation after 2 min and give a short blockade for brief procedures.

2.9.3 Suxamethonium

Suxamethonium is used less nowadays due to its poor side effect profile and the use of alternative drugs to achieve rapid intubation. It is not used in routine practice, but reserved for emergency airway management such as rapid sequence induction and laryngospasm with falling oxygen saturation. It has a faster onset and shorter duration throughout childhood compared to adults.

2.9.3.1 Dosage and Administration

The dose in children is 2 mg/kg IV. The intramuscular route is used for the treatment of laryngospasm when no IV access is present. The dose is 4 mg/kg, onset is within 60 s and duration under 20 min. The deltoid muscle is the best site for injection. Although the tongue has been suggested, its use requires the facemask and oxygen to be removed and causes bleeding into the mouth and airway.

2.9.3.2 Side Effects

Although a mild tachycardia is usual after suxamethonium, bradycardia very occasionally occurs, mostly in infants. There is no need to routinely give atropine before suxamethonium. However atropine should always be given before a second dose of suxamethonium to prevent severe bradycardia or asystole. Muscle fasciculations are milder in children and absent in infants, and muscle pain is uncommon until adolescence. Hyperkalemia occurs in the same patient groups as adults. Although rare, suxamethonium causing hyperkalemic cardiac arrest in children with an unrecognized myopathy (particularly boys with Duchenne dystrophy) is one of the causes of the declining use of the drug. Suxamethonium is contraindicated in any child with myopathy, recent large burn or spinal cord injury. It increases intraocular pressure for several minutes, but on balance, this is not an issue in the management of penetrating eye injuries (see Chap. 24, Sect. 24.7).

Keypoint
Atropine must always be given before a second dose of suxamethonium.

2.9.3.3 Butyrylcholinesterase (Plasma Cholinesterase) Deficiency

A mild form of plasma cholinesterase deficiency (heterozygous for one of several abnormal genes) is common but only increases the duration of suxamethonium by a few minutes, so it is not usually noticed. Children who are homozygote for the genes are rare (1 in 2000–4000, prolonging the action of suxamethonium to 2–12 h), but about 25% of the population have variants with some prolongation of duration (though usually by only a few minutes). Management is sedation and ventilation followed by measuring the cholinesterase activity. Although neonates and infants under 6 months have only about half the adult level of butyrylcholinesterase, this does not prolong the effect of suxamethonium.

2.9.3.4 Masseter Spasm

The tone in the masseter muscle often increases slightly after suxamethonium, but the term 'masseter muscle spasm' refers to rigidity of the jaw that prevents mouth opening for more than 2 min. This rare occurrence has been described as 'jaws of steel'. Many children with this later develop markedly raised creatine kinase (CK) levels and myoglobinuria and are found to have a myopathy. Masseter spasm after suxamethonium may be an early sign of malignant hyperthermia (MH), and 50% of patients who have masseter spasm later test positive for MH on muscle biopsy.

During masseter spasm, the mouth cannot be opened and intubation is impossible. Mask ventilation occurs through the nostrils and is not affected. It may be appropriate to terminate anesthesia after masseter spasm has occurred. However for urgent surgery anesthesia can be continued with a non-triggering technique providing other signs of MH are not present. There is no need to change the machine, but volatile agents should be stopped and high flows used to wash out any volatile agent from the patient and circuit. The child must be admitted for monitoring and measurement of CK levels post op.

2.9.4 Atracurium

Atracurium has a fast onset, short and predictable duration of action and is a good choice for routine use in all ages. The dose is 0.5 mg/kg, although it differs from all other relaxants in that it has a shorter duration in neonates than children. Smaller doses can be used if supplemented briefly by high concentrations of volatile agent, or short-acting opioids. Histamine release is uncommon in children.

2.9.5 Cisatracurium

Cisatracurium has a slower onset and longer duration compared to atracurium and has no advantage over atracurium in children. The dose is 0.15 mg/kg.

2.9.6 Vecuronium

Vecuronium should be considered a long acting relaxant in neonates and infants less than 12 months. It has a large volume of distribution in this age group so that the duration of block after 0.1 mg/kg is 1 h in neonates but only 20 min in children.

2.9.7 Rocuronium

Rocuronium has a faster onset than other relaxants, although the difference is less marked in children than adults. It has a longer duration in neonates and infants than in children. A dose of 0.6 mg/kg lasts about 50% longer in infants than children

(42 min and 27 min respectively), but intubation can be readily achieved with lower doses such as 0.3 mg/kg supplemented with sevoflurane. A high dose of 1.2 mg/kg provides good intubating conditions in 33 s in children and lasts about 75 min. However this type of modified rapid sequence technique is being questioned, with concerns about the safety of trying to hurriedly secure the airway after a period of apnea (see Chap. 1, Sect. 1.6.3).

2.9.8 Reversal of Relaxants

Relaxants should always be reversed in neonates and infants. This age group are at risk of residual neuromuscular block because of increased sensitivity to relaxants, longer elimination half-life of relaxants, susceptibility to hypothermia and less type I muscle fibers in the diaphragm that leave it prone to fatigue. Furthermore, it is difficult to monitor neuromuscular blockade in small infants as direct muscle stimulation often occurs. However older children having long procedures often don't need reversal (after checking with a nerve stimulator). Children are reversed faster and with smaller doses of antagonists than adults.

2.9.8.1 Neostigmine

Neostigmine has a faster onset and slightly shorter duration in children compared with adults. The dose of neostigmine required in infants and children is 20–35 μg/kg, although 50 μg/kg mixed with atropine 20 μg/kg (the same dose as adults) is commonly used for simplicity. Calculating and drawing up the doses of neostigmine and atropine are complicated and prone to errors. A technique that dilutes the adult dose reduces calculation errors and is shown in Fig. 2.8. In this technique, 1 mL of the diluted mixture is given per 10 kg body weight. For neonates, a 1 mL syringe is used to withdraw the diluted mixture, and a portion given based on weight—a 4 kg baby would be given 4/10 of a milliliter.

Glycopyrrolate can be used in place of atropine. It is less commonly used in children as atropine rarely causes arrhythmias or problematic tachycardia. Both atropine and glycopyrrolate can cause flushing in the 'blush' area of the face and neck in infants. This is usually delayed and typically noticed in PACU. Parents should be reassured this is not an allergic reaction and will fade within hours.

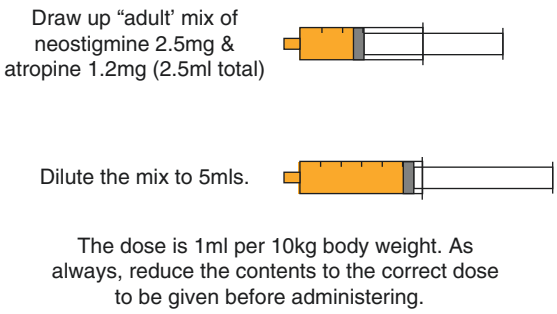


Fig. 2.8 Method of drawing up neostigmine for children

2.9.8.2 Sugammadex

The role of sugammadex in children is not as clear as in adults, as muscle relaxants have a shorter duration in children and the side effects of neostigmine are less problematic in children. It has not been investigated in children as much as adults. Nevertheless, sugammadex reverses rocuronium rapidly and more effectively than neostigmine. Dosing is based on the TOF response: 2 mg/kg if there are two or more twitches of the TOF, and 4 mg/kg if the block is deeper. The maximum dose of 16 mg/kg is used for reversal immediately following an intubating dose of 1.2 mg/kg of rocuronium, (an 'off-label' use of sugammadex in children).

2.10 Midazolam

Oral midazolam is commonly given as a premed at an oral dose of 0.3–0.5 mg/kg. IV midazolam is used as a co-induction agent in adolescents and for sedation of ventilated children in intensive care, but is uncommonly used during anesthesia in younger children. Hepatic metabolism and clearance of midazolam are reduced in neonates, causing a prolonged action in this age group. Children aged between 1 and 4 years have increased clearance but also are resistant to sedation from midazolam. This age group often requires higher doses than adults or infants. Flumazenil is rarely needed in children. The dose is 5 μg/kg to a maximum of 40 μg/kg.

2.11 Clonidine

Clonidine has sedative, anxiolytic and analgesic effects in children. It is used as a premedication, as an adjunct to epidural local anesthetics and to prevent or treat emergence delirium. It is also given orally to treat some children with ADHD, autism and to manage opioid withdrawal. Bioavailability is nearly 100% orally. Nasal administration is not recommended as absorption is unreliable. The elimination half-life is about 5 h, shorter than in adults, but in infants its clearance is reduced and half-life prolonged.

In clinical use, clonidine produces sedation and reduces heart rate and blood pressure although these hemodynamic responses are not usually of concern. Oral clonidine 3–4 μg/kg 60–90 min preoperatively is used as a premed. When combined with local anesthetics, clonidine 1–2 μg/kg prolongs analgesia by at least a few hours. Sedation and hypotension occur mostly in infants, and apnea may occur in neonates. Clonidine prevents emergence delirium, although the Cochrane review showed this was true only when anesthesia included a regional block. It does not reduce delirium after tonsillectomy. IV clonidine 1–2 mcg/kg can be used to treat emergence dysphoria in young children, but this dose often makes the child sleepy for up to 4 h after surgery.

2.12 Dexmedetomidine

Dexmedetomidine has many potential uses in pediatric anesthesia, but its eventual role is not yet known. It produces a sleep-like sedation. It causes little respiratory depression but can cause upper airway obstruction. It is used as a premed and to provide sedation for non-painful procedures such as radiology and EEG. In anesthesia, it is used as a TIVA-sparing agent when maintenance of spontaneous ventilation is important, such as during airway procedures. It also It is one of a few agents thought to be non-toxic to the developing brain. It is only licensed in children for ICU sedation where it is a useful to stabilize postoperative cardiac patients and possibly prevent junctional ectopic tachycardia.

Its advantage over clonidine is a shorter elimination half-life of about 2 h. Metabolism is reduced in the first 1–2 years, especially in infants in whom it has a longer half-life. The IV dose is 0.5 μg/kg gently titrated and repeated if required, followed by an infusion of 0.3–0.7 μg/kg/h. As a premed, 3–4 μg/kg given nasally is preferable, as oral bioavailability is low and variable. The buccal route is an alternative and with a lower dose.

Dexmedetomidine has some disadvantages apart from cost. It causes bradycardia in a dose dependent manner, which is often just monitored because anticholinergics given as treatment may cause significant hypertension if not carefully titrated. Hypotension can also be a problem in older children. Excessive postoperative sedation can be a problem, particularly for infusions longer than 1.5–2 h. It is usually best to halve the infusion rate at this time, and stop the infusion 20 or 30 min before the end of the procedure.

2.13 Antiemetics

The incidence of postoperative nausea and vomiting (PONV) increases with age. It is low during infancy but increases from the age of 3 years. Prophylactic antiemetics are commonly given to older children.

Tip

High-risk procedures for PONV are strabismus repair, prominent ear correction, umbilical hernia repair and open orthopedic procedures.

A common reason for PONV after all types of surgery is too much opioid relative to the severity of pain.

2.13.1 Ondansetron

Ondansetron is the only $5HT_3$ antagonist licensed for PONV in children, and has an optimal dose of 0.15 mg/kg (maximum 4 mg). The time it is given to children during anesthesia does not affect its efficacy. Doses can be repeated every 6–8 h if

required. It is also available as an oral wafer in a dose of 4 mg, which can be used as a single dose in children without IV access weighing more than 20 kg. Ondansetron causes a clinically insignificant lengthening of the QT interval, but should be avoided in children with known or suspected prolonged QT interval. Tropisetron and granisetron are probably less effective than ondansetron and are not licensed in children. Dolasetron is contraindicated in children as it may change the QT interval and cause arrhythmias.

APA PONV Guidelines
Children at risk of PONV: ondansetron 0.15 mg/kg.
Children at high risk of PONV: ondansetron 0.15 mg/kg plus dexamethasone 0.15 mg/kg.

2.13.2 Dexamethasone

Dexamethasone is an effective antiemetic by itself and in combination with ondansetron. The ideal dose of dexamethasone is not known, but 0.15 mg/kg (maximum 8 mg) is effective, recommended and simple as the dose is the same for the two drugs. Rather than acting on a cell-surface receptor like ondansetron, it enters cells and affects the expression of 37 different genes. The effects of this, and why dexamethasone has an anti-emetic effect are not known. Although dexamethasone is generally safe and is widely used, there are several concerns about its effects (Table 2.13).

Note
Ondansetron combined with dexamethasone is more effective than ondansetron alone.

2.13.3 Droperidol

Droperidol is used in children as a rescue antiemetic, or in combination with ondansetron when dexamethasone cannot be used. It has mostly been superseded in children by more recent antiemetics with a better side effect profile. It causes sedation,

Table 2.13 Side effects and other concerns about dexamethasone in children

Concerns about dexamethasone in children
Unknown mechanism of action
Increases BSL for several hours postop and may affect control of BSL in children with labile diabetes
Increases the return-to-theatre rate after tonsillectomy
Causes sensation of perineal warmth when given to awake children
Some evidence it affects wound infection in adults
May cause tumor lysis syndrome in some children with untreated hematological malignancy

and infrequently causes extrapyramidal effects at higher doses and in teenage girls. The FDA issued a warning about prolongation of the QT interval in adults and at higher doses, and it is obviously contraindicated in children with prolonged QT interval. The dose of droperidol is 10 μg/kg as a single dose.

2.13.4 Promethazine

Promethazine (phenergan) is a rescue treatment for PONV unresponsive to other treatments. Sedation and cardiovascular side effects are complications of its use. The dose is 0.1 mg/kg given slowly IV (maximum 12.5 mg). It should not be used in children at risk from sedation, including those with obstructive sleep disorder.

Review Questions

1. Why is remifentanil different to all other opioids in neonates?
2. Name a suitable antiemetic and dose for routine use in children. What combination and doses is suitable for children at high risk of PONV?
3. Why are neonates 'sensitive' to rocuronium?
4. A child has been given suxamethonium as part of a rapid sequence induction for emergency surgery, but 1 min after giving it, the mouth cannot be opened at all. What might this signify? What will you do?

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Behavioral Management of Children

3

Craig Sims and Lisa Khoo

Children are anxious before anesthesia and surgery because of unfamiliar surroundings, a sense of loss of control, the presence of strangers, parental anxiety and many other perceived threats. Like adults, they respond to stress depending on their temperament and personality. At induction of anesthesia some children will say they are frightened, others will cry, withdraw, cling to their parent or become uncooperative. Unlike adults who will remain cooperative despite being nervous, young children will let you know one way or another they are frightened. Many anesthetists may be uncomfortable caring for children because of the potential for frightened children to become uncooperative. Behavioral management includes techniques to reduce children's anxiety at induction and improve cooperation.

3.1 Anxiety at Induction of Anesthesia

Anxiety increases from admission to induction, with induction of anesthesia being the most stressful part of a child's hospital admission (Fig. 3.1). Children can display their anxiety with verbal or physical resistance, crying, screaming, becoming quiet and withdrawn, or expressing fear or sadness. These signs of anxiety are more frequent in younger children and are unfortunately very common: 42% of 2–10 year olds show one of these signs and 17% show three or more. Up to 25% of children who have not had a premed or parent present require restraint at induction. The anxiety experienced by the child depends on many factors, including temperament, their coping strategies, past experiences, the anxiety of parent and the behaviors of staff.

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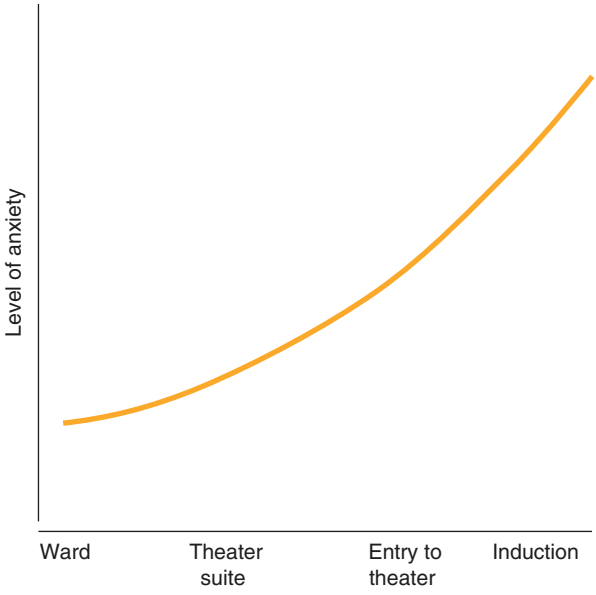

Fig. 3.1 A child's anxiety increases during the different preoperative stages towards induction, although there is great variation between children depending on their temperament, past experiences and many other factors. Based on Chorney JM, Kain ZN. Anesth Analg 2009;109: 1434–40

3.2 Consequences of Anxiety at Induction

There are five consequences of anxiety at induction:

- Reduced cooperation
- Agitation during emergence from anesthesia
- Possibly increased postoperative pain
- Regression of behavior for up to several weeks afterwards.
- Increased anxiety at subsequent hospital admissions and anesthetics.

The stress associated with hospitalization and surgery contributes to postoperative behavior changes (Table 3.1). Initial studies have found these changes in children admitted overnight to hospital, and more recent studies also found them in children having surgery as outpatients. These behavioral changes may persist long after discharge, and a small proportion of children may have them for a few weeks or months (Fig. 3.2). Their incidence depends on the temperament and personality of the child but they are more likely to occur in preschool-aged children and those who were anxious at induction. Children who have a 'stormy' induction are more likely to be agitated when awakening and more likely to have postoperative behavioral disturbances (Fig. 3.3). They may also become more anxious about future anesthetics (Fig. 3.4). These effects are probably reduced with premedication or other strategies to reduce pre-operative anxiety.

Table 3.1 A child's behavior may regress to that of a younger child in response to the stress of hospitalization and surgery

Behavior change after anesthesia and surgery
Sleep disturbances and night terrors
Clingy and separation anxiety
Withdrawn and quiet
Fear of doctors or hospital
Food refusal; disobedience
Tantrums
Enuresis

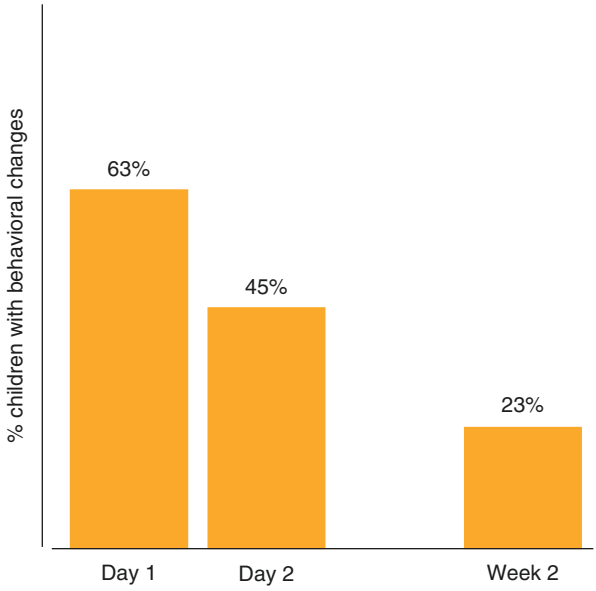

Fig. 3.2 Percentage of children aged 1–7 years with behavior changes at different times after anesthesia and surgery. Based on Kain ZN et al. Anesth Analg 1999;88: 1042–7

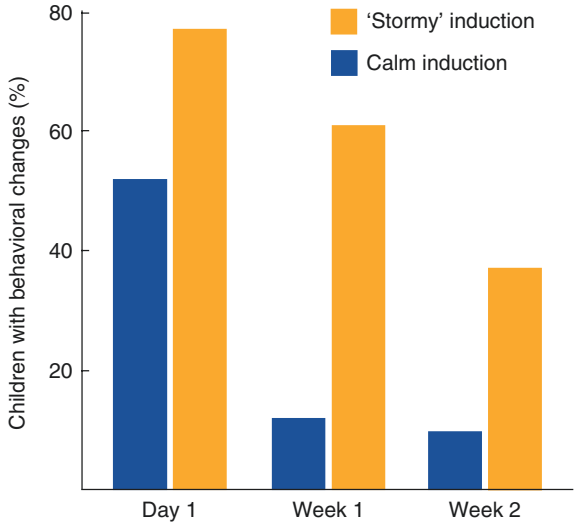

Fig. 3.3 A difficult, 'stormy' induction is associated with an increased incidence of behavioral changes after anesthesia. Since children can't be randomized to calm or stormy inductions, it isn't known if the child's temperament that predisposed them to anxiety also predisposed them to behavioral changes afterwards. Data from Kain ZN et al. Anesth Analg 1999;88: 1042–7

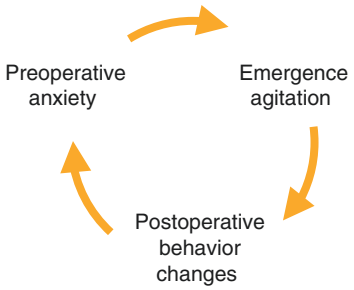

Fig. 3.4 Preoperative anxiety may affect emergence from anesthesia and cause dysfunctional behavior in the postoperative period. This experience may then increase the child's anxiety at the next anesthetic

3.3 Reduction of Anxiety at Induction

Most strategies to reduce anxiety are aimed at the child and parent, and include psychological preparation or education programs, parental presence at induction, and pharmacological premedication. The child's anxiety however, is greatly affected by the behavior of the anesthetist.

3.3.1 Psychological Preparation for Anesthesia and Surgery

The aim of psychological preparation is to reduce the child's anxiety and improve their behavior at induction. A range of preparation techniques are required and must be appropriate to the child's developmental age, temperament and personality.

The most intensive preparation is performed by Child Life Therapists (Play Therapists) and Occupational therapists. They are experts in child development and promote coping strategies through play, education, and self-expression activities. This preparation teaches children coping and relaxation skills, provides information about events and procedures, and supports the child and parents during the preoperative period. Another form of preparation is modelling, in which the child indirectly experiences the theatre environment through video, puppet shows and other media. These programs are labor-intensive and expensive, and are usually reserved for children who have behavioral issues from frequent medical procedures. Unfortunately, although these techniques reduce anxiety leading up to anesthesia, they do not reduce the intense anxiety at the time of induction in most children. The anesthetist can teach simple relaxation techniques such as deep breathing and muscle relaxation on the day of surgery. Younger children can be taught to hold their breath. These techniques then can be brought out if anxiety and distress occur: "remember your job is to take a big breath and hold it still like a statue, so go ahead now and take that breath".

Hospital tours are another form of preparation, but time and economic factors mean that in practice this high-level preparation is given only to a small proportion of children, and often to well-motivated families whose children are least likely to need or benefit from the preparation.

Table 3.2 Summary of recommendations for preoperative information to children

Recommendations for preoperative information
Methods of delivering information: – Video format – Written, especially with illustrations (book)
Information to be included: – Specific, age appropriate information – Include both what will happen and what will be felt or seen – Specifically mention pain if likely to happen, but care with word choices and suggestion – Choices or preferences for aspects of anesthesia can be discussed with adolescents to help them feel more in control and reduce anxiety, but younger children unlikely to comprehend – Provide all children opportunity for questions
Best time to give: – 6 years or younger, give closer to time of procedure – Older than 6 years, give more than 5 days beforehand

The commonest, though least effective form of preparation is written or video information for the child and parent (Table 3.2). The information needs to be specific and contain a description of what will happen, as well as sensory information about what will be seen, heard, smelt, tasted or felt. Less information needs to be given to preschool children as they have a limited ability to conceive alternate physical states. In this age group, it is best to concentrate on giving information to prepare their parents. In the future, web-based programs will give information tailored to each child's developmental age and personality, and may be more effective.

Note
Both the parent and child need to have their anxieties and concerns managed. Always remember the parent-parental anxiety increases the child's anxiety and worsens their behavior at induction.

When to give information depends on the age of the child. Young children don't retain information very long whilst older children may become more distressed if information is given too close to the time of the procedure. Children older than 6 years benefit from receiving information at least 5 days before the procedure. Closer to surgery, the information is better kept less specific and intimidating. Children younger than 6 years can receive information 1 or 2 days beforehand. Some parents do not tell their child that a procedure is going to happen, believing this will cause the child less stress. However, these children are nearly always very distressed at wakeup and afterwards, demonstrating the need to at least mention the procedure to the child beforehand.

If the anesthetist is not used to talking to children, a pragmatic alternative is to provide information to the parents, and then rely on them to explain to the child in

an appropriate manner or language. This approach avoids inappropriate words or concepts, but perhaps risks misinformation.

3.3.2 The Behavior of the Anesthetist at Induction and Its Effect on the Anxiety of the Child

The behavior of an adult affects the behavior of a child. Observational studies of anesthetic staff and children at the time of induction show the behaviors of anesthetic staff can either worsen or reduce a child's anxiety. Aspects including the staff's posture, facial expression and position relative to the child may affect the child's anxiety. The anesthetist can make a big difference to the child's anxiety and experience of anesthesia by getting the child's attention and keeping it. This stops the child from becoming internally focused due to fear, and then becoming inaccessible. Distracting the child at induction avoids behaviors that increase anxiety. Reassurance and empathic statements focus the child on their feelings or distress and increase anxiety. Distraction steers attention away from the medical procedure and reduces anxiety (Table 3.3). The words chosen by the anesthetist also affect the child's behavior. Framing discomfort using playful imaginative or abstract language

Table 3.3 Reassuring, empathic statements focus the child on their feelings of distress and increase anxiety

Anesthetist behaviors that increase a child's anxiety		Anesthetist behaviors that reduce a child's anxiety	
Reassurance, empathy and apologizing	"You'll be OK" "Don't worry" "I know it's hard" "I'm sorry"	**Non-procedural talk**	Talking about toys, pets, favorite movies Story telling
Excessive technical or medical talk	Too much information about procedure or equipment	**Humor**	Jokes
Suggesting control when none exists	"Are you ready to come to theatre now?" "Can I put the mask on now?"	**Choices with clear limitations and does not allow avoidance of procedure**	"Walk or ride on trolley?"; "Strawberry or chocolate mask?" "You can breathe on the mask or just blow it away"
Multiple adults talking		**Medical play**	'Astronaut space mask'
Allowing child to delay		**Firm warm confidence**	
Poor word choice	Needle, sting, hurt Focusing on what child *can't* do	**Good word choice**	Metal tube, plastic straw Focusing on what child *can* do

Distraction steers attention away from the induction and reduces anxiety
Based on Martin et al. Anesthesiol 2011;115: 18–27

Table 3.4 No matter the distraction used, there are several characteristics to maximize its effect

Effective distraction
Is interesting and new to the child
Begins with a sense of anticipation to build excitement
Gets child's attention as soon as entering theatre
Increases as induction approaches and anxiety increases
Is continuous with no pauses or gaps that might lose child's attention
Has the strongest distraction saved for the time of mask acceptance or IV insertion when anxiety is maximal

is helpful—'sparkles' up the arm rather than 'this may sting a little', or 'a beautiful perfume' rather than 'this gas might smell'.

3.3.2.1 Effective Distraction

Although some children will be relaxed with simple non-procedural talk about school or toys, other children are more anxious and benefit from stronger distraction. The choice of a distraction depends on a complex interaction between the anesthetist's personality, the child's age and temperament, equipment available and the theatre environment. Some anesthetists are great story tellers and are able to guide the child into an imaginary world; others can use pretty stickers or a toy, tell jokes, or do a few magic tricks. A popular technique uses video games or movies on a hand-held device. Effective distraction needs to start early, be continuous and increase as induction progresses (Table 3.4).

3.3.3 Pharmacological Premedication

Premedication (premed) is the most reliable way to reduce a child's anxiety and improve cooperation at induction. It also reduces parental anxiety and improves parental satisfaction. However, not every child requires a premed, and the skill is in choosing which child will benefit. A premed may slow wake up, cause dysphoria in recovery and carries a cost in nursing time. The premed is nearly always given orally, though this requires some cooperation from the child. The nasal or buccal route may be an alternative. The advantages and disadvantages of oral premeds are listed in Table 3.5. There are a few situations in which a premed should be avoided or used in a reduced dose. These are when a difficult airway is anticipated, there is severe sleep apnea, an increased risk of apnea, and when there is raised intracranial pressure.

3.3.3.1 Midazolam

Midazolam is widely used because it reliably provides anxiolysis, has a rapid onset and short duration. Oral midazolam has a bitter taste. When the IV preparation (5 mg/mL) is used for oral premedication, its taste is disguised by mixing it with ice cream topping, undiluted cordial or jam. A commercially-made midazolam is available for oral use in some countries.

Table 3.5 Comparison of oral premeds and their advantages and disadvantages

Oral premed agent (time to give before induction)	Advantages	Disadvantages
Midazolam 0.3–0.5 mg/kg, max 15 mg (30 min)	Rapid onset Short duration Anxiolytic Doesn't delay discharge	Bad taste Dysphoria Amnesia
Clonidine 4 µg/kg (60 min)	No amnesia Reduces emergence dysphoria Timing of administration less critical Tastes better than midazolam	Slow onset Long duration- may delay discharge Bradycardia Child easily awakens with noise or stimulation at induction
Dexmedetomidine 3 µg/kg (45 min)	Well tolerated Analgesic, sleep-like sedation Possibly anxiolytic	Intranasal route may be better. Use 2 µg/kg Expensive
Ketamine 2–5 mg/kg (30 min)	A 'heavy' premed for autism, developmental delay, uncooperative older child	PONV Dysphoria Potential for airway obstruction Not suitable for routine use

Midazolam is the most commonly used agent, though there is also strong support for clonidine

Oral midazolam is mostly an anxiolytic with little sedation, making it relatively safe in obstructive sleep apnea and other situations where airway patency may be a concern. The oral dose is 0.3–0.5 mg/kg (max 12–15 mg). The lower dose is usually effective in all but the most anxious child, and reduces the risk of postop dysphoria (Fig. 3.5). The dose can be 'titrated' against the desired effect, particularly in older children—some children appear as well-behaved and likely to be easy to distract at induction, but are scared. A dose towards the lower range might be appropriate. A younger child might be very fearful and have had difficult past anesthetic experiences, and a maximal dose might be appropriate. Midazolam can be given by the buccal route by squirting it between the teeth and cheek or lower lip. Either the IV preparation or midazolam marketed for seizure treatment can be used. The nasal route is another option in uncooperative children—the dose is lower (0.2 mg/kg) and the IV preparation is squirted into the nostril with an atomizer device. Intranasal administration is unpleasant, most children will need to be restrained and it is best used only in exceptional circumstances.

Onset by either route is 12 min, with peak effect at 20–30 min. If midazolam is given too early, a proportion of children, particularly preschool-aged will develop a paradoxical reaction and become dysphoric, uncooperative and hallucinate. This effect usually occurs after 45–60 min and is the reason why it is important to time the administration of midazolam carefully. Midazolam reduces anesthetic requirements, delays emergence but does not generally delay discharge. It produces anterograde and retrograde amnesia, but there are concerns this loss of memory may be a distressing experience for the child, as it is in adults.

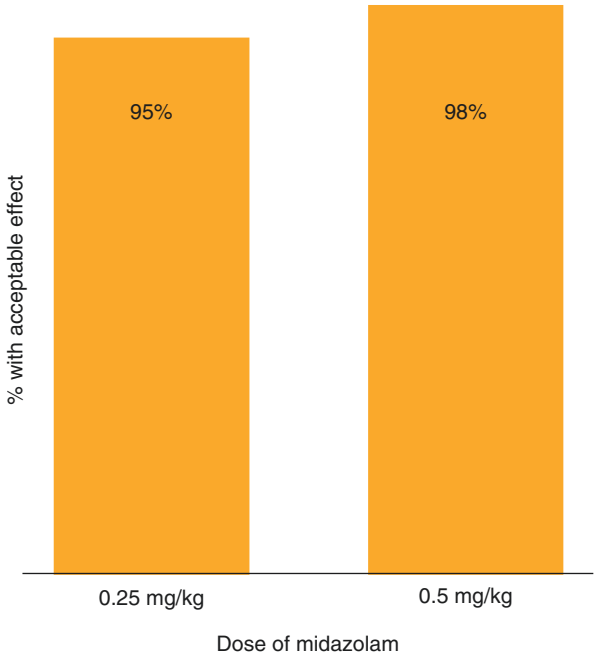

Fig. 3.5 Oral midazolam 0.25 and 0.5 mg/kg are almost equally effective. *Based on Cote, Anesth Analg 2002;94: 37–43*

3.3.3.2 Clonidine

Clonidine is commonly used as a premed at a dose of 3–4 μg/kg, much larger than the IV dose because bioavailability after oral administration is only 55%. Its onset is slow with peak effect at 60–90 min. It is mostly a sedative with some anxiolysis. It reduces anesthetic requirements and emergence dysphoria and improves postop analgesia. Significant bradycardia is very uncommon. There is no commercially available clonidine syrup in most countries, so the IV preparation is mixed with flavoring and given orally. The IV preparation is concentrated and has an unusual concentration (150 μg/mL) which increases the risk of a dose error. In practice, children are easily aroused from their sedated state and can become quite alert and anxious at the time of induction.

3.3.3.3 Dexmedetomidine

Although not licensed for use in children, there are many studies of dexmedetomidine being used as a premed. The IV preparation is used for the oral and intranasal routes, though this preparation remains expensive. Bioavailability is 65% by the nasal route and 82% by the buccal route. It is only 16% by the oral route and so some authors suggest not giving dexmedetomidine as an oral premed. The intranasal dose is 2–3 μg/kg. Its onset is about 25 min, duration 85 min. Some, but not all studies show superiority over midazolam.

3.3.3.4 Ketamine

Oral ketamine is considered a ‘strong’ premed used either alone or in conjunction with midazolam. Monitoring, oxygen and the ability to resuscitate need to be

available. It is best reserved for more difficult patients such as autistic children, older developmentally delayed children or terrified school-aged children who would not otherwise be cooperative. The dose of oral ketamine is 2–5 mg/kg. Midazolam 0.2–0.5 mg/kg can be mixed with it to increase the effect. The higher dose range of ketamine with or without midazolam may produce unconsciousness and airway obstruction. Recovery time is similar to midazolam, however ketamine has a high incidence of PONV, especially if the dose of concurrent opioids is not reduced. Excessive oral secretions do not seem to be a problem after oral ketamine.

Intramuscular ketamine is used as a premed or 'pre-induction' agent in older autistic or developmentally delayed children who are combative and refuse oral premedication. A dose of ketamine 1–2 mg/kg into the deltoid or thigh muscle, through clothing if need be, stuns the patient and is effective. Higher doses (5–10 mg/kg) induce anesthesia and result in prolonged recovery and increased hallucinations.

3.3.4 Parental Presence at Induction

Having one parent present at the induction of anesthesia is routine in most centers. Parental presence prevents the tears and anxiety that would otherwise result from separation from the parent, but it does not reduce the anxiety associated with the induction itself. Premedication reduces anxiety at induction better than parental presence. Despite this there are several advantages to having the parent present (Table 3.6). One of the most important is it allows the parent to witness the induction so that they don't have to rely on their child's description afterwards. If the induction was not the calm and happy one hoped for, the parent can see what happened and put into perspective their child's recollection of events. There are however, concerns about the lack of parental education before participation in the induction, and that some parents may be passively involved or make negative remarks rather than be supportive. These can be addressed by explaining the plan for the induction and how the parent can help, and a warning of how the child may look during and after the induction. Very occasionally a parent may hesitate to leave after induction or want to stay during the surgery. Remind them firstly when the child wakens in recovery the parent will be there and as far as their child is

Table 3.6 Advantages and disadvantages of parental presence at induction

Parental presence at induction
Advantages:
Stops separation anxiety/crying
Allows parent involvement in care of child
Improves parental satisfaction
Raises profile of anesthesia as a specialty
Allows parent to witness care and attention given to their child, even if induction is 'stormy'
Disadvantages:
Does not reduce anxiety at time of induction
Requires escort for parent from theatre suite
May be stressful for parent

concerned, the parent has never left. Secondly, it is safer for their child if they leave as soon as their child is asleep so staff will be able to look after the child rather than the parent. Many parents find it stressful and emotional to be present at the induction of anesthesia but most will wish to participate in subsequent inductions.

Keypoint
Carefully explain to parents about what to expect at induction, and what is expected of them. They can then filter this information to their child.

Tip
Stay calm and confident while the parent is present at induction as they will worry about their child if you look worried.

Warn the parent before and during induction about movement, sounds and appearance.

Reassure the parent that all is well when you ask them to leave.

3.3.5 Hypnosis

Hypnosis is an altered state of consciousness in which there is a state of inner absorption. It is based on the principle of dissociation, in which attention is focused and there is less awareness of the surroundings. Children older than 3 years may be more susceptible to hypnosis than adults as they are more likely to be absorbed by fantasy and storytelling. Some elements of hypnosis are used by anesthetists as part of their induction routine. These elements include guided imagery, storytelling, and speaking in a slow rhythmic manner with description of familiar sights and sounds. The words chosen can modify the sensation of pain by direct suggestion and promote relaxation. Formal hypnosis is used by some anesthetists. It is effective at reducing anxiety in children at induction, and reducing discomfort associated with procedures. The 'magic glove' and switch-wire imagery are two simple techniques.

Keypoint
The behavior of a child regresses during times of stress. A young teenager may need to be treated more as a child, or a child as a younger child when under the intense stress of hospitalization and induction of anesthesia.

3.4 Assessment and Management on the Day of Surgery

The behavior of most children at induction will depend on their management, hence the importance of techniques to reduce anxiety. A small proportion is likely to be uncooperative despite any technique, and a small proportion will always be cooperative despite minimal behavior management (Fig. 3.6). The behavior of most

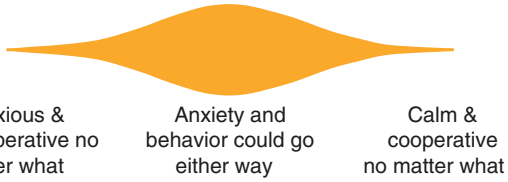

Fig. 3.6 Anxiety and behavior of most children at induction can be influenced by the anesthetist's use of premed and behavioral management techniques

Table 3.7 A summary of age, developmental stage and behavior relevant to induction of anesthesia

Child's developmental stage	
Infant <1 years	Often cry with acts of daily living (nappy change, hunger). Unable to distract
Preschool age 1–5 years	High anxiety about separation and unfamiliar surroundings. Able to distract. Unlikely to be cooperative if anxious. Become aware of surgery and its implications if previous bad experience
School age child 5–10 years	Aware of surgery and its implications. May be very anxious. As become older may be able to remain cooperative despite anxiety
Teenager/adolescent >10 years	Aware of surgery and its implications. May be concerned about awareness and death. May be very anxious but will remain cooperative

could go either way, and this section aims to give practical techniques to reduce children's anxiety and maximize cooperation at induction.

3.4.1 Assessing Temperament and Establishing Rapport

It takes skill and 'art' to assess and prepare a child in the brief time available in a busy day-of-admission service. During the preoperative consultation, the anesthetist has the opportunity to assess the child's behavior, determine whether a premed is likely to be required, provide relevant information, and attempt to establish rapport and trust with the child. The developmental stage of child is a starting point for assessment (Table 3.7).

Questioning the parent and observing the child gives valuable indicators of the need for extra care or a premed. Smile and be friendly, introduce yourself to the parent and child, get down to the child's eye level. Avoid speaking in a loud or strong, intimidating voice. Being at an angle rather than face-to-face is less intimidating. It is not obligatory to always talk to very young children, as they will often be watching and listening anyway. However, child-centered communication includes talking to the child first and getting their permission to talk to their parent. In a brief consultation, the parent can usually be relied on to talk to their child afterwards in an age appropriate manner using (or avoiding) any particular words with special meaning within that family. With teenagers, more of the conversation should be directed to the patient.

Before examining a young child, remember that you are invading their personal, private space. Make sure that a parent is present and the child knows you are a doctor. Proceed cautiously so as not to put them 'on guard'. Privacy during the examination should be ensured for school-aged patients, especially girls. Try to move the child away from the TV or computer game while you are examining or interacting with them, because the child becomes preoccupied and it is hard to assess their temperament—they may appear relaxed and happy whilst watching, but are actually very scared. Toddlers are unlikely to allow a stranger to touch them unless they are sitting on the mother's lap. A gradual start to auscultation of the chest is to listen through the child's clothes, which gets them used to what is going to happen, and then light heartedly warning them about the cold stethoscope that's coming. Sound effects or using play (listening to their toy) to introduce auscultation may help. The child's response to auscultation is a useful sign of their anxiety and behavior. Some confidently pull up their top for you, others will shy away or even cry—a sign that a premed is worth considering.

3.4.2 Preoperative Discussion

Discussing a medical procedure in a clinic setting with a child who has a chronic disease is different to discussing anesthesia with an anxious child shortly before anesthesia. There is often limited time for the anesthetist to develop rapport or to talk and listen to the child. In the stressful situation, children are less able to absorb and process medical information, or to make decisions about themselves. In addition, detailed medical information close to induction increases the child's anxiety. A balance is needed depending on the age and comprehension of the child, between information for consent versus how much is said in front of the child.

Teenagers and older children should be told about the IV insertion, or the options for induction. Some anesthetists discuss the IV with younger school aged children. This may or may not be useful and alternatively the IV can be described with a euphemism and allows the parent to describe it to the child at their discretion.

Younger children shouldn't be given choices as they have a limited ability to conceive alternate physical states. It is often best to decide management in consultation with the parent and then tell the child. You need to be flexible and open to changes in strategy according to the child's response. Some frightened children however will automatically ask for the opposite of your plan in the hope that they will be allowed to do nothing and just go home. Teenagers and older children are often concerned about awareness and not waking up afterwards, and both of these should be specifically mentioned in the discussion.

It is also worth preparing for the induction by either gently holding the child's wrist as if to bring up their veins, or placing a cupped hand on their nose and mouth as if it were a mask. Once again, sound effects may help to make this invasion of personal space acceptable, and the child's response gives another indication of their

temperament. Finally, if a special distraction technique is going to be used at the time of induction (such as stickers, a toy, video game), it is worth mentioning it to build-up anticipation of something exciting or interesting for the child to look forward to.

Keypoint
Pharmacological premedication and distraction are the two best techniques to reduce anxiety and maintain cooperation at induction.

3.4.3 Children Who May Benefit from a Premed

The child's anxiety level usually increases leading up to induction (Fig. 3.1) and allowance needs to be made for this at the time of assessment. There are several signs suggesting a premed may be beneficial (Table 3.8). It would be uncommon for a premed to be given to children younger than 12 months, but practice varies with 1–2 year old children—they are not usually cooperative at induction, but also may not like taking a premed that won't necessarily guarantee cooperation at induction, and may make the child dysphoric if the procedure is short and the premed still having an effect postop.

Young preschool-aged children are the most likely to require a premed. Whether or not one is used depends on a complex interaction between the child's temperament, their anxiety and their coping mechanisms, the procedure, and the anesthetist's ability to distract and occupy the child at induction.

Some of the most difficult children to detect anxiety in are 8–10 year old girls. They are mature enough to initially appear confident and control overt signs of anxiety, but then become unable to control their anxiety and become fearful and uncooperative at induction. They are also an age group in which it is difficult to justify using restraint. It is therefore important to try and pick which children may benefit from a premed, or have a low threshold for giving a premed. Unusually boisterous, school-aged children are another group in whom it may be difficult to detect anxiety. While boisterous behavior reflects the personality of children, in others it is a sign of anxiety.

Table 3.8 Signs from history and examination that may indicate that a premed is needed

Indicators at time of preoperative visit that premed is likely to be required
Preschool age—5 years and younger
Previous hospitalizations or procedures
Previous difficult or traumatic induction
Boisterous, over-talkative school-aged child
Teary
Quiet, shy, clingy, withdrawn
Child remarks 'doesn't like mask or needle'
Poor eye contact
Very anxious parent

Children older than about 10–12 years tend to remain cooperative even if anxious, like adults. They often benefit from a 'small' premed (eg midazolam 0.25–0.3 mg/kg) to reduce anxiety and make their experience more pleasant.

Some children require a 'stronger' premed than midazolam or clonidine. These children include those with autism, previous bad anesthetic or surgical experience, and older anxious children who are defiant. Premed options include clonidine followed later by midazolam, and ketamine with or without midazolam.

Tip
Beware the boisterous school aged boy—their chatty over talkative state may reflect underlying anxiety.

3.4.4 The Child Who Refuses to Drink the Premed

Sometimes, children won't even cooperate to take an oral premed. Some may take the midazolam but then spit it out, though at least some will have been absorbed across the mucosa in the mouth. If the child refuses to take any premed, the next step depends on many factors. Options include giving the child more time to settle into the ward and get used to the surroundings and relax, or to try offering a favorite drink to encourage the child, or giving the parent time to talk or negotiate with their child. Nasal or buccal midazolam, or nasal dexmedetomidine don't require cooperation, though coaxing ("grin and show me your sharp teeth" for buccal midazolam) or restraint might be needed. One could then argue however maybe this is just transferring the tears from the induction room to the ward. If the child has good veins, an IV induction might be most straightforward as it can be performed without the child cooperating. In an older child, surgery might need to be delayed to try again another day, though this risks the child learning refusal means avoiding the procedure and so may try the same strategy next time.

3.5 Practical Management at Induction

The child's anxiety may be maximal at induction, but there are several simple things the anesthetist can do to reduce it (Table 3.9). The theater environment is threatening with bright lights, medical equipment and many people in scrubs. Firstly, optimize the environment to make it less threatening—children's theatres have posters, toys to look at and hold, murals and anything else to 'de-hospitalize' them. Consider the lighting level, the number of staff present in the room and the medical equipment in the child's field of vision. Have everything ready to use with tapes, IV equipment, drugs and distractions all prepared.

If the child walks into theatre, a warm operating table (using a forced air warmer under the sheet) is more comfortable and may help. A few stickers on the theatre

Table 3.9 Summary of techniques leading up to induction that help anxious child stay calm

Techniques to keep child relaxed before induction
Minimize fasting duration
De hospitalize surroundings, allow child to wear own clothes if appropriate
Have drugs and equipment ready to minimize pauses; brief and prepare your team
Warm OR table before child lays down
Consider applying monitoring after induction
Stand at the side facing the child at an angle rather than at head end of table
One person talking and maintaining eye contact
Induce anxious child in ward bed or on parent's lap if very anxious
Maintain rhythm and patter of distraction: start immediately child enters OR, no pauses

table may keep younger children relaxed about hopping onto the table. Walking an anxious child into theatre however carries a risk of the child refusing to hop onto the operating table or trying to leave. Consider taking anxious children into theatre on a stretcher, as the child is more likely to accept the stretcher in a less threatening environment away from theatre and then there is more control over the child's movements. If the child is settled on the stretcher when entering theatre, the child could be induced there rather than shifting them and arousing anxiety and reducing cooperation. An anxious child might sit up on the table but not lay down. It is easier to control the child during induction if they lie down, but forcing them to lie down might tip them into becoming uncooperative there and then.

Consider standing beside the bed to face the child at an angle during induction—the airway is not the main concern at this point in the induction. Standing at the head end of the bed is a carry-over from adult anesthesia, stops eye contact with the child and is frightening for the child.

Distraction is the most important technique to reduce anxiety and maintain cooperation. The best distraction starts before entering theatre and then grabs their attention again the moment the child enters the OR. Only one person should be talking and getting the child's attention. Keep talking, maintaining the patter and rhythm of the distraction you use. Many types of distraction are possible (Table 3.10) depending on a mix of the anesthetist's personality, the theatre environment and child's age. Video clips, and probably virtual or augmented reality in the future, are effective distraction—passive animated video clips for preschool children and interactive games for older children. As children are already familiar with video clips, they need to be unique or special to be a strong distractor at induction when anxiety peaks. Some suggest they are better for IV induction, while inhalational induction is better with distraction that includes interaction between the anesthetist and child.

A relaxed anesthetist helps keep the child relaxed and cooperative. Being confident about airway management helps the anesthetist stay relaxed—another reason why the airway is such a key part of pediatric anesthesia training. While distracting

Table 3.10 Some distraction strategies for use at induction for children of different ages

Distraction strategies
• Bucket of stickers Say a sentence or two about what's on the sticker. Keep asking them to choose between two stickers; Keep showing new stickers to keep child's attention. Parents can often help with this
• Magic tricks Visit a magic store for some easy, close-up magic tricks. A magic coloring book is easy to use and a great relaxer for child and parent
• Play a video clip or game on a laptop computer or hand-held device
• Blow bubbles
• Pull a small toy out of your pocket A dolphin, kaleidoscope, picture viewer, farm animal, dinosaur, something that lights up. Describe the toy to make up a little story
• Tell a story Some include the smell of the volatile into their story (rocket fuel/dinosaur poo/seaweed/ Mum's perfume)
• Ask the child count the number of a certain thing on the ceiling in OR (lights, ceiling tiles)

the child, it is also important not to offer too many choices, or choices where the child has no real choice ("are you ready for mask now?").

Note
Keep the flow of the induction process and distraction going—gaps or pauses make it more likely that the child's anxiety will increase.

3.5.1 Intravenous Induction

IV inductions have become the most common method in many countries. Less cooperation is required from the child compared to inhalational induction, but the anesthetist needs to be adept at pain-free IV cannulation. The techniques of IV cannulation are described in Chap. 1, Sect. 1.5. Some children will only allow one attempt, particularly if the needle is felt. Local anesthetic creams are not always entirely effective and there is often much anticipation and fear in the child's mind. If distraction is not kept going through the induction, the child may focus on the needle, becoming more and more anxious. Sometimes with older children it is worth placing the facemask on to give oxygen with or without nitrous oxide so that the child focuses on the feel and smell of the mask rather than the needle.

Most anesthetists hide the child's hand during the IV insertion. If the child is sitting sideways across the parent's lap, the child's arm that is closest to the parent is brought under the parent's arm and behind their back (see Fig. 1.2). If the child is lying flat, the blanket or a child's toy is used to hide the hand while the IV is inserted. The assistant holds the child's forearm and uses their other hand to keep the child's elbow straight against the bed so it is at a mechanical disadvantage. The assistant

can also use their body to block the child's view of the IV catheter. Adolescents generally remain cooperative with an IV induction but can be extremely nervous, vasoconstricted and have difficult veins. Consider applying an elastic tourniquet as early as possible to maximize the time to distend a vein, and using a fine catheter for induction before inserting and a larger catheter later.

Tip
The facemask can be used to distract adolescents and older children nervous about needles. Give oxygen with or without nitrous oxide. Note that older children may become very dysphoric after 45–60 s of nitrous oxide so IV insertion needs to be prompt if using this technique.

3.5.2 Inhalational Induction

A pleasant inhalational induction requires more behavioral management than an IV induction because the child's cooperation needs to be maintained for up to a minute. A pleasant inhalational induction means the next anesthetist who looks after the child will be permitted to do an inhalational induction. There are two stages: mask acceptance and delivery of anesthetic gases.

The face is a very personal area of the body and mask acceptance can be difficult. (This is why mask acceptance is often used as a measure of cooperation in studies of the effectiveness of premedication.) Having the child relaxed, trusting and distracted all help to facilitate mask acceptance. Your best, strongest distraction is handy to help get the mask on and keep it on—your best sticker, your best joke, the best toy out of your pocket. Some give the mask to the child in the theatre waiting area. However, if the child rejects the mask at this stage, it will be difficult to convince the child to accept it later, no matter how much distraction is used. Some put the mask onto the child's face without any anesthetic circuit attached. However, the mask is no less threatening this way and it then has to be accepted by the child a second time with the circuit attached and gas flowing. It is however helpful to touch the mask onto the child's hand or arm, showing them how soft it feels, before putting it on to their face. Scented, clear plastic masks help with acceptance and during nitrous oxide, but do not hide the smell of sevoflurane.

Tip
Do not underestimate the achievement of getting a facemask onto a young child without losing their cooperation! Mask acceptance can be tricky, so it is best to have the mask connected to the circuit and nitrous oxide running. No point in getting the mask on the face once but without anything connected and then having to do it again.

Delivery of the anesthetic gases also has two stages. Initially, nitrous oxide 50–66% is given for 20–40 s before sevoflurane is introduced. If nitrous is given too long, the child may become dysphoric and reject the mask; too short and the sevoflurane will be smelt when it is introduced and the mask rejected. Nitrous does not help if the child is already crying, and some would say there is no need to use it for children younger than about 2 years. The second gas and concentration effects of nitrous oxide are clinically weak, and the reason for using nitrous oxide is to reduce the impact of the smell of sevoflurane. Although it is possible to perform an inhalational induction without nitrous oxide, it can be difficult to maintain mask acceptance as sevoflurane begins.

After nitrous oxide has been given, sevoflurane is introduced (if the sevoflurane is already flowing when the mask is placed, the acceptance rate is low). Sevoflurane can be started at 8% immediately if the child has had nitrous oxide and a circle circuit is used. Some incrementally increase the sevoflurane, but this prolongs induction, increases excitatory phenomena and is probably a leftover practice from halothane inductions. If a T-piece circuit is used however, it does seem better to use 0.25–0.5% for a few breaths before turning to 8%—perhaps the fresh gas hose directing vapor straight onto the nose under the T-piece connector is too strong with 8% sevoflurane.

Keypoint
Be flexible in your induction strategy. Have a plan B ready to quickly change to if your first option looks likely to end in tears.

3.5.3 The Steal Induction

Children who arrive for induction already asleep can be safely anesthetized where they are—in the mother's arms, in their ward beds, or even their pram or pushchair. With nitrous oxide flowing, the mask is placed as close as possible to the face, trying not to put the cold plastic onto the child's skin initially in case they wake up. The aim is to induce anesthesia without the child waking. Success is termed a 'steal induction'.

3.5.4 Restraint and Therapeutic Holding

Sometimes the smooth and happy induction we all strive for doesn't happen. As a last resort and when other strategies have failed, restraint may be needed to insert an IV or to keep the mask on the child's face during induction. Restraint is considered acceptable in infants, but becomes less acceptable as the child gets older. An induction requiring restraint is more likely to be associated with behavioral disturbances afterwards. Restraint of a child older than 8 or 10 years would be exceptional and is upsetting to the child, parent and staff. It is common at this age to return the child to

the ward for a premed or to reschedule surgery for another time. The older the child, the more distressing it is for everyone involved. Behavioral management aims to predict and avoid this scenario as much as possible.

Various reality factors are considered at the time of induction to decide if restraint is reasonable. The urgency of surgery, parents having taken time off work, the ability to reschedule the operating list and the loss of time with returning the child to the ward are all factors to consider. Great care should be taken with the induction if the child will return to theatre for more surgery—you will succeed in holding the child down and 'getting it over and done with', but the anesthetist for the child next time will face a very difficult task and the child is likely to develop dysfunctional behavior.

There is a technique in restraining a young child lying down. The arms and hands are held to stop them pulling the mask or IV away and the shoulders are held down to keep them at a mechanical disadvantage and the head still. Constraining the legs (allowing movement but stopping kicking) is best as completely restraining the legs gives the child traction to push their pelvis and body up off the bed.

3.6 Refusal to Undergo Anesthesia

The legal and ethical issues involved in consent and informed refusal of treatment are dealt with in Chap. 1. Children will often refuse anesthesia and surgery because of fear. Older children may decide rationally that proceeding with surgery might not be in their best interests, but immediately before surgery it is likely anxiety, fear and an aim of going home and away from the hospital is driving their decision. They are therefore not likely to be competent to understand the implications of not having surgery. The care of a school aged child who is scared and refuses induction can be a huge challenge. Restraining the child for induction is a last resort, and a combination of discussion, negotiation, premedication or returning another day are all strategies to have available (Table 3.11).

Table 3.11 A series of strategies to progress through to deal with a school-aged child who refuses induction or surgery

Strategies for older child who refuses treatment for elective surgery
Discuss, build rapport, identify specific fears
Return to ward, premed with midazolam or use ketamine + midazolam if extreme anxiety and fear (increased risk of PONV with this combined premed)
If refuse oral premed, allow time for parent and child to come to an agreement
Consider seeking help from a colleague who may interact differently with the child
Discharge and reschedule. Consider counselling if circumstances dictate

3.7 Conclusion

Remember that while this might be a routine day for you, this might be the biggest day of the child's and their family's life. Learn to identify, acknowledge and manage the parent's and child's anxiety and be rewarded by witnessing a grateful family's journey through anesthesia and surgery. Bear in mind that at induction, some children will always be happy and cooperative but others will be teary and uncooperative no matter what you do. In between are the majority who could behave either way according to a variety of factors and things that you do. Use the techniques described in this chapter to maximize the number of calm and smooth inductions in your practice.

Review Questions

1. What factors are associated with increased anxiety in children at induction?
2. An 11 year old girl has been brought to the induction room before a hernia repair under GA. She keeps her arms folded and refuses to put out her hand for an IV. What will you do?
3. The mother of a 5 year old boy who has had multiple GA's and appears frightened requests a premed for her son. What premed would you use, and why?

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Airway Management in Children

4

Britta von Ungern-Sternberg and Craig Sims

The core airway skills for anesthetists caring for children are face mask ventilation, LMA insertion, laryngoscopy and intubation, and selecting the appropriate sized ETT. Airway management is such an important part of pediatric anesthesia because respiratory complications are the commonest cause of morbidity and mortality in children without cardiac malformations. Respiratory events cause over three quarters of critical incidents and nearly a third of perioperative cardiac arrests. Not surprisingly, airway obstruction leading to hypoxia and bradycardia or asystole is a huge fear for anesthetists who do not routinely look after children. Airway management, especially face mask ventilation, is the most important skill to learn during pediatric training. It is the technique that will be required when there is airway obstruction and hypoxia.

Tip

Anesthetized children have airway problems more than cardiovascular problems. As a trainee, to gain more experience with airway management, avoid just inserting an LMA early on in the anesthetic then returning the child to recovery with the LMA in situ as you might with an adult.

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Table 4.1 Anatomical differences in infants and children compared to adults and their consequences for clinical practice

Difference in neonate and infant	Consequence
High metabolic rate	Desaturate quickly during apnea or airway obstruction
Large head	Use head ring rather than pillow (Fig. 4.3)
No nasal turbinates	Less resistance to passage of nasal ETT
Soft, compressible floor of mouth in infants	Pressure from anesthetist's fingers can push tongue against roof of mouth obstructing the airway—be careful to place fingers only on bony structures during airway maneuvers
Obtuse mandibular angle of 140° (adult 120) Large tongue relative to mouth size Higher, slightly anterior larynx (vocal cords opposite C3; adult C5)	Tongue closer to roof of mouth and obstruction more likely. Harder to compress tongue with laryngoscope and align visual axes of mouth, pharynx and larynx. Larynx appears to be more anterior at intubation, and forward flexion of neck does not improve laryngeal view
Long, thin U-shaped epiglottis with small amount of cartilage. Broad and fleshy ary-epiglottic folds. Large, mobile arytenoids Vocal cords angled slightly anterior (adult perpendicular)	Large floppy epiglottis more likely to require physical displacement to view glottis (lift directly with straight blade). More likely to have ETT catch on glottic opening Supraglottic structures more likely to feature in pathology
Cricoid ring is narrowest part of airway until puberty (adult: glottic opening)	Determines ETT size
Trachea soft and compliant	Collapse of extrathoracic trachea in upper airway obstruction
Ribcage soft and compliant	Indrawing of chest in upper airway obstruction

4.1 Airway Anatomy

A child's airway is different to an adult's airway and is managed with different techniques and equipment (Table 4.1). The differences are more pronounced in infants—airway problems are four times more common in infants than in older children.

4.1.1 Nasal Breathing

Most infants are primarily nasal breathers for the first months of life. Their oral airway can easily be obstructed by a relatively large tongue and high epiglottis that may rest against the soft palate, and coordination between the respiratory and pharyngeal muscles is immature. Some neonates and infants can switch to mouth breathing if their nose is occluded (8% of preterm babies, 40% of term babies). Infants easily mouth breath after 3–5 months of age. The nose contributes only 25% of airway resistance in infants, compared to 60% in adults—most of an infant's airway resistance is in the distal airways. Nevertheless, a young infant whose nose

is blocked by secretions or a nasogastric tube may struggle and persist with nasal breathing rather than mouth breath.

Keypoint
Infants can feed and breathe at the same time. This is possible because the larynx is high in the neck, bringing the epiglottis and soft palate together. This and other changes allow milk to enter the esophagus at the same time as air is entering the trachea. Two of the consequences of this anatomy are that young infants breath primarily through the nose and they cannot have articulated speech.

4.1.2 The Pharyngeal Airway

Infants have a collapsible pharyngeal airway due to lax tissues and a small muscular contribution to airway patency. Airway patency improves over the first 8 weeks as muscle coordination matures. Skeletal growth during the first year increases the size of the mandible and maxilla relative to the tongue and further improves airway patency.

4.1.3 The Larynx and Cricoid Cartilage

The larynx is higher in the neck to allow breathing during feeding (Fig. 4.1). The larynx descends during the first 2 years, then remains in the same position until

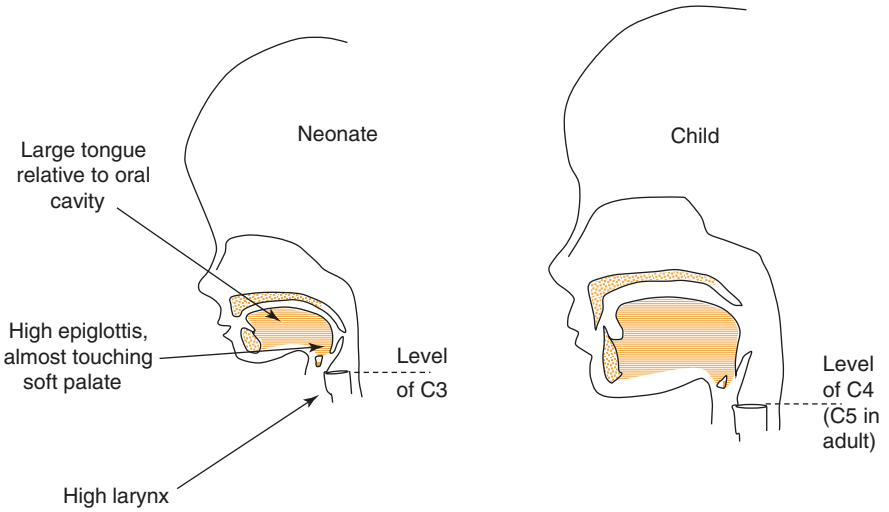

Fig. 4.1 Cross section of infant and child airway, showing anatomical changes that cause obligate nasal breathing (Modified from Isono, Pediatr Anesth 2006;16: 109–22 and Westhorpe, Anaesth Int Care 1987;15: 384–8)

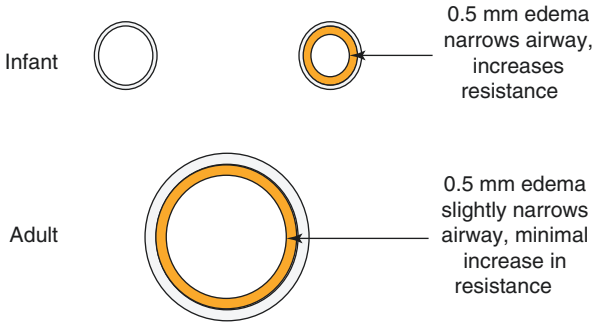

Fig. 4.2 A small amount of mucosal edema over the cricoid cartilage in the infant significantly narrows the airway diameter and increases airway resistance. The same edema in an adult does not significantly affect the airway

puberty when the thyroid cartilages grow and it descends to the adult position. Although the infant larynx is slightly more anterior than in the adult, it is its high position that makes it appear to be anterior at laryngoscopy because alignment of the visual axes of the mouth and glottis is more difficult.

The infant larynx is said to be funnel-shaped because when the vocal cords are widely abducted, its inlet tapers from the glottic opening to the smaller and almost circular cricoid ring. Although recent MRI studies suggest the narrowest part may be the glottis, this part of the airway is pliable and moves out of the way during intubation. The cricoid ring is the narrowest part of the airway until puberty and determines the size of an ETT in children. The cricoid is classically described as circular like a signet ring (because the posterior part is broader than the thin anterior part). It is however, slightly elliptical. Nevertheless, its almost circular shape means that a round ETT can usually make a sufficient seal without a cuff. Mucosal edema at the level of the cricoid is a concern in infants and young children. In a baby with a cricoid diameter of only 4 mm, even a small amount of edema over the cricoid greatly increases airway resistance and may cause post-extubation stridor (Fig. 4.2).

Note
The larynx is higher in the neck of neonates and infants, making it appear more anterior at laryngoscopy.

Keypoint
Airway trauma from intubation in a young child may cause edema and post extubation stridor in the short term, and subglottic stenosis in the long term.

4.2 Assessment of the Airway

Older children can be assessed as an adult would be, although the Mallampati score and thyromental distance tend not to be used because they are not validated in children. History is usually non-specific in routine cases, although symptoms of

obstructive sleep apnea (OSA) may indicate adenotonsillar hypertrophy and more difficult mask ventilation. Younger children may not cooperate with a formal examination. Instead, they are observed for abnormalities of mouth opening and neck movement. Children differ from adults in that a child who is difficult to intubate will usually look difficult to intubate, whereas adults who are difficult to intubate may look normal. However, the unexpected difficult airway does exist and preparations for it need to be taken for any anesthetic.

The most important observation of the airway in children is the jaw size. A small jaw (retrognathia or micrognathia) gives less space between the tongue and soft palate for a clear airway and less space to compress the tongue during laryngoscopy. It is the reason babies with Robin sequence can be difficult to intubate.

Keypoint
Micrognathia is a common and important indicator of intubation difficulty. It makes direct laryngoscopy difficult because there is little room for the blade to compress the tongue and give a direct line-of-sight view of the vocal cords.

4.3 Upper Airway Obstruction

Anatomical differences predispose children to upper airway obstruction, and hypoxia may develop quickly because they have a high oxygen consumption and smaller oxygen reserve (lower functional residual capacity (FRC), higher closing volume).

4.3.1 Signs of Upper Airway Obstruction

The symptoms and signs of airway obstruction vary with the level and cause of obstruction and with the age of the child (Table 4.2). Extrathoracic airway obstruction worsens during inspiration, and so inspiratory stridor and prolonged inspiration are the cardinal signs of upper airway obstruction. The pitch of the stridor may give clues to the location of the obstruction, as does the voice—a muffled voice indicates a supraglottic obstruction (for example, epiglottitis), whereas a hoarse voice or aphonia indicates glottic obstruction (eg laryngotracheobronchitis; croup).

Table 4.2 Signs of upper airway obstruction in children

Signs of upper airway obstruction
Inspiratory stridor and prolonged inspiration Voice changes
Rocking chest and abdomen during breathing
Use of accessory muscles: – Tracheal tug – Flaring nostrils – Intercostal chest retractions
Tachypnea and tachycardia
Anxious and restless initially, lethargic later

Indrawing of the chest wall occurs during obstruction, especially in young children who have pliable, cartilaginous rib cages. Obstruction also causes a rocking paradoxical movement of the chest and abdomen—the abdomen moves outwards from descent of the diaphragm while the chest collapses inwards from negative intrapleural pressure. As obstruction worsens, the work of breathing increases and accessory muscles become active with flaring of the nostrils and tracheal tug. Initially, an awake child with airway obstruction is tachypneic and tachycardic. Eventually the child may tire and respiratory effort fades. Infants and neonates rapidly fatigue and may develop apneic episodes as a result of airway obstruction.

4.3.2 Site of Upper Airway Obstruction During Anesthesia in Children

In sedated or anesthetized children, loss of muscle tone in the airway reduces patency and narrows the entire upper airway. Most obstruction, however, is at the level of the soft palate and the epiglottis. In contrast, upper airway obstruction in adults occurs at the level of the base of the tongue from loss of tone in the genioglossus muscle. At either age, resistance during inspiration generates a negative airway pressure and worsens airway collapse.

4.4 The Mask Airway and Mask Ventilation

Many adult techniques are applicable for the management of a child's airway. Always actively manage the child's airway to learn the best way to obtain a clear airway in that child and to detect airway obstruction within a breath or two. Active airway management means holding the rebreathing bag and moving your hand gently with each breath, assisting the breathing and providing continuous positive airway pressure (CPAP) if needed.

4.4.1 Face Masks

Children have large cheeks and a relatively small nose bridge, resulting in their face being in one plane. This allows masks with a soft, flat cuff to form a seal—even a circular shape such as the Laerdal silicone resuscitation mask can be used. The cuff should be neither too soft nor too hard—soft enough to conform to facial contours, but not so soft that forming a seal is difficult and not so hard that the mask does not conform to the face. Adults have a more prominent nose bridge, and a contoured mask is needed to form a seal. Teenagers have a prominent nose bridge and may need an adult mask.

Table 4.3 Summary of main airway maneuvers to obtain patent airway in a child

Important airway maneuvers to overcome upper airway obstruction
Head and neck position
Jaw thrust (not just chin lift)
CPAP
Oral (or nasal) airway
Positioning child on side may help

The size of the facemask should allow the mouth to be slightly open, but not cover the eyes—sit the top part of the cuff on the bridge of the nose and ensure the lower part sits in the mental groove on the chin. If the mask comes up onto the eyes or down onto the chin, it is too big. If an infant is settled with a soother or dummy in its mouth, sometimes a larger mask can be placed over the top of the soother during the early stages of induction, changing to a smaller mask later when the soother is removed.

4.4.2 Opening the Upper Airway

Table 4.3 outlines the most important maneuvers to open the upper airway. Mask ventilation during upper airway obstruction inflates the stomach. Gastric insufflation is common in young children when ventilation has been difficult, when no pressure relief valve is used on the circuit, or when the operator is not experienced in mask ventilating children.

Tip
Gastric distension pushes the diaphragm upwards and inhibits ventilation. Remove the air by inserting a suction catheter through the mouth—suction may or may not be required.

4.4.2.1 Head Position

Because the larynx is relatively high in a young child's neck, flexion of the neck does not improve airway patency or the view at intubation—there aren't enough cervical vertebral bodies above the larynx for flexion to have any effect. Children also have a relatively large head and don't need a pillow to fill the gap between the back of the head and the bed. Instead, a head ring is used to stabilize the child's head (Fig. 4.3). Babies have an even larger head, and although a head ring alone is usually fine, occasionally a small roll under the shoulders may stop the neck from flexing. Flexion of the head of a neonate or baby may also cause airway obstruction. This is why it is often recommended that an infant's head be in a neutral position.

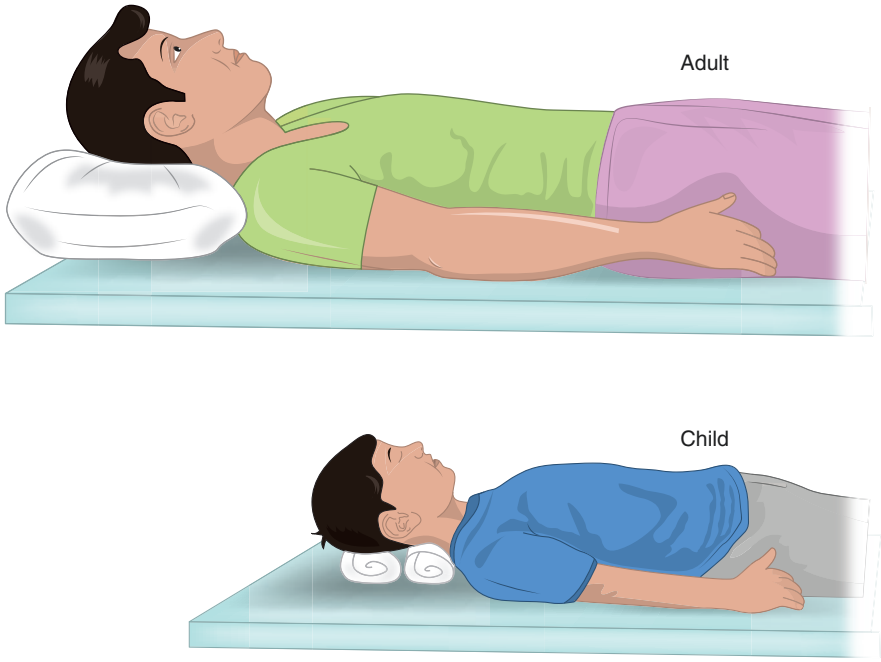

Fig. 4.3 Babies and children have a relatively large head, do not have a gap between the back of the head and their back, and do not need neck flexion for intubation. A head ring stabilizes the head and provides a suitable head position for intubation. Adults need a pillow to fill the gap and flex the neck to achieve the 'sniffing' position needed for intubation

However, neonates and infants benefit from extension of the atlanto-occipital joint just as the older child does, provided extreme extension is avoided.

Note
Positioning for direct laryngoscopy is different in adults and children. Adults are placed in the 'sniffing' position (neck flexed, head extended). Children don't benefit from neck flexion during intubation because their larynx is relatively high. Only extension of the atlanto-axial joint to tilt the head back is needed.

4.4.2.2 Hand Position

In preschool children, the nasal passage is often blocked, making ventilation via the nose difficult. It is therefore important to hold the mouth open during mask ventilation. An oral airway can be used, but appropriate sizing is vital since it can irritate the airway and lead to respiratory adverse events or block the airway if the wrong size has been chosen. The most effective maneuvers to get an open airway are

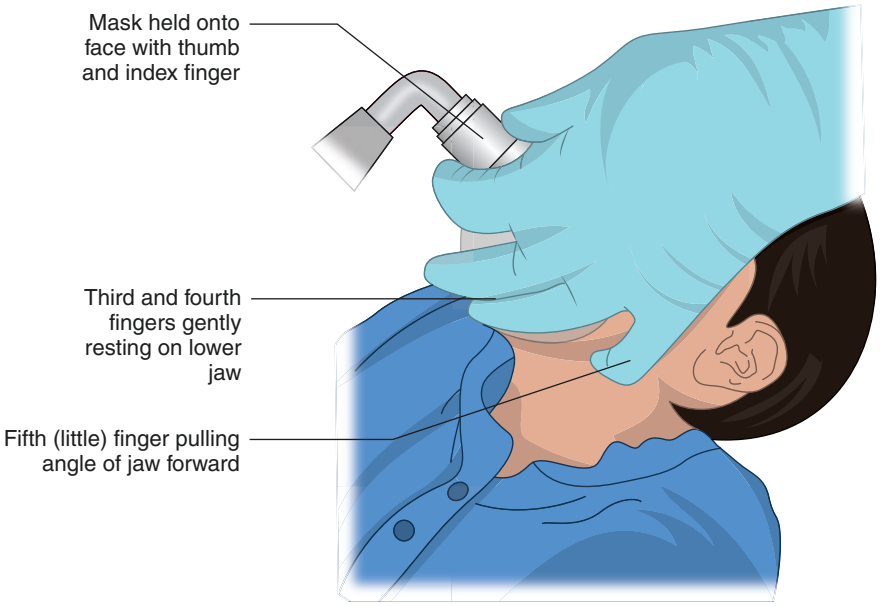

Fig. 4.4 Pulling the jaw forward is more effective than tilting the chin and head backwards. The fourth (little) finger is behind the angle of the jaw pulling it forwards while the mask is held by the thumb and index finger

forward jaw thrust and CPAP. Jaw thrust can be achieved with the third or fourth (little) finger behind the angle of the jaw (Fig. 4.4). Tilting the chin and head backwards is not as effective. It is important not to apply pressure to the floor of the mouth as this may compress the tongue against the palate.

Tip
Try to hold the mask using a technique that incorporates jaw-thrust. This technique doesn't force the mouth shut, doesn't apply pressure to the floor of the mouth, and keeps one hand free for ventilation or CPAP. It avoids the need for a two-handed, two-person technique when difficulties arise.

4.4.2.3 Oral and Nasal Airways

Oral airways may be useful, but are not routinely needed in children. The correct sized airway is chosen by measuring against the side of the face—with the flange at the level of the incisors, the tip should be adjacent to the angle of the mandible. If the airway is too small it is ineffective and if too large it may touch or fold down the epiglottis and cause obstruction or laryngospasm (Fig. 4.5). Insertion of the airway at an inadequate depth of anesthesia can trigger laryngeal responses.

Nasopharyngeal airways are occasionally used as they are better tolerated in the conscious patient. Small, soft nasopharyngeal airways are available, but some are too long if inserted fully with the collar against the nostril. The size of the airway is selected by matching its length to the distance between the nose and tragus of the ear. An alternative to a purpose-made made nasopharyngeal airway is a shortened, age-appropriate ETT taped or pinned in place so that it cannot migrate inwards or outwards, and labelled so that it is not mistaken for a tracheal tube. Position the nasal airway carefully so that it is just below the soft palate, but not touching the epiglottis. They can sometimes cause trauma and bleeding from the nose or adenoids.

4.4.2.4 CPAP

Continuous positive airway pressure (CPAP) refers to a positive airway pressure maintained throughout spontaneous breathing. The aim is to keep the airway pressure positive during inspiration and stop collapse of the extra-thoracic part of the airway (Fig. 4.6a). CPAP increases functional residual capacity, may reduce the work of

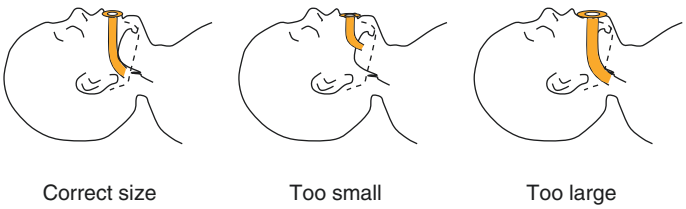

Fig. 4.5 Oral airway size selection. Correct size (left) sits over tongue and away from epiglottis. Too small (middle) is occluded by tongue, and may push the tongue backwards. Too large (right) may touch epiglottis and fold it down or trigger laryngospasm

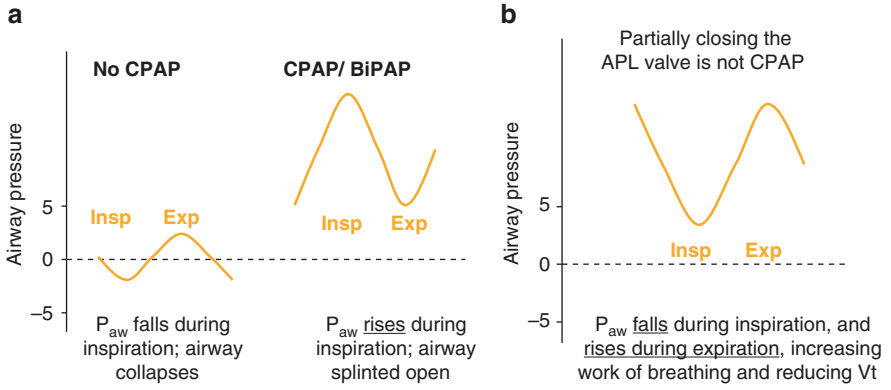

Fig. 4.6 Airway pressure during spontaneous ventilation. (**a**) Without CPAP (left curve), airway pressure becomes negative during inspiration and the extrathoracic airway may collapse and obstruct. In theater, CPAP is provided by gently squeezing the bag just before and during inspiration so that airway pressure is always above atmospheric pressure (right curve). (**b**) Some suggest CPAP by partially closing the adjustable pressure limiting (APL) valve, or partially occluding the T-Piece. When this is done, note that expiration is now the positive waveform, and airway pressure still falls during inspiration. Also, resistance to expiratory flow increases the work of breathing when the APL valve is partly closed. *Insp* Inspiration, *Exp* Expiration

breathing and improves oxygenation. It is a very important airway skill to learn, and is the technique needed during airway obstruction at induction or emergence.

Keypoint
CPAP and jaw thrust are the most important maneuvers to learn to maintain an open airway in children.

Tip: To Apply CPAP
Ensure you have an effective mask seal (use finesse, not force!) with one-handed jaw thrust.

Partially close the APL valve and keep the bag tight during the expiratory pause.

Feel the bag & watch the chest for the start of inspiration.

Gently squeeze the bag as soon as inspiration starts.

Squeeze gently, feeling for feedback that air has entered chest. If the bag is squeezed too hard before confirming this, the stomach might inflate.

Once you have the 'feel' for airway patency and respiratory rhythm, increase the bag squeeze and pressure support, and start to squeeze slightly before inspiration starts (anticipating when the next breath is about to start).

CPAP requires a circuit that can keep the airway pressure positive during inspiration. Simply closing the APL valve on a circle circuit or kinking the tail of a T-piece circuit does not produce CPAP (Fig. 4.6b). The simplest method in practice is to gently squeeze the rebreathing bag at the very start of inspiration, keeping the bag slightly distended during expiration so that there is minimal lag between the start of the child's inspiration and the bag producing a positive pressure. This technique is called CPAP, but is probably more correctly a manual form of pressure support ventilation. Some centers use the pressure-support mode of the anesthetic ventilator during induction.

4.4.2.5 Difficult Facemask Ventilation

Unexpected difficult facemask ventilation is the commonest problem in clinical practice. Although imperfect technique, inadequate anesthetic depth and large adenoids and tonsils are the commonest causes, there are several others to consider (Table 4.4). Difficult mask ventilation is resolved using the same steps as in adults:

Table 4.4 Common causes of difficult facemask ventilation in children

Common causes of difficult facemask ventilation
Technique
Large tonsils and adenoids; obesity
Inadequate depth of anesthesia or paralysis
Laryngospasm
Congenital or pathological conditions
Alveolar collapse and reduced compliance
Air in stomach
Bronchospasm

The first three are the commonest soon after induction

optimize the head position, open the mouth, and consider anesthetic depth, muscle relaxation and equipment issues. Then insert an oral airway, try an LMA or other SAD, and finally attempt intubation.

4.5 The LMA and Other Supraglottic Airway Devices

The LMA has become as popular in children as in adults for allowing a hands-free technique. Avoiding intubation of the easily irritated pediatric tracheobronchial tree confers additional benefits. There are fewer respiratory events during anesthesia in infants and children having minor elective surgery when an LMA is used rather than ETT (Fig. 4.7).

4.5.1 Classic and Classic-Style LMA

The Classic LMA is a scaled-down model of the adult version, and disposable versions are available in pediatric sizes (Table 4.5). The size 1 LMA tends to give a less reliable airway than the larger sizes, and the pre-formed second generation LMAs

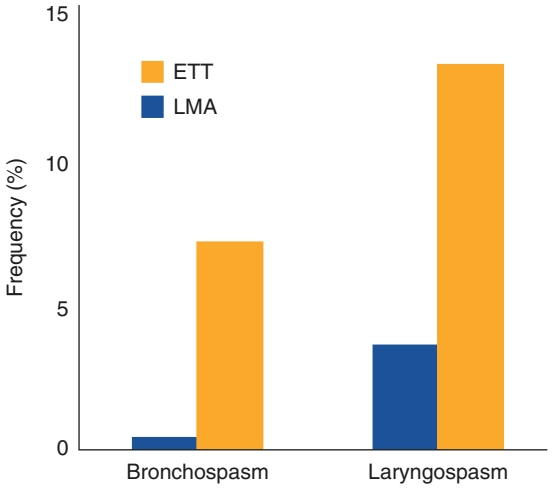

Fig. 4.7 The LMA is associated with a lower frequency of serious airway complications in infants older than 3 months and children. Data from Drake-Brockman TFE et al., Lancet 2017

Table 4.5 Child weight and recommended LMA size

Device size	LMA Weight range (kg)
1	2–5
1.5	5–10
2	10–20
2.5	20–30
3	>30

are superior to the classic model. Inflating the cuff to a pressure of 40 cmH_2O gives the best airway seal in children with the least air leak and sore throat. Inflation of the cuff with a set volume or to a clinical end point causes hyperinflation and increases air leak and sore throat. If there is a leak around the cuff, deflation of the cuff or repositioning of the LMA have a higher rate of success than the often-performed additional inflation (which in turn leads to a stiffer cuff that does not mould to the pharyngeal shape). Insertion of sizes 2.5 and smaller can be straight-in as recommended by the manufacturer, or with a twisting, upside-down technique with a partially inflated LMA—similar to inserting a guedel airway. This rotational technique has a high success rate with the advantage of guiding the LMA tip past the tonsils and down behind the tongue without placing fingers in the patient's mouth.

A clinically acceptable airway is obtained with the LMA in 92–99% of children (similar to adults), but the incidence of partial airway obstruction seen on fiberoptic assessment in children is up to 19% (higher than adults). In infants, the pharyngeal seal is not as good and there is a lower cuff leak pressure compared with older children. Malpositioning is more common with the smaller sizes of LMA, and is usually due to the epiglottis being caught within the LMA. Bilateral jaw thrust by a second person during insertion of the LMA improves positioning. The chest and abdomen sometimes have a rocking movement during spontaneous ventilation due to partial airway obstruction. Despite all of this, a clear airway is usually obtained with an LMA, although it is important to check that the tidal volume is adequate and that the child is not working too hard at breathing. Pressure support ventilation is usual nowadays with modern anesthesia ventilators.

4.5.2 Second Generation LMAs and Other Supraglottic Airway Devices

The first generation LMA is still commonly used in children because of cost, familiarity and good performance in clinical practice. However, there is good evidence second generation devices are superior, with the gastric channel being useful to release trapped air. The pediatric Proseal LMA® (PLMA) does not have the dorsal cuff of the adult sizes, and is not available in single-use versions. The iGel® is effective in infants and children, but there may be a large leak until the cuff warms, softens and conforms to the pharynx. It also has a tendency to migrate outwards, requiring extra taping or repositioning.

4.5.3 Removal of LMAs

LMAs are commonly removed while the child is still deeply anaesthetized. A deeply anaesthetized child in the lateral position usually has a clear airway (unlike adults) and so there is less to gain from leaving the LMA in situ in PACU. Although it is clear awake removal is better in adults, in children it is not so certain and studies point either way, partly because of differences in definitions of 'awake', or of

complications. There is little difference in the incidence of laryngospasm if the LMA is removed deep or awake in healthy children. However, in children with increased bronchial hyper-reactivity or those with risk factors for respiratory adverse events, deep removal is superior to avoid complications. The experience of PACU staff must be considered before planning to leave the LMA in for later awake removal. If removing deep, the child should be in the lateral position. If awake, the child should be very awake, defined by Archie Brain as being after the onset of swallowing and when the child is either able to open the mouth to command or expel the LMA spontaneously.

4.6 Laryngoscopes

There are several blades for direct laryngoscopy available for children. However only two are needed for routine anesthesia in children—the size 1 Miller blade for neonates and infants, and the size 3 (adult) Mac blade for children.

4.6.1 The Miller Blade

The Miller blade is a straight blade for neonates and infants up to about 18 months. It is the classic blade for neonates because of their small mouth, high larynx and floppy epiglottis. Size 1 is the most commonly used size, and size 0 is best for neonates weighing less than about 1 kg. The technique requires some practice, and is outlined in Table 4.6. Common mistakes are failing to control the tongue and sweep it across to the left (same as when using a Mac blade), and failing to get the blade out of the corner of the mouth, so the ETT has to almost be passed down the bore of the Miller blade, blocking the view. Although the classic technique with the Miller blade is to lift the epiglottis directly, it is usually adequate to lift it indirectly, like a Mac blade, and use laryngeal pressure if needed to improve the view. This technique was described by Miller himself, and perhaps has the advantage of causing less stimulation during laryngoscopy.

Note
The infant Miller blade was first described in 1946 by RA Miller (NOT RD Miller of *Miller's Anesthesia*). Free full text of the original description online. Anesthesiol 1946;7: 205.

Table 4.6 Tips for using the Miller blade in infants and neonates

Technique for using the size 1 Miller blade in neonates
Insert blade in right corner of mouth and sweep tongue swept across to the left
Look in the mouth as you gently advance the blade
Get the blade out of the corner of the mouth and have your assistant retract the right corner of the mouth
Lift the epiglottis indirectly and use external laryngeal pressure

4.6.2 The MacIntosh Blade

The adult size 3 MacIntosh blade is suitable for children of all ages, including older infants. In small children, only the thin, distal part of the blade is inserted, leaving plenty of room in the mouth. Small MacIntosh blades are available but are only scaled down adult blades without proper adjustment of their proportions. If these small blades are used for intubation, the thick part of the blade is in the mouth and takes up more space. They also have a significant curve requiring more mouth opening and force to obtain a direct line of vision. The size 1 MacIntosh and Miller blades have been shown to give an equivalent view in infants as young as 3 months. Although the Mac blade is tempting to use because it is familiar, the Miller blade is needed for neonates, so it is best to gain experience with it on larger infants as well.

Tip
Most children are easy to intubate. If the cords are not clearly seen, resist pulling harder- use external laryngeal pressure (the 'three-handed' intubation technique).

4.6.3 Videolaryngoscopes

The Storz CMAC and McGrath videoscopes are available in pediatric sizes and have a familiar shape and technique for use. Their role in routine airway management is growing, and their role in difficult airway management is discussed later. It would seem reasonable nowadays to routinely use a videoscope with a Miller or Mac-shaped blade for intubation of all neonates and infants, to get the best view and to avoid the occasional awkward intubation using direct laryngoscopy.

4.7 Endotracheal Tubes

Although uncuffed endotracheal tubes (ETT) were traditionally used in pediatric anesthesia, cuffed ETTs are now routinely used in many centers.

4.7.1 Cuffed Endotracheal Tubes

Cuffed ETTs are now routinely used in pediatric anesthesia because of their advantages over uncuffed ETTs (Table 4.7). The main advantages are the absence of leak and the benefits for ventilation and its monitoring, and the reduction in tube changes when the wrong sized uncuffed tube is initially selected. Cuffed tubes were traditionally avoided because of concerns about trauma and edema of the mucosa of the cricoid ring, but these concerns have been minimized with modern design and materials. Despite the advantages of cuffed tubes, there are still situations when uncuffed tubes are needed (Table 4.8).

Table 4.7 Advantages and disadvantages of cuffed and uncuffed ETTs in children

Type of ETT	Advantages	Disadvantages
Cuffed	No leak – less pollution – able to monitor tidal volume – able to apply PEEP Reduced laryngoscopies for ETT size change Lower incidence sore throat	Smaller ID, increased resistance and blockage Need to monitor and adjust cuff pressure Maximum cuff pressure of 20 cmH_2O used Different cuff type, position and ETT OD between manufacturers Slightly more expensive
Uncuffed	Long safety record No problems with cuff position between manufacturers	Leak – pollution – problems applying PEEP – problems measuring $ETC0_2$ and tidal volume ?Risk of aspiration (at least in ICU) May require two or more laryngoscopies to select correct tube size

ID internal diameter, *OD* outside diameter

Table 4.8 Even though cuffed ETTs are routinely used, uncuffed ETTs still have a role in certain clinical situations

Role of uncuffed tubes in contemporary practice
'Sizing' airway diameter in suspected subglottic stenosis
Neonates <3 kg
Some difficult airways where larger ID facilitates use of fiberscope
Children with croup

However, cuffed tubes are not without problems. Firstly, sizing of a cuffed tube requires thought and careful technique. The internal diameter of a cuffed tube is smaller than an uncuffed tube to allow for the diameter of the cuff. In general, the correct sized ETT is calculated with the Motoyama formula:

For children 2 years and older: ***Internal diameter of cuffed ETT (in mm) = age/4 + 3.5***.

However the formula does not calculate the correct size for every child. Sometimes the bulky cuff of the ETT will not pass through the cricoid ring. It is obvious when this is the problem—the tip of the ETT passes through the cords but then won't advance. Passing the bulky cuff has the potential to traumatize the mucosa of the cricoid ring, and it is best to downsize 0.5 mm. There is a formula for tube size using 3.0 rather than 3.5, but it may result in tubes a little small for some children.

Secondly, cuffed pediatric tubes from different manufacturers have different specifications, so the external diameter of tubes with the same ID can be different. The Microcuff® brand is thin-walled and has a smaller outside diameter than other brands. For this reason, a Microcuff tube larger than another brand's tube can sometimes be used (Table 4.9). Also, tubes from different manufacturers have different

Table 4.9 Table showing cuffed ETT sizes for infants and young children

Child's age	Cuffed ETT ID (mm)	
	ETTs with standard, thick walls	Microcuff ETTs (Salgo formula)
<6 months	3	3
6 to <12 months	3	3.5
12 to <18 months	3.5	3.5
18 months to <2 years	3.5	4
2 to <3 years	4	4
3 to <4 years	4	4.5
4 to <5 years	4.5	4.5

The Microcuff® brand of ETT has a thin wall and low-profile cuff with a smaller outside diameter compared to other tubes, affecting the age range for different sized tubes. (Based on Salgo B. Acta Anaesthesiol Scand 2006;50: 557–61)

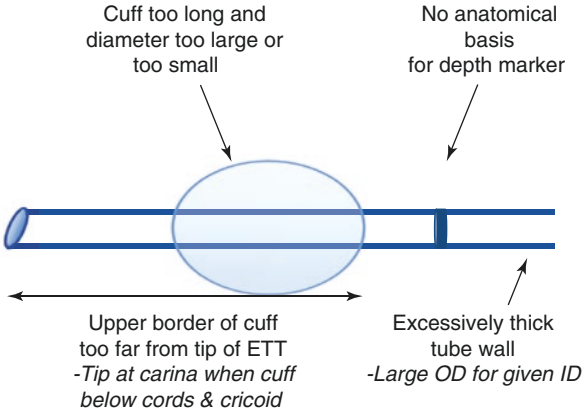

Fig. 4.8 Common design problems of many commercially available cuffed endotracheal tubes for children

cuff positions and markings in different positions along the shaft (Fig. 4.8). The position of the cuff on the tube is important—the cuff must sit below the cricoid while the tip of the tube is above the carina.

Finally, the internal diameter of a cuffed tube in any given child is at least is 0.5 mm smaller than the uncuffed equivalent for that child. This is not usually a problem unless the child is breathing spontaneously through the tube for a prolonged duration. However, in neonates the difference between a 3 and 3.5 mmID is significant in terms of resistance, susceptibility to blockage or kinking, and ease of suctioning.

4.7.2 Uncuffed Tubes

Uncuffed tubes can be used in children because the narrowest part of the airway is the almost-circular cricoid ring, where the tube makes a seal. In adults, the narrowest part of the airway is the glottic opening between the vocal cords, and any tube able to pass through is too small to make a seal at the cricoid—so a cuff is needed. A small

leak around the ETT in children is used as a surrogate indicator that there is not excessive pressure on the mucosa overlying the cricoid. However a leak does not entirely exclude mucosal pressure—the slightly elliptical shape of the cricoid allows some pressure from the ETT against the lateral walls of the cricoid. Nevertheless, uncuffed ETTs have a long record of safe and satisfactory use. Aspiration around them is rare, and there is a very low risk of post extubation edema and stridor.

4.7.2.1 Uncuffed ETT Size

Tube size is based on age, and to a lesser extent, weight. A term baby will need a 3.5 or 3.0 ETT, depending on size (Table 4.10). The size of ETT increases during infancy until around 2 years, when the modified Cole formula is used for the initial ETT:

For children 2 years and older: ***Internal diameter of UNcuffed ETT (in mm) = 4 + age/4***.

The calculated size is usually rounded up if the child is large for their age. It is often worth rounding down if the child has had a recent URTI. Some would use 4.5 rather than 4 in the formula because of the trend towards children being larger for age in western societies, but this is not common practice. In any event, the formula calculates only the initial, most likely size, hence the rule is to always have an ETT one size smaller and larger available. Once a child reaches puberty or around the age of 10–12 years, uncuffed ETTs are rarely used.

The formula calculates the internal diameter of the ETT. However, the external diameter forms the seal in the airway. The external diameter for any given internal diameter varies slightly between manufacturers, between standard ETT and preformed ETT's, and particularly with armored (reinforced) ETTs which have a significantly larger external diameter than a plain ETT.

Table 4.10 Initial ETT size and depth selection

Age	Initial UNCUFFED ETT size (ID, mm)	Initial CUFFED ETT size (ID, mm)	Insertion depth Oral (cm)	Insertion Depth Nasal
Neonate <1 kg	2.5	–	5–6	6–7.5
Neonate	3	–	7–9	9–11
Term baby <3 kg	3	–	9	9–11
Term baby >3 kg	3.5	3	9	11
6 months	4	3.5	10–11	12–14
18 months	4.5	3.5	11–12	14–15
2 years+	Age/4 + 4	Age/4 + 3.5[a]	12 + Age/2	15 + Age/2
9–11 years	6.5	6[b]		
>10	–	6+		

The final ETT size required may be different and the insertion depth should be adjusted to ensure bilateral air entry

[a]Care should be taken to judge whether the cuff is too large to pass through the cricoid ring

[b]The cuffed 6.0 ETT has a very bulky cuff that may be held up at the cricoid even though the formula predicts it is the correct size

Children who are very small for age (eg cerebral palsy or other chronic illness) often still have a larynx that is a normal size for their age—although the child may look small, they often require the same sized ETT based on their age. However, the depth of insertion is likely to be less than usual in these children.

The size of the ETT is assessed during insertion. It is gently passed through the vocal cords, feeling for resistance at the subglottic, or cricoid, level. If gentle pressure does not allow the tube to pass, a smaller tube should be selected.

Note
ETTs that are one size smaller and larger than the initial size should always be available. It is important the ETT should be the correct size—one allowing effective ventilation, use of PEEP and correct depth of insertion.

4.7.2.2 Depth of Insertion of the ETT

At intubation, the depth of the tube is adjusted so it will neither fall out nor enter the right main bronchus. Intubation marks on the tube vary widely between different manufacturers and are often unsuitable. Microcuff tubes are more anatomical and have accurate markings. When cuffed tubes are used, the cuff needs to be below the cricoid cartilage. There are many formulae for insertion depth. A formula for cuffed tubes is:

$$\textit{Position at lips}\,(\textit{cm}) = \textit{cuffed tube ID}\,(\textit{mm}) \times 3.$$

A formula for cuffed or uncuffed oral tubes is:

$$\textit{Position at lips}\,(\textit{cm}) = \textit{age} / 2 + 12.$$

On a supine CXR the tip should be more than 1 cm above the carina (0.5 cm in infants) and more than 1 cm below the cricoid (0.5 cm in infants). A simple way to position the depth is to watch the cuff pass just beyond the cords and note the measurement at the lips. Tables of suitable lengths are also available.

4.7.2.3 No Leak Around the ETT

After intubation, ventilation is performed while listening for a leak around the uncuffed ETT (classically at a pressure of 20 cmH_2O). If there is no leak, the tube would usually be changed for one that is 0.5 mm smaller.

4.7.2.4 Excessive Leak Around the ETT

Another common problem is an excessive leak around the ETT, typically at pressures less than 15 cmH_2O. A large leak can be heard or felt and the rebreathing bag may not fill adequately between positive pressure breaths after intubation. The leak is too large if a sustained pressure cannot be held without the rebreathing bag collapsing while being squeezed. Changing to a larger ETT would then be appropriate,

as an excessive leak causes problems with ventilation, interpretation of the capnogram, application of PEEP and theater pollution.

Note
The same sized ETT is used for both oral and nasal intubation in children—the narrowest part of pediatric airway is the cricoid cartilage. Adults have large turbinates and need a smaller nasal ETT.

4.7.3 Oral and Nasal Preformed Tubes

Preformed, curved tubes such as the RAE (Ring, Adair, Elwyn) tube are often used in children for head and neck procedures. They are available in oral and nasal (north-facing) types. Although the preformed shape reduces kinking, their length in the trachea is determined by the position of the curve at the lips or nose, rather than by positioning under direct vision. Furthermore, various brands of tubes differ in length which does not increase proportionally with size. All of these factors increase the incidence of endobronchial intubation. Oral (south-facing) RAE tubes can be more difficult to pass through the vocal cords—tips to help are in Fig. 4.9. Nasal RAE tubes are discussed in more detail in Chap. 18, Sect. 18.1.

Note
Preformed ETTs are more likely to cause endobronchial intubation, especially if a larger size than usual for age has been used to prevent an excess leak, or if the neck has been flexed.

A gauze pad can be placed between the chin and ETT to pull the RAE tube outwards slightly if it is endobronchial.

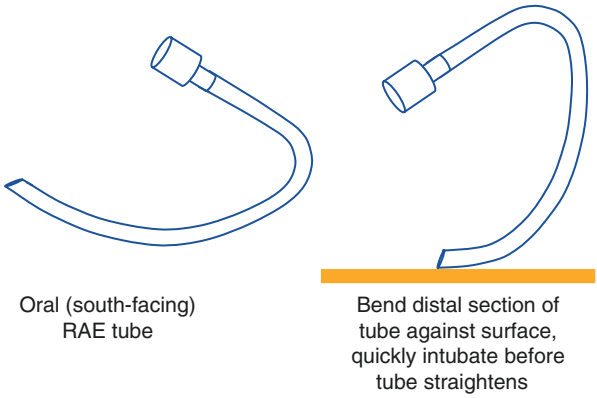

Fig. 4.9 Often, the distal part of the RAE tube 'out of the packet' has lost the curve which allows easy alignment with the laryngeal opening, resulting in the tip getting stuck on the posterior commissure. Re-establish the curve by bending the tip against a flat surface and quickly intubate before the tube straightens

4.7.4 Suction Catheters for the ETT

The correct size catheter is needed when suctioning pediatric ETTs. During suctioning, room air is entrained through the open end of the ETT and around the suction catheter. If the catheter is too large there is not enough space around it for air to pass and the tracheobronchial tree and lungs are exposed to negative pressure, possibly collapsing them. The correct size of the catheter (in French gauge) is twice the internal diameter of the ETT (eg 4.0 ETT, 8F catheter).

4.8 Intubation

Intubation in children is usually straightforward. The best view at laryngoscopy is achieved by extending the atlanto-occipital joint while keeping the head on a flat surface, stabilized by a head ring. With the high laryngeal position in children up to 4 years, there is no cervical spine above the larynx to flex and flexing the neck forwards like in adult intubation does not help.

4.8.1 What to Do When the Tube Won't Pass

Occasionally, the vocal cords can be seen but the ETT won't pass beyond them. The tube is usually being held up at the cricoid ring because the ETT is too large. Do not force the tube—the cricoid will be traumatized and become edematous, causing stridor post op. The first step is to try a smaller ETT which is sometimes needed and does not indicate pathology. Rarely, even a much smaller ETT won't pass beyond the cords, and this may suggest subglottic stenosis—narrowing of the trachea just below the vocal cords, most commonly caused by intubation in the neonatal period. Options are gentle intubation with a smaller ETT, using an LMA or postponing surgery. The concern is that repeated attempts at intubation will cause subglottic edema and airway obstruction, especially in infants and young children. It would be prudent to give dexamethasone 0.5–0.6 mg/kg IV if there is concern about airway edema from intubation attempts, and arrange referral to an ENT surgeon for diagnostic bronchoscopy.

4.8.2 Intubation vs LMA in Neonates and Small Infants

There are advantages and disadvantages in managing a baby's airway with an LMA during anesthesia. The LMA avoids problems related to intubation, but there are several concerns about a small baby breathing spontaneously through an LMA. Firstly, the size 1 LMA does not always give a reliable airway in neonates. Furthermore, the distance between the child's airway and operative site is short, and it can be difficult to manipulate the airway during the case if any problems arise. Thirdly, there may be a leak around the LMA that prevents maneuvers to maintain

end expiratory lung volume, or causes gastric inflation. Finally, spontaneous ventilation means that the deadspace, resistance and work of breathing from the circuit must be considered. Using pressure support ventilation or manually assisting the baby's respirations can overcome most of these problems.

For these reasons, endotracheal intubation is commonly used for anesthesia in neonates and small infants. An LMA may be selected if the case is brief (less than 60 min), there are no other factors compromising respiration, and the anesthetist is able to adeptly and swiftly manipulate the airway if any problems occur. Generally in infants and young children, there are fewer respiratory events during in the perioperative period in those having an LMA rather than an ETT (Fig. 4.7).

4.8.3 Intubation Without Muscle Relaxants

Acceptable intubating conditions in children are more frequently achieved when a muscle relaxant is used. However, muscle relaxants are not always needed and have their own side effects and problems. In young children, intubation without relaxants is easily achievable—their tissues are more elastic, volatile agents provide adequate muscle relaxation and quickly reach high concentrations, and larger doses of volatile agents can be used with less concern about cardiovascular depression. About half of pediatric anesthetists intubate without relaxants, so the advantages and disadvantages of the technique are debated (Table 4.11). Even if relaxants are used, their action is potentiated by volatile agents in children so doses equivalent to the ED95 dose are sufficient (eg 0.3 mg/kg rocuronium, 0.25 mg/kg atracurium).

4.8.3.1 Deep Sevoflurane

An end tidal concentration of sevoflurane of 4–4.5% is required for successful intubation. Nitrous oxide and fentanyl reduce the concentration required. The technique is improved by giving propofol 3 mg/kg after induction. A milliliter or two of lidocaine syringed distal to the tongue base followed by brief face mask ventilation reliably results in local anesthetic coating the larynx, further improving intubating conditions. Non-relaxant techniques using deep anesthesia will decrease blood pressure and are not suitable for children at risk from hypotension.

Table 4.11 Advantages and disadvantages of intubating without muscle relaxants in children

Advantages	Disadvantages
Gives good intubating conditions in most children	Not ideal conditions
Muscle relaxation not needed for most surgery	Reduces blood pressure
Avoids relaxant and reversal agent side effects	Increased hoarseness and vocal damage in adults (unknown in children)
Useful for brief cases requiring intubation	

4.8.3.2 IV Agents

Propofol 3–4 mg/kg with alfentanil 10–15 μg/kg (or remifentanil 2–3 μg/kg, although bradycardia is a concern) give satisfactory intubating conditions in most children. Higher doses of remifentanil increase the success rate but also increase the incidence of bradycardia and hypotension. Propofol alone is not usually adequate.

4.9 Extubation

Extubation awake or under deep anesthesia has the same advantages and disadvantages in children as in adults. However, many PACU staff are less familiar dealing with children and this should be considered if leaving an unconscious child in recovery. If deep extubation is performed in a young child, it is best for the anesthetist to personally monitor the child until awake (remembering that the anesthetist is ultimately responsible for the patient's airway in PACU).

Neonates and infants are usually extubated wide awake to avoid laryngospasm, which quickly causes hypoxia and bradycardia in small babies. An infant is ready to be extubated when it is breathing regularly, neither breath-holding nor having apneas, and is moving the limbs semi-purposefully. While in well children there is no difference between deep and awake extubation, deep extubation is beneficial in children with risk factors for respiratory adverse events, particularly those with an upper respiratory tract infection or asthma.

Tip

When anesthesia is lightened for extubation, young children may suddenly cough, strain, develop chest wall rigidity and either not breathe effectively or become hard to ventilate with high airway pressures. Cyanosis may develop. Infants and young children are especially prone because of their hyperactive airway reflexes. It can be frightening having a small, blue infant that you cannot ventilate through the ETT.

The solution is to hand ventilate with 100% oxygen while eliminating other causes (Table 4.12). Keeping the rebreathing bag small helps to judge compliance and effectiveness of positive pressure breathing. Watch the chest closely for expansion, looking for pauses between coughs or strains when ventilation can be achieved. It is useful to keep the bag tightly distended and ready to squeeze so that there is minimal lag in achieving a positive pressure and any short gaps between coughs are not missed. If needed, deepen anesthesia with propofol 1–3 mg/kg or volatile agent, or paralyze.

It is best to predict and watch for this ventilation problem in small children. Consider gently hand ventilating towards the end of the case to get the feel for the child's compliance and instantly recognize a cough or change in respiration.

Table 4.12 Differential diagnosis of causes of difficulty ventilating through ETT

Causes of difficulty ventilating via ETT
Emergence
Biting ETT
Obstructed ETT (secretions, blood, kinking)
Bronchospasm
Endobronchial intubation
Pneumothorax

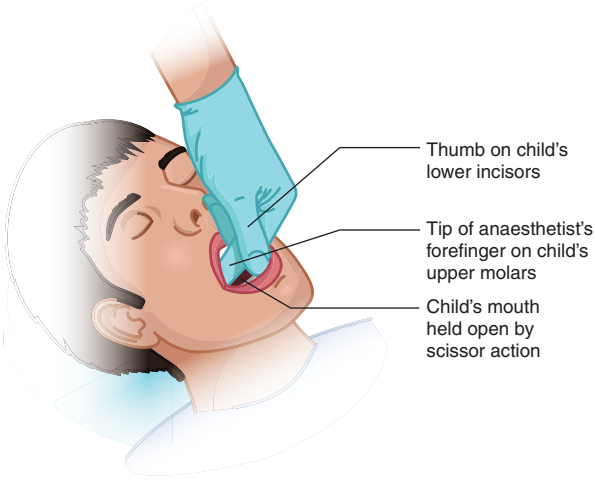

Fig. 4.10 Scissor action using forefinger and thumb to prevent the child biting the pharyngeal sucker and damaging teeth

4.9.1 Biting on the ETT

Children have strong bite reflexes and are prone to bite the ETT before extubation. Some anesthetists will insert a guedel airway or gauze roll alongside the ETT to avoid this, but dental trauma is a concern. Usually there are gaps in the teeth preventing total occlusion of the ETT. If biting does obstruct the ETT, the jaws can be separated slightly using the thumb and first or second finger in a scissor action on the upper molars and lower incisors (Fig. 4.10). This scissor action is also useful to prevent biting during pharyngeal suction before extubation. Rarely, biting may totally occlude the ETT, and hypoxia develops. A small dose of propofol or even suxamethonium can be used to relax the jaw if an emergency. Children often pass through this 'biting stage' during emergence and then enter a 'mouth-opening' phase, which usually signals a safe time for extubation.

Tip
If the child is biting the ETT they are not ready for extubation. When sufficiently awake, the child will enter a 'mouth opening' phase, when it is safe to extubate.

4.9.2 Post Extubation Stridor

A croupy cough or inspiratory stridor is uncommon after anesthesia with modern endotracheal tubes. Post extubation stridor still occasionally occurs in small children. Contributing factors include intubation that is traumatic or with an ETT that is too large, movement of the ETT within the trachea during the procedure, and edema of at the level of the cricoid cartilage from surgery or pre-existing conditions such as an URTI. Management is detailed in the Chap. 1 Sect. 1.9.2.

4.10 Tracheostomy Tubes

Unlike adults, most tracheostomies in children are long-term and are performed to bypass upper airway obstruction. The tracheostomy tube size is chosen according to the internal diameter using the same formula as for an ETT, although a smaller size may be used to facilitate speech. Different lengths are available so that endobronchial intubation does not occur. They are often uncuffed, and the leak around them may be too large to allow IPPV during anesthesia. For surgery, pediatric tracheostomy tubes are often replaced with a cuffed (usually reinforced) ETT after induction.

4.11 Laryngospasm

Laryngospasm occurs more frequently in children than in adults because of the child's sensitive and reactive airway. It is usually easy to recognize and treat, but has the potential to cause morbidity and mortality if managed poorly. It is not a serious problem when managed early and quickly, and should not be feared. However, if poorly managed laryngospasm can bring the child to a bradycardic hypoxic arrest, may cause negative pressure pulmonary edema and will instill anxiety in parents about their child's next anesthetic.

4.11.1 Definition

Laryngospasm is due to closure of the vocal cords. Supraglottic tissues may also contribute—there may be tilting of the arytenoids and epiglottis inward toward the glottis and closure of the false cords. Some argue that laryngospasm is an all or nothing phenomena and that there is no 'partial' laryngospasm. However, in practice there are varying degrees of severity and completeness that have implications for management.

4.11.2 Risk Factors

Some procedures and pre-existing conditions increase the risk of laryngospasm (Table 4.13)—current or recent URTI is a major risk factor. There is also no doubt

Table 4.13 Factors affecting incidence of laryngospasm in children

Risk factors for laryngospasm
Patient
Current or recent URTI within last 2 weeks
Young age
Passive smoking
Asthma
Nocturnal dry cough
Wheezing during exercise
History of hay fever or eczema
Family history of asthma, eczema or hay fever
Procedure
Blood or secretions in upper airway
Shared airway
Sudden surgical stimulation
Emergence (compared to induction)
Technique
Inhalational rather than IV induction
Thiopentone rather than propofol as induction agent
Desflurane as maintenance agent (lowest risk with propofol maintenance)
'Light' anesthesia, particularly during instrumentation of airway
Invasive airway management (lowest risk with facemask and laryngeal mask airway)
Probably no difference between 'deep' or 'awake' extubation

Table 4.14 Techniques suggested to prevent laryngospasm

Preventative method	Comments
'Deep' or 'awake' insertion and removal of device	Biting, coughing indicating anesthesia depth neither 'deep' nor 'light' enough
Pharyngeal suctioning then 'pseudocough' as ETT removed	Recommended
IV lidocaine	Effective for short time; exposure to potential toxicity
Propofol 0.5–1 mg/kg before removal of device. Perhaps more if anesthesia already 'light'	Only if planning 'deep' removal. Effective, also reduces emergence agitation. Recommended

that the risk of laryngospasm can be reduced by experience and attentiveness to the airway. Some preventative techniques have been suggested, but only propofol is useful in clinical practice (Table 4.14).

4.11.3 Mechanism

Laryngospasm is triggered by secretions or airway instrumentation stimulating the glottic and supraglottic mucosa. The resulting glottic closure continues after removal of the stimulation. This reflex closure can also be triggered by intense surgical stimulation in distant viscera. Propofol, and to a lesser extent sevoflurane, suppress laryngeal reflexes, contributing to their popularity in pediatric anesthesia. Although

secretions on the vocal cords are thought to be a common cause, laryngospasm can also be caused by sudden surgical stimulation in the presence of inadequate anesthetic depth and analgesia (circumcision and anal dilatation are classic causes). Deep anesthesia reduces the likelihood of laryngospasm.

4.11.4 Clinical Presentation

The warning signs of impending laryngospasm are cough, breath holding and straining in inspiration and expiration. Signs of upper airway obstruction and inspiratory stridor may occur although total closure of the vocal cords is silent. Laryngospasm can develop over a period of time, but more often occurs instantly.

Tip
A cough under anesthesia with a face mask or LMA is a warning sign of laryngospasm. Immediately deepening anesthesia with a bolus of propofol is worthwhile.

4.11.5 Management

Management depends on the severity of the obstruction and whether hypoxia is present. The first aim is to recognize and begin treatment before hypoxia develops so that there is more time to try basic maneuvers and assess options. The second aim is to resolve the laryngospasm reasonably quickly to avoid respiratory sequelae. Early treatment, using suxamethonium if appropriate, keeps the hypoxic period short (Fig. 4.11).

4.11.5.1 Jaw Thrust and CPAP with Oxygen

Initial therapy is jaw thrust and CPAP with 100% oxygen via a facemask—aim to assist any inspiratory effort by keeping the rebreathing bag tightly distended and ready to squeeze at, or even just before, inspiration. When there are minimal or irregular respiratory efforts, it may be worth keeping the bag distended and gently squeezing it at a rapid rate so that some oxygen will enter the lungs if the vocal cords partially relax and separate. Assisting inspiration in this way is often adequate therapy for partial laryngospasm. The stomach may distend with gas if vocal cord closure is complete and high pressure CPAP is used. If this happens, the stomach is aspirated when the laryngospasm has resolved.

4.11.5.2 Propofol

Anesthesia can be quickly deepened with propofol. A bolus dose of 2–4 mg/kg can be given, depending on the severity of the upper airway obstruction and how lightly anesthetized the child is thought to be. This is reasonably successful and usually

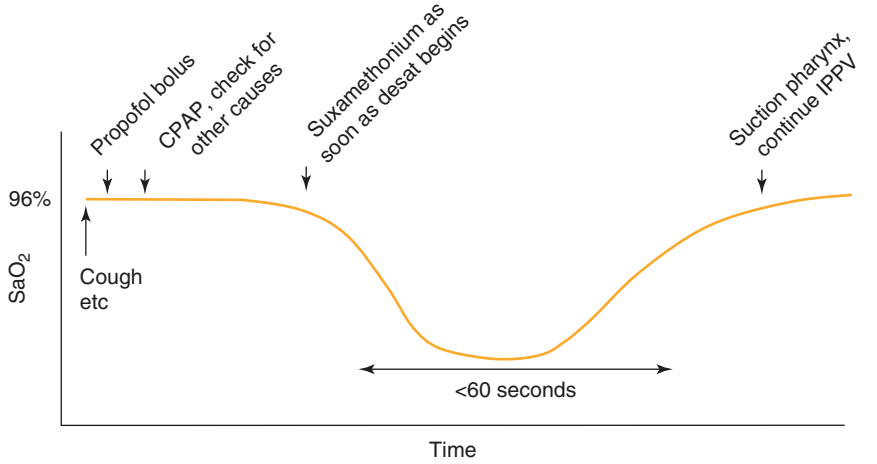

Fig. 4.11 A timeline of oxygen saturation during laryngospasm. A cough or signs of airway obstruction has been detected early, before desaturation. A bolus of propofol is given, then CPAP begun while also considering other causes of airway obstruction. If no breath has occurred, suxamethonium is given early, as soon as saturations begin to fall. Prolonged, severe hypoxia and bradycardia are avoided

worth trying if hypoxia has not developed. However, it is not always successful and suxamethonium should always be at hand.

4.11.5.3 Suxamethonium

Suxamethonium is always effective, and should be given if laryngospasm is causing complete airway obstruction and hypoxia. It should be given after airway maneuvers with or without propofol have been tried and when the oxygen saturation begins to fall. Even if IV suxamethonium is given when the saturation just starts to fall below 90%, the saturation will be very low by the time it has worked and mask ventilation is possible.

> **Note**
> If the child is hypoxic from laryngospasm, it is too late to try a bolus of propofol.

The dose of suxamethonium to treat laryngospasm is 0.5–2 mg/kg IV. A small dose such as 0.1 mg/kg is able to relax the vocal cords. However, if only a small dose has been given there may then be doubt about whether enough has been given if the saturations are still not rising. By giving a larger dose of suxamethonium, this doubt is removed and the duration of paralysis is still only a few minutes. If laryngospasm occurs during a gas induction and there is no IV, IM suxamethonium is

given once simple airway maneuvers have been tried. The dose is 4 mg/kg into the deltoid muscle. Although the peak effect by the IM route is 3 or 4 min, the vocal cords relax much sooner.

Tip
Anesthetists become stressed about laryngospasm because they fear the consequences of hypoxia. Bail out early! The risk from suxamethonium is much lower than that of prolonged, severe hypoxia. Consider suxamethonium treatment early and when the oxygen saturation is in the low 90s and falling.

After giving suxamethonium, concentrate on watching the chest for expansion. Make sure that the chest is rising and falling and that the tidal volume is adequate. The saturation may stay low for a short while and cause some concern. However, the displayed reading is averaged over the last 12–15 s and is old data. It is best to watch the chest and concentrate on ventilation, being confident that if 100% oxygen is being given and ventilation is adequate, the saturation will improve.

After the saturations have improved and while the suxamethonium is still working, the pharynx is suctioned to remove any secretions that might irritate the larynx. If the stomach has been distended with gas, an orogastric catheter is inserted and the stomach aspirated. The aim is to do both of these things while the suxamethonium is working so that laryngospasm is not triggered again. Intubation is not routinely required in the treatment of laryngospasm, and it is reasonable to continue gentle mask ventilation until spontaneous respiration resumes. Intubation would be performed usually only if surgery has yet to be performed or if laryngospasm occurs a second time.

Note
The aim during laryngospasm is to achieve mask ventilation with oxygen. Intubation is not mandatory.

Some anesthetists are reluctant to use suxamethonium to treat laryngospasm, or even pride themselves in not having to use it. The consequence of this approach is to bring some children close to cardiac arrest, creating stress for all concerned. Indeed, laryngospasm is the main respiratory cause of cardiac arrest in children. Although it has its side effects, suxamethonium is a safe drug. It has caused deaths from rhabdomyolysis in children with unrecognized myopathies, resulting in a ‘black-box’ warning in the US. This was at a time however, when suxamethonium was used almost routinely to intubate children. Infrequent use in situations such as laryngospasm has a low risk, and the risk of cardiac arrest or death from inadequately treated hypoxia is far greater than the risk from suxamethonium.

4.11.5.4 Treatment of Laryngospasm When Suxamethonium Is Contraindicated

If suxamethonium is contraindicated, atracurium or rocuronium are alternatives. The laryngeal muscles are more sensitive than the diaphragm to neuromuscular blockade, so less than the intubating dose is effective and keeps the duration of blockade reasonably short. However the smallest effective dose has not been studied and is not known. The availability of sugammadex may make rocuronium more attractive in this situation, but the safety and effectiveness of this technique have not been studied.

4.11.6 Sequelae

Most children have no sequelae. The parents should be given a brief description of the problem and reassured that their child is usually not likely to have a problem with future anesthetics. Some children will be oxygen dependent for a few hours after they wake up, particularly if they have an underlying URTI. This is possibly due to loss of FRC and retention of secretions during the laryngospasm causing V/Q mismatch that resolves when the child wakes up, coughs and re-expands atelectatic segments. An alternative to bear in mind is the possibility of pulmonary aspiration of gastric contents or negative pressure pulmonary edema, though these are uncommon.

4.11.6.1 Negative Pressure Pulmonary Edema

This is an uncommon problem usually due to prolonged upper airway obstruction from laryngospasm that has not been quickly resolved. The signs and symptoms are the same as for pulmonary edema in adults. Treatment is observation, IV frusemide and CPAP.

4.12 The Child with a Difficult Airway

Management of children's airways is often mildly difficult, or 'awkward' as a result of imperfect technique or inadequate anesthesia, or anatomical changes associated with young age (Fig. 4.12). Difficult airways due to pathology or syndromes are rare, and a child with a difficult airway usually looks difficult. Unless they are in a rare group with an isolated glottic or subglottic lesion, children with a difficult airway usually have syndromal or abnormal facies that alert the anesthetist (Table 4.15). There are many different anesthetic approaches and equipment choices for these children. Usually, younger children will not tolerate awake techniques and so intubation is performed under general anesthesia.

Children with a difficult airway who are younger than 1 year or smaller than 10 kg have more complications than older children. Most children with a difficult airway, and certainly young children with a difficult airway, need to be managed in a specialist center. Management of unexpected difficult mask ventilation and

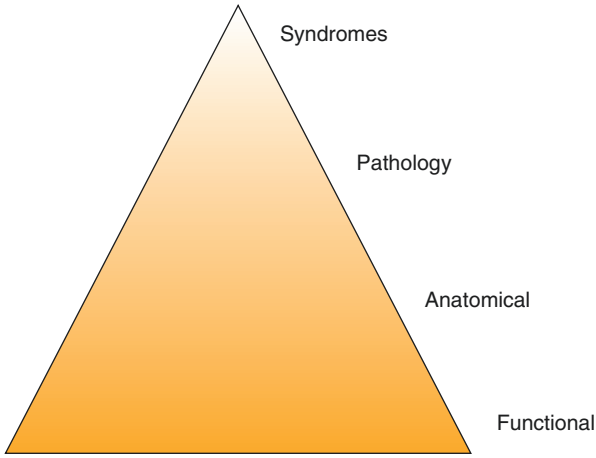

Fig. 4.12 Functional causes of difficult mask ventilation include "light" anesthesia, excitation during sevoflurane induction, poor head position or technique, and laryngospasm. Anatomical causes include obesity, tonsillar hypertrophy and the neonatal airway. Causes due to pathology and syndromes are less common

Table 4.15 Facial syndromes associated with a difficult airway

Condition	Main cause of difficulty	Airway change with growth
Robin Sequence	Micrognathia	Improves
Goldenhar (hemifacial microsomia)	Asymmetrical micrognathia Vertebral abnormalities may limit neck movement	Worsens
Treacher Collins	Micrognathia, small mouth, funnel-shaped larynx	Worsens
Apert syndrome	Micrognathia, mid face anomalies	Worsens
Hunter and Hurler syndromes	Deposition of mucopolysaccharides in tongue and larynx	Worsens

unexpected difficult intubation follow guidelines from professional organizations (Tables 4.16 and 4.17). There is some evidence supporting making only three attempts at laryngoscopy rather than the currently suggested four.

Keypoint
Consider management in specialized centers for children, especially young children, with difficult airways.

4.12.1 Induction of the Child with a Known Difficult Airway

Inhalational induction with an IV in situ is the commonest technique for this group of patients. This gives a gradual induction during which the airway can be assessed—the facemask seal and ability to generate pressure within the breathing circuit can be checked; the 'feel' of the child's jaw and effects of head position can also be assessed, and gentle CPAP tried. Strategies to assist achieving a patent airway after

Table 4.16 Management of unexpected difficult intubation in children

Management of unexpected difficult intubation	
1	Four or less attempts at laryngoscopy – optimize position and technique – consider videolaryngoscope
2	LMA or other SAD
3	Face mask ventilation, reverse paralysis, wake patient
4	CICO pathway

Based on DAS/APA guidelines 2015

consciousness is lost include CPAP, placing the child in the lateral position and insertion of an oral or nasal airway. Applying CPAP and gently assisting ventilation is useful at this stage. Although traditional teaching is not to assist ventilation in this manner, it deepens anesthesia more quickly and takes the child through the lightly anesthetized, partially obstructed stage all children pass through. It also allows the anesthetist to assess the airway patency, the effectiveness of gentle ventilation, and positions or strategies that improve or worsen airway patency. Finally, it provides information to help the anesthetist to decide if paralysis can be used for intubation. Classically, only simple chin lift and jaw thrust are used during induction of a child with a difficult airway, but these provide little information to the anesthetist about the child's airway.

Tip
Gentle CPAP and inspiratory support during inhalational induction is a useful strategy to assess and improve the difficult airway.

4.12.2 The LMA

The LMA has a central role in the management of the child with a difficult airway. It gives a good or adequate airway in a large proportion of children with syndromes and other abnormalities, and is a common way of facilitating fiberoptic intubation. The LMA bypasses the problem such as jaw and tongue in Robin sequence, and often gives an adequate seal in the laryngopharynx of children with other conditions causing a difficult airway. Using an LMA for anesthesia in children with a known difficult airway has been shown to be a safe and useful strategy to avoid intubation for many procedures. However such a technique does require an assessment of the adequacy and security of the airway, the likely risk of airway obstruction during the procedure and how this would be managed.

4.12.3 Intubation

There are many different laryngoscopes available for endotracheal intubation. As in adults, multiple attempts at intubation increase complications in children. Direct

laryngoscopy must be abandoned after no more than four attempts. If the child has a known or suspected difficult airway, direct laryngoscopy is a poor first choice for intubation and has a low success rate. A videolaryngoscope or fiberoptic technique should be used for the first attempt at intubation.

Note
Direct laryngoscopy should not be used as the first technique when a child is suspected or known to have a difficult airway—the first-attempt success rate is less than 5%.

4.12.3.1 Videolaryngoscopes

Although standard-shaped blades are adequate for normal or 'awkward' intubations, hyperangulated blades are needed for difficult intubations. Videoscopes with a pediatric, hyperangulated blade (CMAC D Blade Ped, Glidescope, McGrath X-blade and AirTraq) require a technique that must be practised. An introducer is used to shape the ETT before insertion, as the manufacturer's stylets are too large for children. The recommended blade size of the Glidescope for different weights is shown in Table 4.17. The position of the camera on the blade relative to the larynx is important, with some work suggesting a Glidescope blade one size smaller than the size based on weight can be used to improve the view of the larynx. Some children with a difficult airway will still require a fiberoptic scope as a first technique (Fig. 4.13).

4.12.4 Fiberoptic Intubation

Fiberoptic scopes are available in a range of pediatric sizes, including those small enough for neonates. They are passed either through a second generation LMA (via a Bodai swivel connector so that anesthetic gases can continue to be given) or through a special bronchoscopy facemask with a port for the scope to pass through. When a small diameter scope is available, an ETT (without its connector) can be rail-roaded over the scope into the trachea. If only a large scope is available, an

Table 4.17 Glidescope blade size for children is based on weight

Weight	Glidescope blade size
<1.5 kg	0
1.5–3.6	1
1.8–10	2
10–28	2.5
>10 kg[a]	3

[a]The camera position with the size 3 blade may be too proximal in some children at the lower end of the weight range

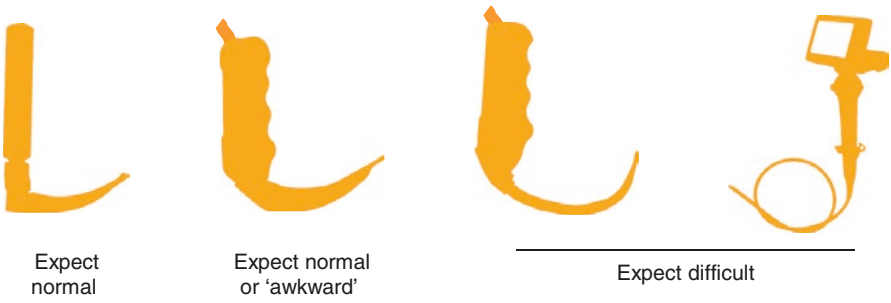

Fig. 4.13 A normal-shaped videolaryngoscope blade is satisfactory for routine or mildly difficult ('awkward') intubations, but difficult intubations need a hyperangulated blade or fiberoptic technique

indirect technique can be used by passing a guidewire through the suction channel into the trachea. The ETT is then passed over an airway exchange catheter. The indirect technique is difficult and has many potential problems.

The commonest technique for fiberoptic intubation in young children is general anesthesia and topicalization of the airway, followed by insertion of an LMA or other supraglottic airway device (SAD), then intubation through the LMA. A SAD without glottic bars is preferred, as the intubating LMA is not available in pediatric sizes. After intubation, the LMA is usually removed. The ETT needs to be held in place while the LMA is removed, but the ETT may not be long enough to safely do this. This problem is solved by either shortening the LMA shaft or lengthening the ETT by joining another ETT to it, or using a purpose-made pusher to hold the tube in place. A cuffed ETT is commonly used to avoid unnecessary changes of tube size. The smaller internal diameter of the cuffed tube may require a smaller diameter fiberscope compared with an uncuffed tube. The cuff of the tube also has a pilot balloon that makes it more difficult to remove the LMA over it.

Tip
During fiberoptic intubation, the scope must be small enough to pass through the ETT, and the ETT must be small enough to pass through the LMA.

4.12.5 Can't Intubate, Can't Oxygenate (CICO)

CICO in children follows the same path as in adults—optimize mask ventilation attempts, try an LMA, paralyze, then proceed to front of neck access (Table 4.18). Fortunately, this situation is rare, because front of neck access is more difficult in children than adults. In children, needle access tends to be the first step in management guidelines. This is because scalpel or surgical access in a child is more difficult and best done by an ENT surgeon. However, several factors also make needle

Table 4.18 Steps to follow in CICO scenario in children

Steps to follow in CICO	
1	Optimize mask ventilation Oral airway Two-person technique
2	Attempt ventilation via LMA
3	Paralyze
4	If ENT available: tracheostomy or rigid bronchoscopy If ENT not available: Needle cricothyroidotomy
5	Scalpel cricothyroidotomy or other surgical airway

Based on APA/DAS guidelines 2015

Table 4.19 Reasons front of neck access in CICO in children is more difficult and more dangerous than in adults

Factors making front of neck access more difficult in children
High larynx—needle insertion at steep angle
Soft, compressible trachea—may perforate anterior and posterior walls together
Small diameter trachea—perforation of posterior wall likely
Small cricothyroid membrane—risk of laryngeal damage, stenosis and vocal changes
Commercially available kits for emergency access not suitable for children and have a low success rate in vitro
Cricothyroid membrane difficult to identify in neonates and infants
Uncertain cannula size—small reduces posterior wall perforation but increases resistant to flow

access more difficult and more dangerous (Table 4.19) and some suggest it should only be used in children older than 8 years. This is because the larynx is high in the neck, and there is little room between the chin and cricothyroid membrane to angle the needle, forcing a steep insertion angle. This in turn increases the risk of perforating the posterior wall of the soft and compliant trachea. A smaller needle reduces the risk of perforation, but increases resistance to gas flow. A needle size of 18G (neonates and infants) or 14G (children) is suggested.

Note
Saturations <80% are considered critical and warrant urgent management using a failed intubation or CICO guidelines. (<50% if cyanotic congenital heart disease).

An oxygen source is then connected to the needle and the chest observed. Purpose-made devices have a luer lock fitting. A T-piece or anesthetic circuit can be connected using the connector from a 3.5 mmETT, as this matches a luer fitting. High pressures are needed to generate enough flow. Commercially available jet ventilators such as the Manujet (VBM Medical) control both flow rate and pressure but do not allow expiration, so breath stacking and pneumothorax are a risk. Also, they

do not allow detection of a kinked catheter. The expiratory profile of devices such as the Enk Flow Modulator and T-piece devices is better, and these are now recommended.

4.13 High Flow Nasal Oxygen (THRIVE)

High flow humidified air and oxygen given via nasal cannulae during spontaneous ventilation (Nasal CPAP) has been used for many years as part of neonatal intensive care, and has reduced the number of infants requiring intubation and positive pressure ventilation. High flow oxygen given via nasal cannulae to anesthetized, apneic children (THRIVE) delays the onset of desaturation as it does in adults. This technique may have benefit in difficult, prolonged intubation in children.

High flow oxygen given via nasal cannulae to anesthetized, spontaneously breathing children (HFNO) may have a role in airway procedures such as laryngotracheobronchoscopy or supraglottoplasty. Barotrauma is a significant risk of either high flow technique in small children. If a facemask is applied over the nasal cannulae during high flow oxygen for even a second or two, the delivered tidal volume is enormous.

Review Questions

1. You are to anesthetize a term baby weighing 3.5 kg. Why is a straight bladed laryngoscope usually used for intubation of babies? What sized cuffed and uncuffed tube would be appropriate for this baby?
2. During intubation of a 3 year old, you are unable to pass an age-appropriate sized ETT. You try again with the next smaller sized ETT, but still can't pass it beyond the cords. What might be the cause and what problems could occur after the child is awake?
3. At the end of anesthesia but before extubation of 3 year old, you are having difficulty ventilating and the saturations are falling. You notice the child is biting the ETT. What will you do?
4. Describe a technique for fiberoptic intubation in children.
5. Regurgitation during LMA anesthesia. Describe your course of action. What might happen if regurgitated fluid enters the breathing circuit filter?
6. You are going to anesthetize an 8 month old for orchidopexy. Discuss how you will manage this infant's airway during anesthesia. Include discussion of the equipment you would have ready in case your initial airway plan was unsuccessful.

Further Rewading

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Fluid Management in Children Undergoing Surgery and Anesthesia

5

Ric Bergesio and Marlene Johnson

As with drug treatment, fluid treatment in children demands more precision than in adults. This chapter explains the management of fluids in infants and children in the peri-operative period. Topics include fluid resuscitation, maintenance fluids and the replacement of ongoing losses. Fasting guidelines and the management of electrolyte disturbances are also included.

5.1 Body Fluid Composition

Babies are 'wet' at birth—total body water (TBW) is about 70–75% of body weight in neonates, higher in preterm neonates. It falls by 5% in the first week, accounting for the weight drop of newborn babies, and falls to the adult level of about 60% by 1 year of age. The extracellular fluid volume is greater than the intracellular fluid volume (the opposite of adults), until 1 month of age when they become equal. ICF then becomes larger than ECF through to adulthood (Fig. 5.1). Adult values are achieved by 1 year of age. Blood volume is higher in neonates and falls with growth (Table 5.1).

5.1.1 Hemoglobin

The hemoglobin concentration is high at birth because of the hypoxic environment in-utero. At birth, the hemoglobin level can be 160–200 g/L, depending on when the cord was clamped relative to uterine contraction. Most of the

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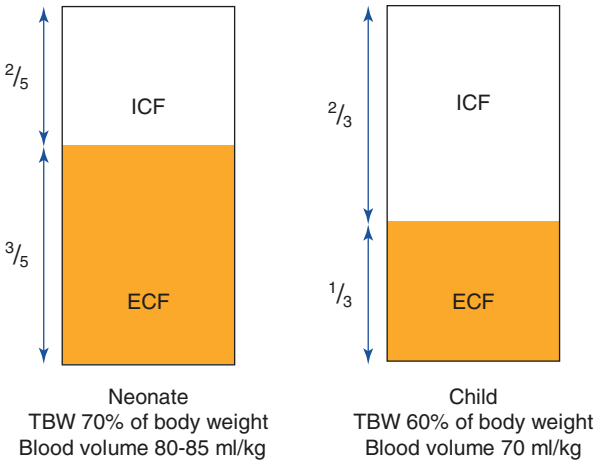

Fig. 5.1 Changes in body water composition with age. Modified from Jain, Pediatrics Rev 2015

Table 5.1 Blood volume at different ages

Age	Estimated blood volume (mL/kg)
Preterm	100
Term neonate	90
Infants and children	70–80
Adult	70

hemoglobin at birth is fetal hemoglobin (HbF). Although red blood cells containing adult hemoglobin (HbA) are produced from birth, production is low in response to the increased availability of oxygen and downregulation of erythropoietin. Eventually oxygen delivery is inadequate relative to metabolism, and erythropoietin production is stimulated again. These factors result in a falling hemoglobin, reaching a low point of 90–110 g/L at 2–3 months (called the 'physiological anemia', Fig. 5.2). The hemoglobin level in very preterm infants can decline even lower (80 g/L) due in part to repeated phlebotomy, and the effects of transfusions on endogenous erythropoiesis. Nearly all of the hemoglobin at the time of physiological anemia is HbA, so tissue oxygen delivery is actually improved due to the lower oxygen affinity of HbA compared to HbF. Platelet numbers are at adult levels from birth.

5.1.2 Coagulation Changes

Coagulation factors are produced by the fetus and have low levels at birth, but this is balanced by lower levels of inhibitors than in adults, a stronger binding fibrinogen molecule and lower activity of the fibrinolytic system. Clotting tests can therefore be prolonged despite no bleeding tendency. The rotational thromboelastogram (ROTEM) of a neonate has clinically minor differences until about 4 months of age, when it becomes the same as that of an adult.

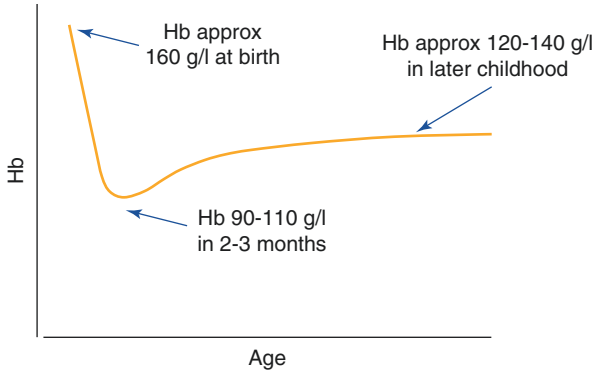

Fig. 5.2 The hemoglobin level dips in early infancy ('physiological anemia of infancy') as HbF production ceases and is replaced by HbA

5.2 Preoperative Fasting

Minimizing fasting in children reduces anxiety and irritability as well as physiologic and metabolic derangements. Neonates in particular, have low glucose stores and are at risk of hypoglycemia—a 10% glucose in 0.22% saline infusion is started if the fasting time is longer than the usual time between the baby's feeds.

The duration of fasting of children before anesthesia has traditionally followed the 6-4-2 rule: 6 h for light food and milk, 4 h for breast and formula milk, and 2 h for clear fluids. Recently, this has changed to the 6-4-1 rule in many countries and is discussed below.

5.2.1 Clear Fluids

Clear fluids include drinks that contain no fats or solids, such as clear apple juice, cordial, lemonade and pulp-free orange juice.

Many centers are moving away from a 2 h clear fluid fasting time, instead encouraging children to consume clear fluids (up to 3 mL/kg) until 1 h before elective or minor emergency surgery (the 6-4-1 rule). This is safe and does not increase the incidence of aspiration. Some centers accept even shorter fasting times (using a 6-4-0 rule).

5.2.2 Milk

Milk is cleared from the stomach in a biphasic pattern—an initial phase of rapid clearance of liquid followed by a slower phase of clearance of solids.

Gastric emptying times vary between milk products and depend on protein (whey and casein) and fat content. Breast milk has a higher whey-to-casein ratio than other milks and empties faster from the stomach. Because of this, many centers accept shorter fasting intervals for breast milk than other types of milk. Cow's milk is rich

Table 5.2 Fasting times for children

Substance	Fasting period
Clear fluids	1 h
Breast milk[a]	3 h if <12 months age
Formula milk[a]	4 h if <12 months age
Solids, cow's milk	6 h

Note the different fasting periods in infants for different milks that have different amounts of fat and protein

[a]There is variation in fasting duration and age limits for milk—see text

in casein and fat, and empties slowly. Formula milk is intermediate in composition and emptying time.

While there is consensus about fasting periods with clear fluids, this is not the case with milk, and there is variation across different regions. A fasting duration of 3 h for breast milk and 4 h for formula is commonly used for infants, with fasting increased to 6 h for all types of milk in children 1 year and older.

The Australian College currently suggests these shorter durations for breast and formula milk only until 6 months of age, rather than 12 months. In infants older than 6 months, it suggests 6 h fasting for both breast and formula. Some centers include cow's milk with formula, and some in Europe allow cow's milk and products such as yoghurt in all ages up until 4 h before anesthesia. An example of a commonly used set of fasting times is listed in Table 5.2.

Note
Different types of milk have different fat and protein contents, and the fasting duration after ingestion of each type is different.

5.2.3 Solids

Solids tend to have variable gastric clearance times. Emptying may be prolonged with increasing fat and calorie content and the size of the meal, and the 6 h duration generally applies only to a 'light' meal.

In children with traumatic injuries, the time to complete gastric emptying is unknown. However, not all of these children need to be treated as if they have a full stomach. Factors that affect gastric emptying include the severity of trauma, pain, anxiety, administration of opioids and the time interval between trauma occurring and last meal.

5.2.4 Unusual Foods

Food that becomes liquid in the stomach (jelly, icy poles, and lollipops) can be considered the same as liquids. Chewing bubble gum is also considered a clear liquid

for fasting, but if it is swallowed, it is treated as a solid. Fluid thickeners do not alter gastric emptying and fasting times should be determined by the type of fluid they are used to thicken.

Note
Rare conditions affected by fasting:
Glycogen storage diseases, Fatty acid oxidation disorders, Urea cycle defects, Organic acidurias (including MMA), Homocystinuria.

5.3 Intravenous Fluid Requirements

There are three components to fluid management in children: replacement of existing deficits, maintenance requirements, and replacement of ongoing losses.

5.3.1 Replacement of Existing Deficits

Fluid deficit can cause dehydration or shock, and may be due to hemorrhage, gastrointestinal losses, insensible losses or sequestration from the intravascular space into tissues. These deficits can be estimated from weight loss, clinical signs and laboratory investigations.

Dehydration is difficult to assess, and individual clinical findings by themselves are unreliable. Symptoms and signs are more numerous and more severe with worsening dehydration (Table 5.3). The best measure of fluid loss is serial weight measurements, but this is often unavailable.

Table 5.3 Signs and symptoms of dehydration and shock in children

Signs and symptoms	
Dehydration	Shock
Looks unwell or deteriorating[a]	
Altered consciousness: lethargy, restless[a]	Reduced consciousness
Decreased skin turgor[a]	
Sunken eyes[a]	
Tachycardia[a]	Tachycardia, then bradycardia
Increased respiratory rate[a]	Increased or decreased respiratory rate
Normal skin color	Mottled skin, pale
Warm extremities	Cold extremities
Dry mucous membranes	
Normal blood pressure	Hypotensive
Capillary refill <2 s	Capillary refill >3 s
Normal peripheral pulses	Reduced peripheral pulses
Reduced urine output	

[a]These signs of dehydration, if present, are suggested as 'red flags' warning of progression to shock or collapse. (Based on National Institute Clinical Excellence guideline CG84)

Dehydration may be detectable when a child is 2.5–5% dehydrated. Severe dehydration causes circulatory shock, and the child may become acidotic and hypotensive. Hypotension is a late, premorbid sign because young children are able to mount a strong sympathetic response and maintain blood pressure until severe hypovolemia develops. Clinical signs, serum electrolytes and glucose can guide replacement.

Keypoint

If a child is 5% dehydrated, this means they have lost 5 mL per 100 g of body weight, or 50 mL/kg.

Clinical dehydration is detectable when a child is 2.5–5% dehydrated.

If a child presents with symptoms and signs of dehydration in the **absence** of shock, they are approximately 5% dehydrated.

If shock is present, there is at least 10% dehydration.

Practice Point

The capillary refill time—Pressure on the skin for 5 s then observe the time for blanching to disappear. Normal refill time is 2 s or less. 2–3 s is borderline abnormal. The finger is the best site, the sternum is an alternative. Refill times are longer in the foot. Refill time doesn't correlate with blood pressure, reflecting the child's ability to maintain BP until late.

Skin turgor—Gently pinch a fold of skin for a few seconds and let go. Normally, the skin will recoil to its original position instantly. A delay in return to normal suggests dehydration. In a child, the best place to test skin turgor is on the abdomen.

Keypoints

Shock

If the child has signs of shock or is at increased risk of developing shock (presence of red flags), 10–20 mL/kg of an isotonic crystalloid solution should be given immediately. A further 10–20 mL/kg bolus may be given if signs of shock persist. Judicious fluid boluses of 5–10 mL/kg should be used in cardiac disease and severe trauma.

After resolution of signs of shock, rehydration should occur with an isotonic crystalloid +/− glucose. 100 mL/kg (ie. 10% dehydration) should be given over 24–48 h in addition to maintenance fluid requirements.

Dehydration

For children presenting with dehydration in the absence of shock, 50 mL/kg (ie. 5% dehydration) of an isotonic crystalloid +/− glucose should be given over 24–48 h in addition to maintenance fluids.

Table 5.4 The 4-2-1 formula for calculating hourly maintenance fluid requirements of children

Weight	Fluid rate (mL/kg/h)
First 10 kg	4
Next 10–20 kg	2
Part of weight over 20 kg	1

For example, a 24 kg child would need 40 mL/h for the first 10 kg, 20 mL/h for the next 10 kg, and 4 mL/h for the rest of the weight, giving an hourly maintenance rate of 64 mL/h

5.3.2 Maintenance Fluids

Maintenance fluids replace fluid and solute losses from the kidney, gut, respiratory tract and skin. Approximately 50% of the losses are from the renal system and 50% from the lungs and skin. Maintenance fluid requirements are a function of metabolic rate and caloric requirements, and so are higher in neonates than in children and adults. They are also higher in the presence of fever, burns, or sepsis.

In the 1950s, Holliday and Segar linked water requirements and caloric expenditure to body weight, and then linked electrolyte requirements to the composition of milk. Their work resulted in the formula for maintenance fluid requirements. This formula calculates a full day's fluid requirements: 100 mL/kg per day for the first 10 kg of body weight, then 50 mL/kg per day for the next 10 kg of body weight, and 20 mL/kg per day for the rest of the weight. The formula has been adapted to give a more practical, hourly calculation- the '4-2-1 rule' (Table 5.4). This formula is widely used, but there are concerns it overestimates the fluid requirements in the postoperative period or in sick, hospitalized children.

Isotonic crystalloid fluids should be used for maintenance fluids. The choice of fluid varies between regions, but includes 0.9% saline, Ringer's lactate (Hartmann's solution), Plasmalyte or other balanced electrolyte solutions. A glucose-containing fluid (typically 2.5 or 5% glucose in saline) should also be considered if the child is fasting. However glucose-containing hypotonic fluids may cause hyponatremia. There have been numerous cases of hyponatremia in hospitalized children receiving hypotonic fluids such as 4% glucose with 0.18% saline and 0.25% glucose with 0.45% saline, and these fluids should not be kept in the wards or theatre.

5.3.3 Ongoing Losses

Ongoing losses are replaced with fluids that are similar to the fluid being lost from the body. Most losses are salt-rich and are replaced with an isotonic fluid such as 0.9% saline or Ringer's lactate.

5.4 Fluid Management During Anesthesia

The main purpose of perioperative intravenous fluid is to restore or maintain homeostasis—blood volume, pH and electrolytes, tissue perfusion and metabolic function. Although a single fluid that is suitable for use during and after surgery in children

would be simple, this is not possible and the anesthetist must think about each child's requirements— which fluid and how much?

5.4.1 Which Fluid?

Isotonic fluids are recommended for maintenance and replacement of losses during anesthesia and surgery. There are several types of fluids available (Table 5.5). Although some of these fluids contain glucose, most children do not need glucose during surgery.

5.4.1.1 Glucose-Containing Fluids

Like adults, most children mount a hyperglycemic response to surgery. Exceptions are listed in Table 5.6. It may be difficult to identify all children at risk of hypoglycemia and a high index of suspicion should be maintained. Nevertheless, most children undergoing short surgical procedures do not require intraoperative fluids containing glucose. If the child is unable to drink and eat post-operatively, maintenance fluids containing glucose can be commenced after surgery.

Table 5.5 Some IV fluids commonly used in the perioperative period and their potential problems

Fluid	Uses	Concerns
0.9% sodium chloride	Resuscitation boluses Replacement of deficit/losses Intraoperative boluses and maintenance	Hypoglycemia Hyperchloremic metabolic acidosis if given in large volumes
Ringer's lactate, Plasmalyte	Replacement of deficit/losses Intraoperative boluses and maintenance	Hypoglycemia
0.9% sodium chloride +5% glucose	Post-operative maintenance	Hyperglycemia if given as bolus
Ringer's lactate/ Plasmalyte +5% glucose	Post-operative maintenance	Hyperglycemia if given as bolus
Balanced electrolyte solution +1% glucose	Replacement of deficit/losses Intraoperative maintenance Post-operative maintenance	Not commercially available in most countries

Table 5.6 Risk factors in children for hypoglycemia during IV fluid therapy

Groups of children at risk for hypoglycemia
Neonates
Infants undergoing major or prolonged surgery
Children younger than 2–3 years who are malnourished, have failure-to-thrive (<3rd centile body weight), or have had a prolonged fast
Children with extensive regional blockade that may stop the hyperglycemic response during surgery
Children receiving TPN
Children with metabolic syndromes

Neonates and young infants are at risk of hypoglycemia because they have reduced gluconeogenesis and low glycogen stores in the liver. These and other children who are at risk of hypoglycemia need glucose containing perioperative fluids and blood glucose monitoring. In these children, an intravenous fluid containing 1–2.5% glucose is appropriate, but is only available in some countries. Neonates have higher glucose requirements and their fluid management is described below (see Sect. 5.6).

Practice Point
Hypoglycemia in neonates is usually considered to be <2.6 mmol/L. In diabetic children, it's 4.0 mmol/L.

5.4.2 How Much?

The volume of fluid given during surgery takes into account the pre-operative deficit (fasting and pre-operative losses such as bleeding or vomiting), maintenance requirements as well as ongoing intraoperative losses.

In longer surgeries, the volume should be adjusted to clinical parameters such as standard and invasive monitoring, serial blood gas measurements and surgical events such as bleeding. Urine output may decrease due to raised ADH, and can be an unreliable sign of volume status.

5.4.3 A Summary of Practical Fluid Management During Anesthesia

The volume, sodium and glucose requirements of the child are considered. For healthy children who are undergoing minor procedures and will resume oral intake soon after surgery, 10–20 mL/kg of IV fluid during the procedure is acceptable. The infusion can be ceased at the end of the operation or run at maintenance rate until drinking. Suitable fluids include Ringer's lactate or 0.9% saline. This may also reduce the incidence of post-operative nausea and vomiting. Although there is usually no need to specifically replace the fasting deficit now short fasting times are used in children, many would still give 10–20 mL/kg of fluid in case of nausea or vomiting that might stop the child from drinking postoperatively.

For children undergoing major surgery associated with fluid and blood losses, Ringer's lactate, Plasmalyte or other balanced salt solutions are appropriate. Large volumes of 0.9% saline may lead to hyperchloremia and subsequent metabolic acidosis, and should be used cautiously.

If the child is at risk of hypoglycemia (Table 5.6) and is not a neonate, an isotonic crystalloid with 1–2.5% glucose can be used. In many centers, such a solution is not available and 0.9% saline with 5% glucose is used instead. This can be given as a bolus of 5 mL/kg during the procedure, or as an infusion at 0.5–1 times the maintenance rate. It is important to monitor blood glucose levels regularly when administering glucose.

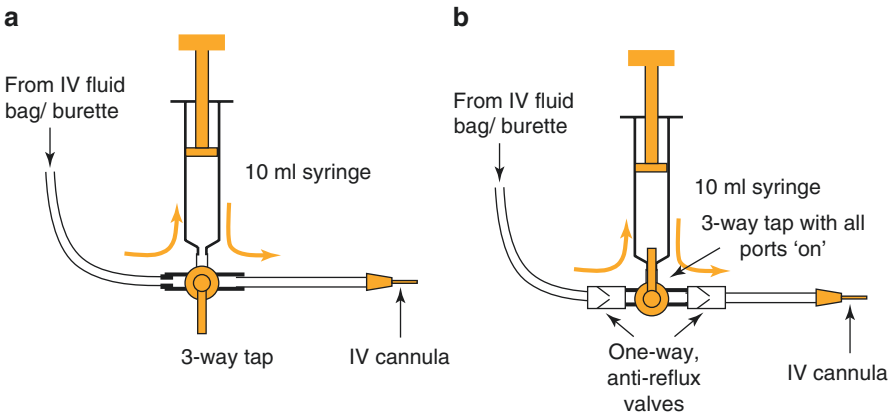

Fig. 5.3 (**a**) A three-way tap and extension is used to rapidly syringe in fluid boluses to small children. This arrangement allows a large volume of fluid (5 or 10 mL/kg or more) to be given surprisingly quickly. The three-way tap is turned to fill the syringe from the fluid bag, then turned to inject. A 10 mL syringe is the most efficient syringe size to use. (**b**) Alternatively, one-way anti-reflux valves either side of the three-way tap allow the syringe to function as a 'piston pump' without turning the tap (O'Callaghan, Singh. Anaesthesia 2009)

Neonates who are not yet fasting between feeds should have 10% glucose with 0.22% saline continued at maintenance rate. Isotonic IV fluids are used in addition to this to replace salt-rich losses during surgery.

5.4.4 How to Give a Rapid Fluid Bolus to Small Children During Surgery

IV pump sets are not used in small children. Their priming volume is large and there is a large volume within the giving set between the fluid bag and patient. Instead, a three-way tap and short extension is placed between the fluid bag (which usually includes a burette) and the child (Fig. 5.3).

Practice Point

Children with short fasting durations presenting for minor surgery have a minor fluid deficit that does not need specific correction. However, a bolus of 10–20 mL/kg of Ringer's lactate seems sensible to replace any deficits and reduce the impact of any delay in resumption of oral intake from nausea and vomiting.

Infants younger than 3–6 months presenting for minor surgery need some glucose-containing fluid. A 5–10 mL/kg bolus or infusion of saline or other isotonic fluid with 2.5–5% glucose is reasonable.

Neonates require special consideration (see below). If the neonate is receiving IV 10% glucose with 0.22% saline, it is continued at maintenance rate and losses replaced with isotonic IV fluid.

5.5 Postoperative Fluids

After minor surgery, oral fluids are quickly resumed and no postoperative IV therapy is needed. For major surgery, the postoperative fluid requirements depend on the expected postoperative fluid loss and the weight of the child.

Major surgery is associated with increased ADH secretion and fluid retention. Although the 4-2-1 formula for calculating maintenance requirements is widely used, there is concern the volumes calculated are too large and may contribute to hyponatremia. Many would reduce the maintenance rate of fluid in the postoperative period to two thirds or 80% of that calculated by the formula.

Keypoint
In post-operative or unwell children, the calculated rate for maintenance fluids is reduced to two thirds or 80%. This is due to increased secretion of ADH.

Isotonic fluids are recommended for post-operative maintenance infusions in infants older than 3 months and all children. Although hypernatremia might be possible with isotonic fluids, the real and previously common risk of hyponatremia is avoided. If full maintenance fluids are continued post-operatively, serum electrolytes should be monitored at least daily. Children at risk of hypoglycemia or those not able to resume oral fluids after surgery will require the addition of glucose to their maintenance fluids (eg 5% glucose in 0.9% saline) and blood glucose monitoring. Neonatal fluid requirements are discussed in the next section.

Keypoint
A child receiving full IV maintenance fluids needs daily electrolyte measurements.

5.6 Fluid Management in Neonates

Neonates have high fluid and caloric requirements but have a reduced renal capacity to excrete excess sodium and water. They are at risk of hypoglycemia because of low glycogen stores and reduced gluconeogenesis in the liver. After birth, pressure changes in the heart cause increased atrial natriuretic peptide levels. This stimulates a postnatal diuresis of sodium and water. This normally occurs 24–48 h after birth, but may be longer in the preterm neonate. It is common practice to withhold IV fluids containing sodium until this has occurred as the neonatal kidney has limited capacity to excrete excess sodium.

When fasting, neonates require a glucose infusion of 4–8 mg/kg/min (2.4–4.8 mL/kg/h of 10% glucose) to prevent hypoglycemia (Table 5.7). Preterm neonates may require a higher rate. Ten percent glucose solution is commonly used in

Table 5.7 Maintenance fluid rates in neonates, commonly given as 10% glucose with 0.22% saline

Age of neonate	Total fluid required mL/kg/day
Day 1	60
Day 2	80–90
Day 3	100–120
Day 4	120–150

neonates in whom the postnatal diuresis has not yet occurred. After approximately 48 h of age, 10% glucose in 0.22% saline is the preferred solution.

Older neonates who are able to fast between feeds are also able to fast before surgery without receiving IV glucose pre-operatively. However they should be given glucose during anesthesia.

An infusion pump should be used in all neonates to control the low maintenance fluid rate and prevent inadvertent boluses of glucose. Blood glucose should be monitored intraoperatively. Hypoglycemia is defined as a blood glucose level <2.6 mmol/L in a neonate.

Isotonic crystalloid solutions are required to replace intraoperative fluid losses. These can be administered via a separate lumen on the IV line or through a second cannula.

The volume of replacement fluid depends on the surgical condition. Herniotomy for example, is associated with minimal fluid shift and only maintenance fluid is required. Major surgery, such as laparotomy, is associated with fluid shifts that need to be corrected with an isotonic IV fluid such as 0.9% saline, Ringer's lactate or 4% albumin. The volumes of these fluids are small because of the small size of the baby and they are often given as boluses from a syringe.

Fluid boluses are often given during neonatal anesthesia to counteract hypotension associated with anesthesia. Large volumes of fluid however may cause fluid retention and generalized edema in the neonate after surgery. There is growing belief that intraoperative fluids should be mildly restricted and greater reliance placed on inotropic support in neonates undergoing major surgery.

Practice Fluid Calculations

Q. A 10 kg child undergoing laparotomy for intussusception. They are given 30 mL/kg 4% albumin preoperatively to correct deficit. There is minimal blood loss. What are their intraoperative fluid requirements?

A. Maintenance with isotonic crystalloid solution. 40 mL/h + ongoing 5–10 mL/kg/h = 90–140 mL/h. Any blood loss can be replaced with the same solution until the transfusion target is reached.

Q. A 3 kg neonate, 24 h old, undergoing laparotomy for duodenal atresia. What are their preoperative and intraoperative fluid requirements?

A. Preoperative: Maintenance of 10% glucose 10.8 mL/h (glucose = 6 mg/kg/h = 3.6 mL/kg/h). Intraoperative: continue maintenance fluids + ongoing 15–30 mL/h of isotonic crystalloid solution. Any blood loss or pre-op deficit

is replaced with isotonic crystalloid or 4% albumin, until the transfusion threshold is reached.

Q. A 5 kg 3 month old infant undergoing herniotomy. There is minimal blood loss. What are their perioperative fluid requirements?

A. Pre-operative: IV fluids are not required if the fasting time is minimal. Intraoperative: maintenance of 20 mL/h (ie 4 mL/kg/h) of 0.9% saline with 5% glucose. A 10–20 mL/kg bolus of isotonic crystalloid solution (NOT this glucose containing solution) could be given in addition, to replace the fasting deficit. Postoperative: the baby will be able to feed immediately after surgery and fluids can be discontinued.

Q. A 7 kg infant with a small bowel obstruction has signs of dehydration and shock. The estimated percentage dehydration is at least 10%. What are the pre-operative fluid requirements?

A. 20 mL/kg rapid bolus (140 mL) of Hartmann's solution or saline is given as initial therapy of shock. This is repeated if there are ongoing signs and symptoms of shock. 100 mL/kg to replace deficits is given over next 24 h in addition to normal maintenance requirements (100 mL/kg for the first 10 kg body weight). Total isotonic crystalloid fluid requirements: 700 mL (replacement) + 700 mL (maintenance) = 1400 mL. Infusion rate of 1400/24 = 58 mL/h.

5.7 Electrolyte Problems

5.7.1 Hyponatremia (Serum Na^+ < 135 mmol/L)

Hyponatremia occurs when sodium losses are more than fluid losses, or there is water retention without simultaneous sodium retention, or if fluid losses are replaced with a fluid low in sodium. It can present with mild symptoms of irritability and confusion, or severe symptoms of unconsciousness and seizures associated with cerebral edema.

Management of hyponatremia depends on the sodium concentration and the severity of the symptoms. A sodium concentration greater than 125 mmol/L can be replaced slowly over 24 h with an isotonic solution, whilst a very low sodium (less than 120 mmol/L) or the presence of seizures require rapid correction to approximately 125 mmol/L with 3% saline then slow infusion with normal saline 0.9% as described below. The maintenance requirement for sodium is approximately 2 mmol/kg/day. Deficits can be estimated from the following calculation:

$$\textbf{mmol of } Na^+ \textbf{ required} = \left(130 - \textbf{current serum } Na^+\right) \times 0.6 \times \textbf{Weight}\left(\textbf{kg}\right)$$

One mL/kg of 3% sodium chloride will normally raise the serum sodium by 1 mmol/L.

5.7.2 Hypokalemia

Maintenance potassium requirements are approximately 2–4 mmol/kg/day, but potassium is not usually required on the first postoperative day. The rate of intravenous replacement should not exceed 0.2–0.4 mmol/kg/h to avoid arrhythmias. In PICU potassium can be given by infusion via syringe driver and ECG monitoring. On general wards potassium can be added to the maintenance fluid with the dose added depending on the plasma potassium level.

5.7.3 Hyperkalemia

In infants and children, rapid transfusion of blood via a central catheter has been reported to result in hyperkalemia and cardiac arrest. Management of life threatening hyperkalemia follows the same principles as in adults. It includes hyperventilation to raise the pH and shift potassium into cells, and IV glucose (2 mL/kg of 50%) and insulin (0.1 units/kg). Calcium gluconate 10% (0.5 mL/kg) and sodium bicarbonate (1 mL/kg) can be given to stabilize the myocardium. Resonium (1 g/kg) may be given rectally or orally to reduce potassium absorption. Dialysis may be required in patients with severe hyperkalemia complicating acute renal failure.

5.8 Blood Transfusion

As in adults, fluid corrects hypovolemia, and blood corrects anemia. During surgical blood loss, normovolemia is maintained with asanguineous fluids and the hemoglobin falls in an exponential manner (Fig. 5.4). The allowable blood loss for any child can then be calculated (Fig. 5.5). This formula does not apply for a child who loses blood without simultaneous fluid replacement. Hemoglobin is still measured at regular intervals to monitor the child and determine when blood needs to be given.

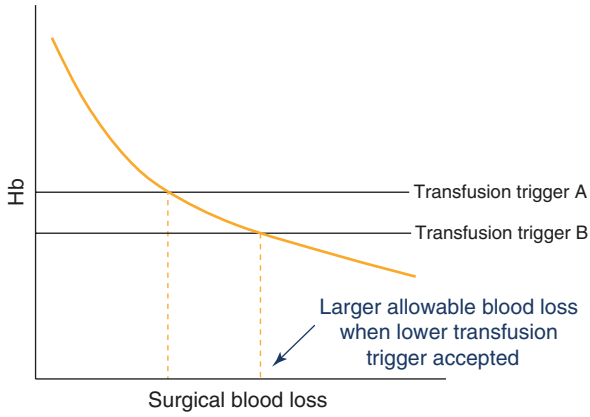

Fig. 5.4 Hemoglobin falls exponentially during blood loss if normovolemia is maintained with asanguineous fluid. Accepting a lower transfusion trigger (B instead of A) permits much greater blood loss before transfusion is necessary

$$\text{Allowable blood loss} = \frac{\text{initial Hb} - \text{final Hb}}{\text{initial Hb}} \times \text{blood volume}$$

Fig. 5.5 A simplified formula to calculate allowable blood loss (ABL) in children and adults. 'Initial Hb' is the hemoglobin before blood loss and 'final Hb' is the lowest acceptable or 'transfusion trigger' Hb

There are no strictly agreed hemoglobin levels that trigger a transfusion in children, and the need for transfusion is based on an assessment of the clinical situation, the child's age and their underlying condition. In general however, children usually tolerate acute anemia better than adults because they have normal cardio-respiratory systems that can compensate for anemia. In hemodynamically stable patients, transfusion is likely needed if the Hb is lower than 70 g/L, and unlikely to be needed if higher than 90 g/L. Hemoglobin concentrations of 100–120 g/L are commonly used in neonates or children with cyanotic heart disease. In certain situations, hemoglobin levels of 50–70 g/L are accepted in children. Previously well children given supplemental oral iron can increase their postoperative hemoglobin by about 10 g/L each week.

Example
To calculate allowable blood loss (ABL) for a 10 kg child with initial Hb of 120 g/L who will tolerate a Hb of 80 g/L: estimated blood volume is 800 mL, therefore ABL = 800 × (12 − 8)/12 = 270 mL.

5.8.1 Amount of Blood to Give

Children are transfused using the same size bags of packed cells for adults. These bags contain approximately 250 mL of blood with a hematocrit of about 0.6–0.7. A burette is used as part of the IV giving set to measure the volume. In children who are not actively bleeding but are anemic, the volume of packed cells is calculated:

$$\mathbf{10\,mL/kg\,of\ packed\ cells\ increases\ the\ Hb\ by\ 20\,g/L}$$

$$\mathbf{or: Volume\ of\ packed\ cells\ to\ give = weight \times (desired\ Hb - initial\ Hb) \times 0.5}$$

If there is ongoing bleeding, formulae such as above can only give a guide to volume needed before more blood loss has occurred. Packed cells may be mixed with albumin in the burette and given at a rate to correct hypovolemia. Mixing packed cells with albumin facilitates rapid administration through a fine-bore catheter. Blood should be warmed and given through appropriate filters. Caution should be taken whenever transfusing blood rapidly, especially via a central venous catheter as cardiac arrest can occur due to sudden hyperkalemia. The doses of other blood products are listed in Table 5.8.

Table 5.8 Doses of blood products and tranexamic acid in children

Product	Dose
FFP	10 mL/kg
Cryoprecipitate	5–10 mL/kg
Platelets	5–10 mL/kg
Fibrinogen concentrate	70 mg/kg
Factor VII	90 μg/kg
Tranexamic acid	15 mg/kg[a]

[a]Usually followed by maintenance infusion 2 mg/kg/hr for 8 h (or bleeding cessation)

Some institutions irradiate blood before transfusion to prevent graft-versus-host disease in certain groups of children. Guidelines vary, but the groups can include neonates and infants less than 4 months age, cardiac surgery patients, ECMO or LVAD patients, directed donations from relatives, immuno-compromised patients and after intrauterine transfusion. Irradiation increases leakage of potassium from the red cells into the transfused plasma and shortens storage time.

5.8.2 Critical Bleeding and Massive Blood Transfusion

Massive transfusion in children is defined as red cell transfusion of 50% of the total blood volume (TBV) in 3 h, or of 100% TBV in 24 h, or >10% TBV per minute. Current critical bleeding protocols, based on traumatic blood loss in adults, favor early, concurrent use of platelets and coagulation factors. They lead to earlier administration of blood and blood products but are yet to be shown to reduce morbidity or mortality. The ideal dose and ratio of products to administer is unclear but can be guided by formal coagulation profile and point-of-care testing. Critical bleeding may be useful for situations such as trauma or unexpected massive surgical bleeding from a torn major vessel.

Massive blood loss can be expected to occur during some types of pediatric surgery. These surgeries include craniofacial reconstruction, neurosurgery, and surgery for tumor resection or scoliosis. Blood loss during surgery differs from that in trauma because normovolemia is maintained but hemoglobin concentration falls exponentially until the transfusion trigger is reached and red cells begun (Fig. 5.6). The concentration of coagulation factors also falls, but there is some reserve in the concentrations needed for coagulation, and factors are required later than red cells if coagulation was initially normal. There is also some reserve in the number of platelets needed for clotting, as well as release from the spleen so thrombocytopenia is usually the last to develop during blood loss. Massive transfusion is especially challenging in small children and infants. The hematologic and metabolic changes in children during massive transfusion follow the volume of loss and replacement, and are summarized in Table 5.9.

Differences between children and adults make practical management of critical bleeding more difficult. A unit of red cells may represent a large proportion of the child's blood volume and it may need to be given in doses of less than one unit. It

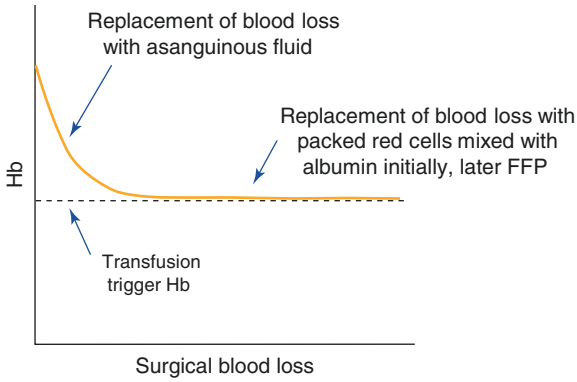

Fig. 5.6 Hemoglobin concentration during surgical bleeding loss when lost blood is initially replaced with crystalloid or other asanguinous fluid, then red cells once the transfusion trigger has been reached

Table 5.9 Metabolic and hematologic changes follow a pattern in line with the degree of blood loss

Number of blood volumes	Developing change
<0.4	Dilutional anemia
0.4–1	Dilutional coagulopathy Possible hyperkalemia
1+	Ionic hypocalcemia Ionic hypomagnesemia
2+	Thrombocytopenia
>2	Hypernatremia

may also be difficult to perform calculations of volumes during rapid blood loss. The rapidity of blood loss and its replacement relative to the child's blood volume may exceed that of adults, but IV access may be through small catheter. Finally, the priming volume of the IV fluid set and blood warmer may be large relative to the child's body size.

A practical approach to managing massive blood loss in surgery is shown in Fig. 5.7. Initial blood loss is replaced with crystalloid. When red cell therapy is required, packed red bloods cells are mixed with iso-oncotic albumin and infused to replace ongoing losses. Adjusting the amount of albumin controls the hematocrit of the infused blood, and therefore the Hb level of the child. A proportion of 50–60% albumin to 40–50% packed cells usually maintains the Hb at 80–90 g/L. Diluting red cells facilitates administration through small diameter IV catheters and allows fast administration to maintain normovolemia. As blood loss continues, coagulation is monitored with point of care devices such as ROTEM. If coagulopathy develops, fresh frozen plasma (FFP) mixed with packed cells is infused, with this mixture continued until blood loss ends. Other factors and platelets are given as bolus doses if required.

This approach separates the decision of what fluid to give from its speed of administration—the predetermined mixture is given rapidly when blood loss is rapid, and slowly when blood loss is slow. The infusion of blood also becomes like the infusion of a drug and maintains the hemoglobin at a constant level. Maintaining the hemoglobin concentration near the transfusion trigger minimizes the number of red cells lost into the wound, and once surgical loss has finished, the hemoglobin concentration is raised to the desired level for the postop period.

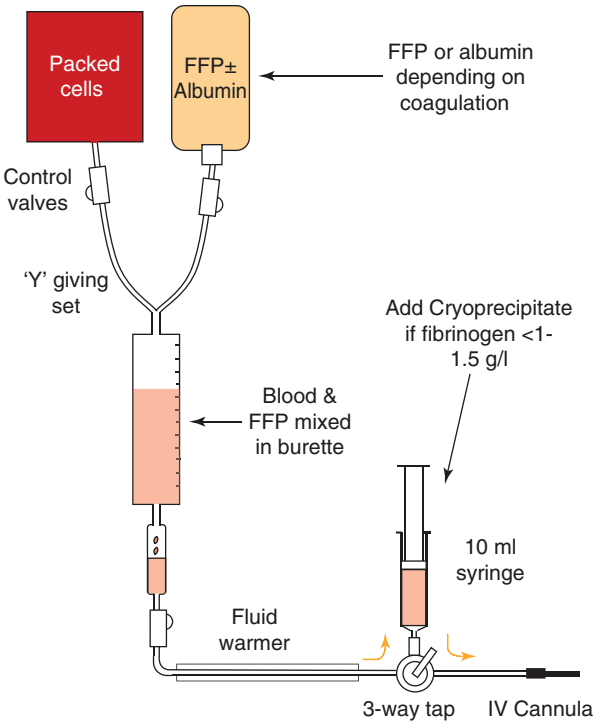

Fig. 5.7 Suggested practical set-up for administering large volumes of blood and blood products to small children during surgery with massive blood loss (Acknowledgment: Brian McIntyre, Hospital for Sick Children, Toronto)

Table 5.10 Dose of calcium to be given slowly IV to correct hypocalcemia during massive transfusion

Patient ionized calcium (mmol/L)	Dose of Ca Chloride (mg/kg)	Dose of Ca Gluconate (mg/kg)
0.9–1.0	10	30
0.8–0.9	20	60
<0.8	30	90

As in adults, maintaining normothermia, normal calcium and avoiding hyperkalemia are vital. Children are particularly at risk from hyperkalemia caused by rapid infusion of older, stored blood given via a central vein. The severity of hypocalcemia can be reduced with frequent small doses of calcium based on the measured calcium level (Table 5.10). The calcium level is frequently measured to avoid marked and potentially lethal hypercalcemia.

5.8.3 Neonatal Blood Transfusion

Cross match of blood for neonates is not straightforward. Neonates have ABO antigens on the red cell surface, but no circulating ABO antibodies of their own for the first 4 months. Also, maternal ABO antibodies may be in the neonate's blood. Because of this, a sample is needed from the neonate for the ABO group and direct

antiglobulin test (DAT), and also blood from the mother to test for antibodies. The neonate may also have ABO hemolysins from the mother that would hemolyze ABO-compatible blood given to the neonate. For these reasons, some centers use type O blood for all neonates. Blood is irradiated in some centers to prevent graft vs host disease in neonates (who are unable to suppress infused lymphocytes). All blood is leuco-depleted and CMV safe.

'Mini-packs' of packed cells are sometimes available for neonatal blood transfusion. These are several (usually 4) small packs that all come from the same donor, and permit transfusions over a period of time without exposing the neonate to multiple blood donors. Blood for neonates needs to pass through a macrofilter (170 μM) before administration. A technique for intraoperative transfusion of neonates is to hang the packed cells via a filtered giving set, draw up the blood through the giving set into a syringe, then warm the blood in the syringe before administration.

5.9 Colloids

Albumin is the most commonly used colloid in children. Other colloids cause more allergic reactions and only have limited reported experience in children. There are not strong guidelines for the use of albumin— it may have a role in neonates and cardiac patients, but there is no evidence for its use in children with brain injury, burns or post-surgery. Crystalloids are an alternative for volume replacement or resuscitation in neonates and children, but edema in the postoperative period is a concern. A combination of albumin and crystalloid may be the best option.

Gelatins are associated with high incidence of allergic reactions and limited efficacy. When compared to albumin in neonates they have an increased risk of necrotizing enterocolitis. The third-generation tetra-starches have an improved side effect profile compared with previous generations of starches. They have a low molecular weight and accumulate less in the reticuloendothelial system, but still have an effect on the renal system. It is unlikely they offer any advantage over albumin, and they may increase bleeding.

Review Question

1. An 8 month old baby is diagnosed with intussusception and scheduled for laparotomy. The heart rate is 160 bpm and blood pressure is 75/45 mmHg. His serum electrolytes are:
   Na^+ 132 mmol/L (normal 135–145)
   K^+ 3.0 mmol/L (normal 3.5–5.5)
   Cl^- 102 mmol/L (normal 95–110)
   Creatinine 90 μmol/L (normal 60–110)
   Lactate 3 mmol/L (normal 1–1.8)
   (a) How severely dehydrated is this baby?
   (b) Describe your fluid management before and after surgery

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Equipment and Monitoring for Pediatric Anesthesia

6

Craig Sims and Tom Flett

Children can be as small as several hundred grams or as large as adults, and so a range of equipment sizes and types is required. This chapter focuses on aspects of equipment and monitoring specifically for children, and factors to consider when using adult equipment for children. Equipment for the airway is discussed in Chap. 4, Sects. 4.5–4.7.

6.1 Breathing Circuits

Although the T-piece is the classic circuit for children, many circuits can be used safely for pediatric anesthesia. For a circuit to be suitable for children it must have low deadspace and low resistance. Preferably, the circuit should have a small compressible volume, be lightweight, compact, efficient and easy to use.

6.1.1 Deadspace

The deadspace of a circuit is the portion of the circuit between the patient and the point that fresh gas enters. For a circle this is at the Y-piece where inspiratory and expiratory limbs meet. For a T-piece this is at the side arm of the 'T' where the fresh gas enters. For a Bain circuit it is at the end of the circuit where the inner fresh gas line joins the expiratory limb. Deadspace is increased by angle connectors, filters,

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Cobbs connectors, respiratory monitors and facemasks. It causes rebreathing and requires the patient to increase minute ventilation to maintain normocarbia. Children have small tidal volumes and increased deadspace may form a significant proportion of tidal volume. For this reason, deadspace can be a problem particularly in small children who are breathing spontaneously, and is one of the reasons why neonates and infants tend to be ventilated during anesthesia.

Note
An infant breathing spontaneously is most prone to the problem of deadspace as the tidal volume may be close to the equipment deadspace volume.

6.1.2 Resistance

Resistance of breathing circuits adds to the work of breathing. Neonates and infants have difficulty increasing their respiratory effort for more than a short period of time and are particularly at risk of problems from circuit resistance. Resistance in a circuit arises from the hoses, valves and attached filters. In practice however, the greatest source of resistance in anesthesia is the shaft of the ETT or LMA.

6.1.3 The T-Piece Circuit

The original T-piece was a simple metal 'T' designed by Dr. Phillip Ayre to use in babies undergoing cleft palate repair (Fig. 6.1). This simple device offers no resistance and minimal deadspace, but there is entrainment of room air and dilution of the anesthetic gases. Dr. Jackson Rees from the Liverpool Children's Hospital added an open-tailed bag. The bag allows breathing to be monitored or assisted. This is the circuit now referred to as the 'T-piece circuit'.

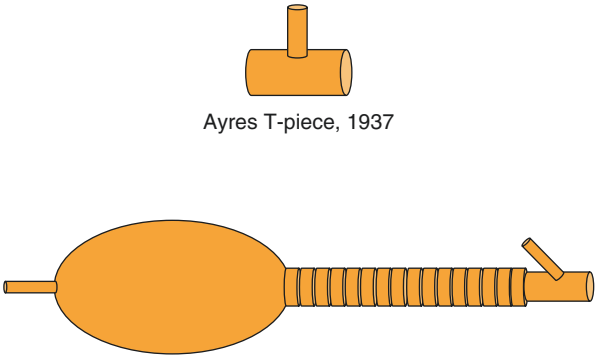

Fig. 6.1 Evolution of the original T-piece to become the T-piece circuit in contemporary practice

The total volume of the expiratory limb and bag of the T-piece must be greater than the tidal volume. It does not matter if the expiratory limb is very long or short. Long expiratory limbs can be used when the patient is remote from the anesthetist, such as in MRI. Different sized bags can be used on the expiratory limb—commonly a 500 mL bag for neonates and infants, and a 1 L bag for children. Two liter bags are also available but difficult to hold and use properly. During mechanical ventilation, the bag is replaced by a hose between the expiratory limb and the ventilator.

6.1.3.1 Rebreathing and Fresh Gas Flow

During expiration, exhaled gas mixes with fresh gas flow in the expiratory limb. During the expiratory pause (the time between end expiration and beginning of inspiration), more fresh gas accumulates in the expiratory limb, pushing exhaled gas further down the limb and away from the patient. During inspiration, fresh gas enters the patient along with fresh and exhaled gas from the expiratory limb (Fig. 6.2). The proportions of fresh gas and exhaled gas breathed by the patient depend on several factors. These are the minute volume, including the rate and respiratory pattern, the CO_2 production, and the fresh gas flow.

The fresh gas flow needs to be greater than the peak inspiratory flow rate, or five times the minute ventilation, to eliminate all rebreathing. However, a small amount of rebreathing is acceptable and provides humidification and reduced volatile agent use. Various formulae for the acceptable fresh gas flow have been suggested, but 2.5–3 times the minute ventilation is commonly used (although rates as low as 1.5 times minute ventilation are possible in adults with their slower respiratory patterns). These formulae pre-date $ETCO_2$ monitoring and nowadays fresh gas flow

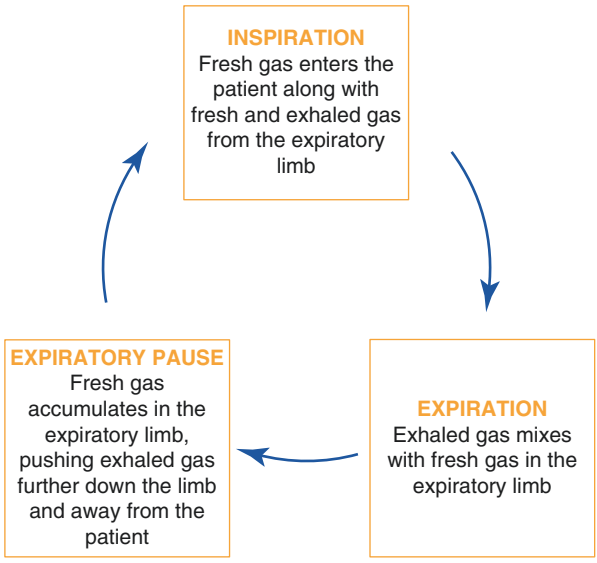

Fig. 6.2 The respiratory cycle and gas within the T-piece circuit

Table 6.1 Advantages and disadvantages of the T-piece circuit

Advantages of T-piece circuit	Disadvantages of T-piece circuit
Light weight	Complex to assemble if not familiar
Low resistance, no valves	Variable rebreathing
Low deadspace	Inefficient, with high FGF required for large child, particularly during spontaneous ventilation
Fast wash in	Low humidity Requires learnt technique to hold rebreathing bag correctly
Low compliance (1 mL/cmH_2O) and ability to 'feel' compliance of chest or detect leak in system	Can be difficult to scavenge, and the bag may twist and obstruct expiration and the outflow of gas
Portable for recovery or outside anesthetic locations	Not able to mechanically ventilate with modern anesthetic workstations
Compact with whole circuit in field of view	
Whole circuit can be sterilized and no filter required	

Table 6.2 Suggested initial fresh gas rates for T-piece circuit in different age groups

Patient size	Initial fresh gas rate (L/min)
Neonate and infant	3
Child	6
Adolescent	9

Fresh gas rates can be adjusted after monitoring $ETCO_2$ and rebreathing ($FiCO_2$) during use

can set to an initial level (Table 6.1) and then adjusted individually according to an acceptable $FiCO_2$.

The respiratory pattern also affects the circuit's efficiency. During spontaneous ventilation, there is only a short pause between the end of expiration and the beginning of inspiration, so relatively high fresh gas flow is required. During IPPV, the expiratory pause is longer and a lower fresh gas flow is possible.

6.1.3.2 Advantages

There are several advantages of the T-piece, as outlined in Table 6.2. The compact nature of the T-piece allows the whole circuit to be in the field of view with no need to reach out to adjust spill valves. The other major advantage is the small compression volume which allows lung compliance to be assessed, and easier manual ventilation of poorly compliant lungs.

The feedback, or feel of the lung compliance with the circuit has led to the term 'educated hand' for ventilation with the T-piece. There has been criticism that the educated hand does not exist and the anesthetist cannot feel or assess the child's compliance any better than with mechanical ventilation. However, there are two points of detail to ensure that the hand is 'educated'. The first is to keep the volume of the bag small. A suitable size bag is selected for the patient size and it is kept only partly filled. A large bag bulges out around the hand and increases compression

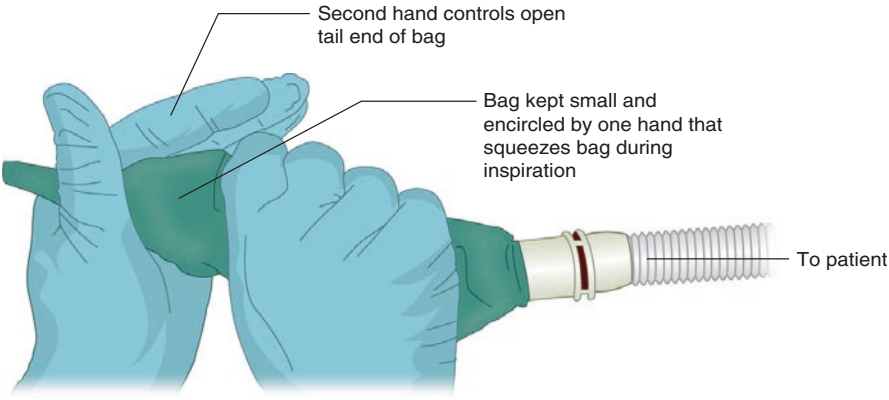

Fig. 6.3 Two-handed technique to ventilate small child with poorly compliant lungs. Keeping the T-piece bag small and avoiding an excessively high fresh gas flow rate allows the assessment of compliance and more effective ventilation

volume. Small infants benefit from a two-handed bag squeeze technique, where one hand encircles a partly inflated bag and the second hand controls the occlusion of the tail (Fig. 6.3). The second is to keep the fresh gas flow rate as low as possible while allowing for the size of the patient. A high fresh gas flow rate makes the bag feel tight and it becomes harder to assess compliance.

6.1.3.3 Disadvantages

Perhaps the greatest disadvantage of the T-piece is the time it takes to become skilled in its use. It is held differently to all other circuits and skill is required to occlude the tail correctly to deliver continuous positive airway pressure (CPAP) and ventilation. The skill to perform this takes time to learn and discourages many from the circuit and its advantages.

Although it looks simple, the T-piece is complex in form and function. It is made up of several components that can be incorrectly assembled. Its function is complex because of the interaction between the factors that affect rebreathing and thus $ETCO_2$. Squeezing the bag faster doesn't necessarily reduce the $ETCO_2$ as it would with a circle system (Fig. 6.4). Faster respiratory rates shorten the expiratory pause, which then shortens the time for fresh gas to accumulate in the expiratory limb. The shorter expiratory pause increases rebreathing unless the fresh gas rate is also increased or is already high relative to the minute ventilation.

Another disadvantage is that the T-piece cannot be attached to modern ventilators that are integrated within the anesthetic machine and cannot be separated from the circle, thus preventing mechanical ventilation.

Finally, the circuit can be difficult to scavenge, and is used in some countries without scavenging. Scavengers may be difficult to attach and remove from the tail of the bag, and may kink the tail and obstruct outflow from the circuit and expose the child to barotrauma. Some variants of the T-piece include a valve with a

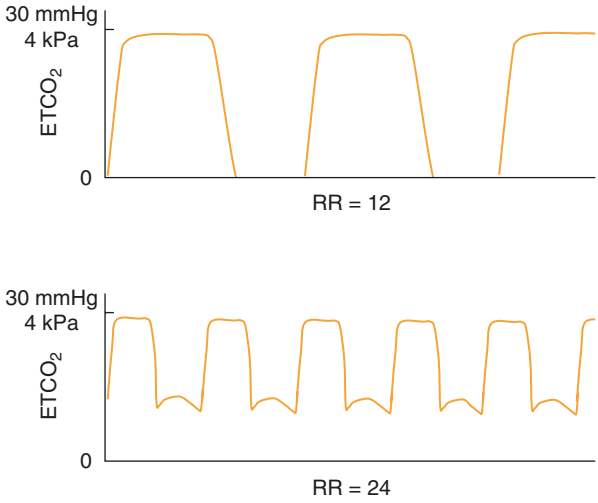

Fig. 6.4 Squeezing the bag faster on a T-piece circuit does not necessarily reduce the $ETCO_2$. Increasing the respiratory rate and increase minute ventilation, but it also shortens the expiratory time and there is more rebreathing unless the fresh gas flow rate is increased

scavenging port between the expiratory limb and bag, but this makes the circuit more cumbersome and introduces the risk of barotrauma if the valve is left closed. A convenient and safe scavenging system described by Keneally and Overton is used in many Australian and New Zealand centers.

6.1.4 The Circle Circuit

In the past, it was thought that the circle could only be used for larger children because of the resistance from the inspiratory and expiratory valves. This is now known to be incorrect, and the circle circuit is the commonest circuit in pediatric anesthesia.

Children of any age can be managed using an adult circle circuit provided ventilation is controlled or assisted in neonates and infants. When using a circle system, the standard 22 mm diameter hoses are usually replaced with 15 mm diameter hoses, and the 2 L bag replaced with a 500 or 1000 mL bag. These changes are not essential but reduce the bulk and weight of the circuit, reduce circuit volume and compression volume, and reduce wash-in time. The volume of the soda lime absorber also affects compression volume.

6.1.4.1 Advantages

The advantages of the circle for pediatric anesthesia are familiarity, economy and efficiency, built-in scavenging, airway humidification and the ability to mechanically ventilate.

6.1.4.2 Disadvantages

The circle circuit has a larger compression volume than the T-piece. As the rebreathing bag is squeezed, part of the volume enters the patient but a proportion goes into

compressing the gas within the hoses and absorber. The compression volume can make it more difficult to assess lung compliance in neonates, and is one of the reasons why the T-piece remains popular in this patient group. Other minor disadvantages are the circle system's bulk and weight, slower washin and washout rates, and need to use a filter to protect the absorber and hoses from contamination.

Keypoint
The circle circuit is being used more commonly for small infants and children. The biggest advantage of the T-piece is its low compression volume, which allows successful manual ventilation of the smallest patient and in the most difficult-to-ventilate situations— the circle circuit is fine when ventilation is going well, but its large compression volume makes assessment of ventilation difficult when things aren't going well.

6.2 Breathing Filters

As in adults, filters provide humidification and prevent microbial contamination of the anesthetic circuit. Although the same general considerations apply in children and adults, three areas are of importance when using filters for pediatric anesthesia.

6.2.1 Filter Deadspace and Resistance

Filters are usually placed between the patient and the T-piece or the Y-piece of the circle and add to the deadspace of the breathing system. During spontaneous breathing, the tidal volume may be only a few mL/kg and deadspace needs to be minimized to stop rebreathing. The deadspace of filters for infants and babies is usually 8–10 mL, and 20–25 mL for larger children.

Resistance from the filter increases work of breathing. It becomes important when a very small baby is breathing spontaneously through a filter, or when a filter that is too small is being used for a larger child. The resistance of the filter may reduce the amount of gas leaving the circuit during inhalational induction when there is no mask seal and there is neither a negative inspiratory pressure from the child nor a positive pressure on the rebreathing bag forcing gas out through the filter.

6.2.2 Anti-microbial Efficiency

Pleated, hydrophobic membrane filters are considered best for pediatric use, but there is wide variation in the performance of filters from different manufacturers. Their smaller size makes them inefficient and ineffective when tested under

adult-sized conditions. However, when tested at conditions closer to the inspiratory flow rates that a small child would generate, the filters perform almost as well as adult sizes. However, some professional societies have guidelines that recommend a new sterile circuit be considered for each case.

Note
Small filters are not suitable for large patients—the filter does not block pathogens and its resistance is too high.

6.3 Ventilators

Ventilators in modern anesthetic machines are usually suitable for neonates, children and adults. Features needed to permit ventilation of neonates during anesthesia are listed in Table 6.3. The most important is the ability to deliver a small tidal volume at a fast rate. To do this, the ventilator must be capable of delivering low inspiratory flow rates. For example, to deliver a 600 mL tidal volume to an adult patient over 2 s, the ventilator generates an inspiratory flow of 18 L/min (in other words, gas leaves the bellows at a rate of 18 L/min). But to deliver a 20 mL tidal volume to a neonate over half a second, the ventilator must generate a flow of only 2.4 L/min.

Mechanical ventilators in adults are usually set to volume-controlled mode—the desired tidal volume is set on the ventilator. Ventilators in children are usually set to pressure-controlled mode—the desired inspiratory pressure is set (Fig. 6.5). This is because pressure mode in children has some advantages over volume ventilation, although less so nowadays with modern ventilators.

6.3.1 Pressure-Controlled Ventilation

This is the commonest mode of ventilation in pediatric anesthesia. The delivered tidal volume is not affected by a small leak around the ETT, or by a change of fresh

Table 6.3 Features of a ventilator suitable for neonates, infants and small children

Features of a neonatal ventilator
Essential:
Able to deliver small tidal volumes – Low inspiratory flow rate – Short inspiratory time
Fast respiratory rates (up to 60 breath/min for neonates)
Small compression volume
Able to control FiO2
Desirable:
Able to deliver PEEP and CPAP
Able to measure small expired tidal volumes

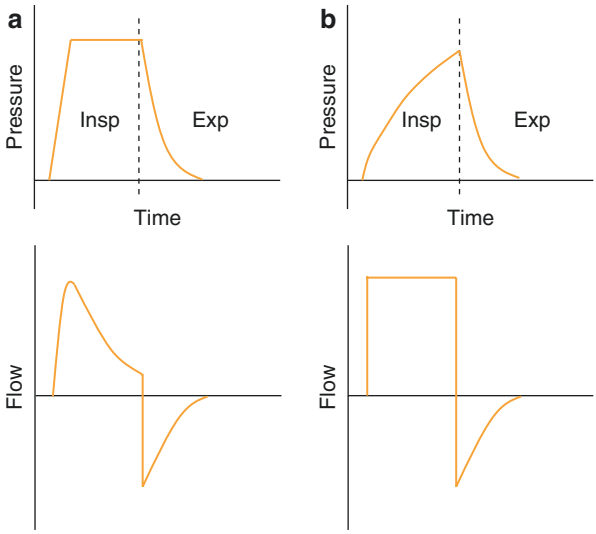

Fig. 6.5 Proximal airway pressure and flows in pressure-controlled and volume-controlled modes. (**a**) During pressure controlled ventilation, a constant pressure is held during inspiration but flow declines exponentially. (**b**) During volume controlled ventilation, pressure gradually builds during inspiration

gas flow or change of circuit compliance. Similar inspiratory pressures are needed for adolescents and babies, reducing the risk of accidental barotrauma. Typical initial settings for a normal child are inspiratory pressure 15–20 cmH_2O, I:E ratio 1:2, and rate 16 breaths/min for preschool ages, 18 breaths/min for infants, and >20 breaths/min for neonates. The ventilator delivers the set pressure for the set inspiratory time and inspiratory flow decreases during inspiration as alveolar pressure reaches proximal airway pressure (decelerating flow pattern).

Three factors affect the delivered tidal volume in pressure-controlled ventilation:

1. Compliance of lung and chest wall, either from internal lung pathology, pneumoperitoneum or from external pressure on the chest or abdomen from the surgical team or drapes.
2. Inspiratory pressure.
3. Inspiratory time.

As inspiratory time lengthens, the inspiratory pressure is applied for longer and the delivered tidal volume increases. The I:E ratio affects inspiratory time and therefore affects the tidal volume. However, as inspiratory time lengthens the alveolar pressure eventually plateaus and equals the ventilator pressure, so no flow occurs and any further lengthening of the inspiratory time does not increase tidal volume (Fig. 6.6). (In general, longer inspiratory times improve oxygenation by increasing the mean airway pressure and redistributing gas to less compliant alveoli, while allowing a lower peak pressure for the same volume. Longer inspiratory times however increase the risk of gas trapping, intrinsic peep and barotrauma by reducing expiratory time, and are not tolerated by the patient so well, necessitating a deeper level of anesthesia).

A significant disadvantage of pressure-controlled ventilation is the ventilator pressure alarm will not detect an obstruction or kinking of the ETT. If the ETT

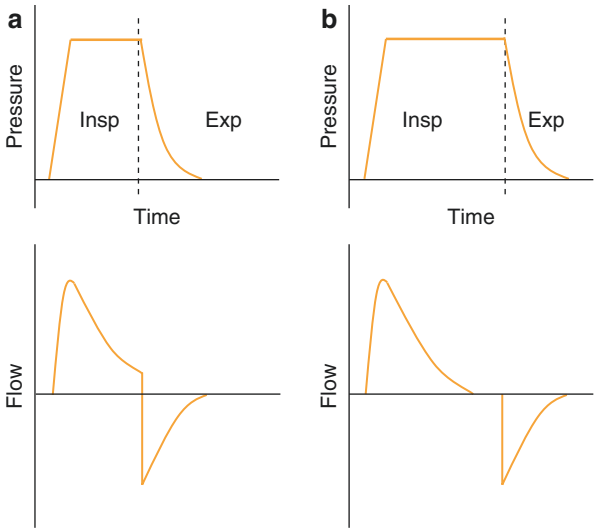

Fig. 6.6 The effect of inspiratory time during pressure-controlled pressure ventilation. (**a**) Inspiratory flow is still occurring at the end of inspiration. Lengthening inspiration will increase tidal volume. (**b**) Inspiratory flow has ended before inspiration has finished because alveolar pressure has reached airway pressure. Lengthening inspiration will have no effect on tidal volume

kinks, the ventilator will continue to cycle to the preset pressure with some movement of the bellows due to compression of circuit volume, even though no volume is delivered to the patient. If the obstruction is partial, there will be no pressure alarm, delivered volume will fall and the capnogram may show either hyper- or hypocarbia.

6.3.2 Volume-Controlled Ventilation

In this mode, the tidal volume is selected and the airway pressure varies with lung compliance. There are several traditional reasons why this mode is less commonly used in pediatric anesthesia.

1. A variable leak around an uncuffed ETT affects the tidal volume.
2. Changing the fresh gas flow may alter the delivered tidal volume:

   Inspired tidal volume is made up from two components—the volume from descent of the bellows plus the volume of fresh gas entering the circuit during inspiration. For example, if the fresh gas flow is 6 L/min, 100 mL of gas enters during a 1 s inspiration and is added to the volume coming out of the bellows. A small child may therefore have significant changes in their tidal volume as fresh gas flow is altered. The fresh gas flow affecting tidal volume is a problem of older anesthetic machines with stand-alone ventilators that are not integrated into the anesthetic machine. However, modern machines with built-in ventilators have 'fresh gas compensation' so changes in fresh gas flow do not affect the delivered tidal volume. Instead, the descent and volume of gas leaving the bellows varies as the fresh gas flow is altered. Drager machines do this by diverting fresh gas flow into the rebreathing bag

during inspiration, and most other brands electronically measure the fresh gas flow and adjust the volume delivered from the ventilator.

3. Circuit compliance affects the delivered tidal volume:
   The adult circle circuit has a compliance of 7 mL/cmH_2O. With an inspiratory pressure of 20 cmH_2O, 140 mL of the ventilator output is lost expanding the hoses and compressing the gas within. If a baby is being ventilated with a tidal volume of 60 mL, this circuit loss is significant and means that a stand-alone anesthetic ventilator would need to be set to 200 mL. However, modern anesthetic machines compensate for circuit compliance. On these machines, a setting of 60 mL will mean 60 mL is delivered to the patient.
4. Concerns about barotrauma:
   If the ventilator has been used for an adolescent with a tidal volume of 600 mL and is then connected to an infant, the ventilator may cause barotrauma. However, modern ventilators include a pressure release function, usually at 40 cmH_2O so that inspiration immediately stops when this pressure is reached and expiration begins. This safety feature provides some protection from accidentally large tidal volumes.
5. Inability of older ventilators to deliver small tidal volumes:
   Modern ventilators however can deliver tidal volumes as low as 30–50 mL.

In summary, volume-controlled ventilation is less common in children because of several problems, though these have been mostly overcome with modern technology. Although there are some theoretical advantages with the decelerating flow pattern of pressure ventilation, either mode can safely be used provided chest expansion and patient variables are monitored and ventilation adjusted appropriately.

Keypoint
Pressure-controlled ventilation is most commonly used in pediatrics because the delivered volume is not affected by circuit compliance, small leaks around an uncuffed ETT or changes in fresh gas flow. However, delivered volume is affected by changes in lung compliance and kinking or obstruction of the ETT.

6.3.3 Pressure Support Ventilation

Pressure support is a patient triggered, flow cycled mode that is attractive for pediatric ventilation as it splints open the upper airway by providing a positive airway pressure during inspiration. It overcomes minor upper airway obstruction during LMA use, reduces work of breathing caused by resistance in the breathing system and helps maintain end expiratory lung volume. However, some ventilators are not able to trigger and synchronize with the rapid small breaths of children. Ventilators that trigger inspiration using flow rather than airway pressure tend to synchronize better. Younger and smaller children usually need higher levels of pressure support than older, larger children. The time required for the ventilator to reach the set

pressure from the start of inspiration is the rise time (or slope). Work from neonatal ICU shows neonates synchronize best with a 0 rise time. Clinically, children appear to do well with a rise time of 0.2–0.3 s.

Tip
With modern ventilators offering pressure support ventilation, no patient should breath unassisted against the resistance of anesthetic equipment—even as little as a few cm H_2O of assistance reduces work of breathing and should always be used.

6.4 Warming Devices

Children, especially infants, are prone to hypothermia. Children have a large surface area relative to basal metabolic rate (BMR). An adult has a BMR equivalent to a 100 W light bulb, but a neonate only has the equivalent of only a 2 W torch bulb. The main route of heat loss is cutaneous, mostly by radiation and convection as in adults but also by evaporation in preterm infants who have thin, porous skin. It is logical to stop heat loss through the skin and transfer heat back through it to prevent and treat hypothermia.

6.4.1 Forced Air Warmer

Forced air warmers transfer so much heat they compensate for any losses by other routes. They also allow the creation of a microclimate around neonates and infants so that heating the entire OR to uncomfortable temperatures has become unnecessary. Forced air warmers are more effective in children than adults because such a large proportion of the surface area of children can be covered in warm air. Pediatric sized blankets can be placed over the child, or small children can be placed on top of a purpose made blanket blowing warm air up and around the child while allowing unrestricted access. Care must be taken when using these blankets to ensure that the air channels are not compressed by the child's limbs or equipment. Prewarming children with a forced air warmer prevents redistribution hypothermia after induction but is often not practical as not all children will tolerate the blanket while awake.

Burns readily occur if the warmer is used without a manufacturer's blanket to disperse the hot air flow. Burns are also a risk even if the blanket is used correctly. The temperature at the insertion point of the hose into the blanket is high and a small child's foot or hand up against the blanket at this point is exposed to air hotter than body temperature.

6.4.2 Overhead Radiant Heater

Overhead radiant heaters are infrequently used in OR but are still common in NICU. They are ineffective because only a small surface area is heated, and most infrared radiation produced strikes the skin at an angle and is reflected rather than absorbed. The heat is also uncomfortable on the top of the surgeon's heads.

6.4.3 Warming Mattress

These are electric warming pads placed underneath the child. Their effectiveness is limited because not much heat is lost through the back, there is only a small surface area available for heat transfer, and compression of skin vessels in the back reduces heat transfer. Nevertheless, the electric mattress maintains normothermia and can be used in conjunction with a forced air warmer. The NICE guidelines from the UK suggest a heating mattress if a forced-air warming device is cannot be used.

6.4.4 Active Humidifier

Airway heating and humidification was common in the past. However, only about 10% of heat is lost through the airway and a proportion of this can be prevented with passive humidifier filters. Electrically powered active humidifiers introduce the risks of disconnections, leaks and burns, and are not usually used in the OR (Table 6.4).

6.4.5 Fluid Warmers

Fluid warmers are often used for children. They help to prevent hypothermia, but do not transfer enough heat to re-warm a patient. Because of the slow infusion rates used in children, fluid is exposed to room temperatures as it travels along tubing between the warmer and the child. Therefore, fluid must be warmed as close as possible to the child's IV catheter. This is done by positioning the warmer close to the

Table 6.4 Routine methods of reducing heat loss and actively warming children in OR

Warming methods routinely used in children
Forced air warmer
Warm OR (if can't create warm microenvironment)
Warm IV fluids
Passive humidifier (Heat and moisture exchange filter)
Blanket or plastic covering over child
Electric heater mattress (Inditherm®)

child and minimizing the time fluid is exposed to room temperature. The Hotline® fluid warmer uses a heated water jacket that encloses and encircles the IV fluid tubing right up to the patient connection. It is very effective and useful in pediatric practice, but is not effective at very high flow rates.

Keypoint
Children are at greater risk of hypothermia compared with adults because of reduced heat production relative to surface area. Forced air warmers are the most efficient method to maintain normothermia and treat hypothermia. Increasing ambient temperature and warming IV fluids are the two other commonly used methods in OR to prevent hypothermia.

6.5 Monitoring

Monitoring standards are the same in children and adults, and are set out in professional college and association documents or guidelines. Minimal monitoring tends to be applied before induction of children, at least in the wary child, so that they remain calm, relaxed and more likely to cooperate at the time of induction. The oximeter and other monitors are then applied at induction. This section focuses on the aspects of monitoring that are different in children.

6.5.1 Pulse Oximetry

The pulse oximeter is a vital and useful monitor for children during and after anesthesia and sedation. Oximeters average the signal over 10–12 s to reduce motion artefact, but in children the saturation can change very quickly and it is common to see a color change in the lips before the oximeter detects a change. Oximeters are accurate in neonates because fetal and adult hemoglobin have the same absorption spectrum. Small, wrap-around probes are commonly used. The right hand in neonates measures preductal saturation—it measures saturation of the blood flowing to the brain. The ductus arteriosus linking the pulmonary artery and aorta is normally closed, but in some children it is patent with left-to-right shunting of blood. If the neonate reverts to fetal circulation, there is right-to-left shunting of deoxygenated blood through the ductus to the aorta, causing lower saturations in the left arm and legs. In practice the left arm and legs are frequently used for measurements—it can be difficult to find a probe location on the neonate that works, and reversion to fetal circulation is rare.

There is a range of probes available to suit children. If a probe that is too large is used, such as an adult probe on the finger or toe of an infant, a proportion of the oximeter light bypasses the tissue and is directly detected. This penumbra effect may give a saturation reading in the 80s. Some spring clip probes compress a small

child's digit too much, affecting the reading or causing pressure marks. A final issue to bear in mind is that because children generally have healthy lungs, it is possible to have excellent saturations on oxygen despite severe hypoventilation.

Tip
If a child is hypoxic and you are trying to improve oxygen saturation, watch the chest, not the oximeter. The chest MUST be going up and down if you are to succeed. The oximeter is giving you an averaged reading that is 10 or 12 s old.

6.5.2 Capnography

The rapid respiratory rates and small expired tidal volumes of children affect the accuracy of capnometers. Although main-stream analyzers are more accurate, the weight and bulk of the sensor have made side-stream analyzers more popular.

Keypoint
While this section mostly deals with technical issues that cause underestimation of PaCO2, an important cause of false low $ETCO_2$ is gross under ventilation. This is why it is important to always observe chest expansion and assess compliance with manual ventilation.

6.5.2.1 Problems with Small, Rapid Tidal Volumes

With side-stream analyzers, the small volume of expired gas mixes with inspired gas along the length of the sample line, distorting the capnogram. Distortion may obliterate the plateau of the capnogram, and at respiratory rates faster than about 40 breaths per minute the inspired carbon dioxide appears elevated. Distal sampling (sampling closer to the alveoli) may be used in neonates and infants to increase the amount of expired gas and decrease the amount of contaminating fresh gas that is sampled (Fig. 6.7). This can be done using a special 15 mm ETT connector, or placing a small diameter IV cannula down into the lumen of the ETT. The cannula is usually passed through the sampling port on the angle connector, narrowing the lumen of the ETT and increasing resistance. Another approach to improve the accuracy of capnography in children uses Microstream technology. These monitors use small diameter tubing and a lower sample rate than usual to reduce mixing within the sample line. Gas analysis is done using a narrow bandwidth of infrared radiation in a much smaller analyzer chamber.

6.5.2.2 Leak Around the ETT

A leak around the ETT allows part of the exhaled gas to escape around the ETT. The error this causes is worsened by any pressure in the circuit, either during IPPV or PEEP. Any positive airway pressure during the expiratory pause forces

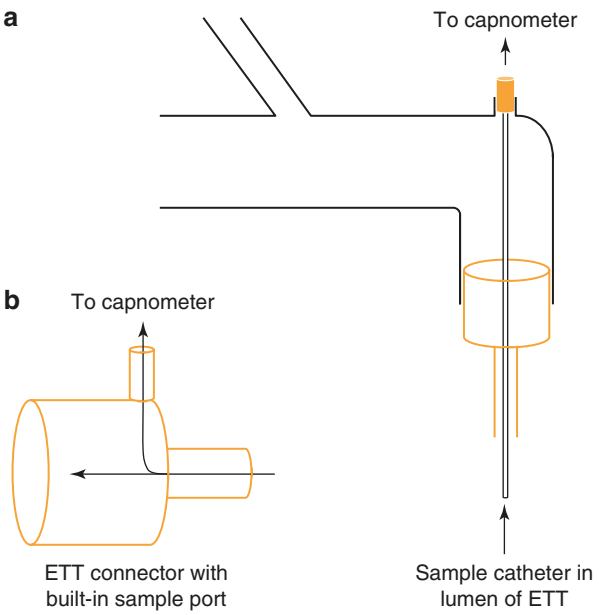

Fig. 6.7 The accuracy of capnography in neonates and small children is improved by distal sampling to contamination of the expired gas sample with fresh gas. (**a**) A fine sampling catheter (such as an IV cannula) is inserted into the lumen of the ETT. (**b**) A purpose-made ETT connector with an in-built sample port replaces the usual ETT connector

first exhaled gas and then fresh gas back down the ETT and out around the leak, diluting the gas sample for capnography. The larger the leak around the ETT, the greater the error (Fig. 6.8). Even if PEEP is not used, the ventilator causes a small amount of back pressure as the bellows fills and its spill valve opens, affecting the capnogram.

Tip

Be careful when the capnogram is peaked and does not plateau. Consider sampling more distally or reducing the size of the leak with either a larger ETT or a cuffed ETT, or even a throat pack. Consider manual ventilation to check that the ETCO2 is not low because of gross under ventilation.

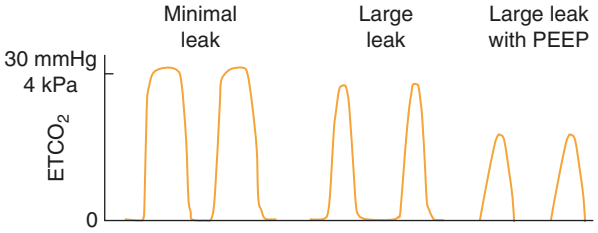

Fig. 6.8 The effect on the capnogram of a leak around the ETT. A large leak allows fresh gas to flow back down the ETT during the expiratory pause, diluting expired gas. Adding PEEP increases the back flow of fresh gas and worsens dilution and accuracy

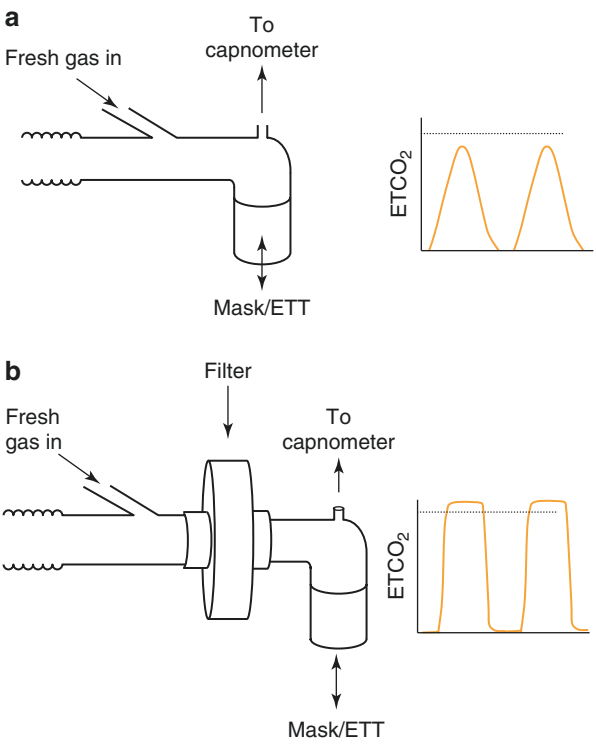

Fig. 6.9 (**a**) Fresh gas in the anesthetic circuit dilutes expired gas, distorts the capnogram and reduces the $ETCO_2$ value. (**b**) Placing a filter between the fresh gas inlet and the sample site reduces dilution of the expired gas

6.5.2.3 Fresh Gas Entrainment and the T-Piece

The CO_2 sample port is located close to the fresh gas inlet on the T-piece circuit and fresh gas mixes with exhaled gas. Distal sampling helps to minimize this effect. Alternatively, placing a filter between the fresh gas and sample port separates fresh and exhaled gases, improving $ETCO_2$ sampling and providing humidification (Fig. 6.9).

6.5.2.4 Cyanotic Heart Disease

Children with congenital heart disease who are cyanosed have a right-to-left shunt of blood through the heart. As part of the cardiac output does not pass through the lungs, the $ETCO_2$ underestimates the $PaCO_2$.

6.5.3 Transcutaneous CO_2 Monitoring

Transcutaneous CO_2 monitoring ($TcCO_2$) measures the $PaCO_2$ with a sensor on the skin that is heated to arterialize the blood. It is mostly used in neonatal intensive care where the sensor is applied to the skin of the chest or abdomen. Several aspects of the technique limit its routine use in theatre. It requires calibration before use, may cause local skin problems, is affected by tissue edema or hypoperfusion and the

response time is too slow for it to replace $ETCO_2$. However, when properly set up, it measures $PaCO_2$ more accurately than $ETCO_2$, and has a role in theatre during high frequency ventilation when capnography cannot work.

6.5.4 Temperature

The esophagus, nasopharynx, rectum and axilla are all clinically useful sites for monitoring temperature in children. Core temperature is best measured in the distal third of the esophagus, where the probe is adjacent to the heart and great vessels, and least affected by respiratory gases. A nasopharyngeal probe is commonly used and is sufficiently accurate unless there is a large leak around the ETT that exposes the probe to inspiratory gas. The axillary site allows probes to be cleaned and reused, but the probe must be positioned high in the axilla adjacent to the axillary artery, and protected from ambient temperature by keeping the arm adducted.

6.5.5 Depth of Anesthesia Monitors

The EEG in young children is different from adults. The background frequency decreases from 10 Hz in adults to 7–8 Hz in 2 years olds and 5 Hz at 6 months of age. Children less than 5 years also have short bursts of EEG activity while awake, and have specific EEG patterns associated with transition in and out of drowsiness and sleep. Monitors based on the processed EEG including BIS, Entropy and Narcotrend using pediatric electrode systems have reasonable correlations with doses of volatile or intravenous anesthesia in older children. High concentrations of sevoflurane paradoxically increase the BIS, possibly by altering the raw EEG. These monitors cannot be used in children aged less than 1 year because of the EEG differences in infants compared to children. Furthermore, while there is some evidence in adults that anesthesia depth monitors improve outcomes, this has not been studied or proven in children. Nevertheless, for children aged 1–13 years, if BIS is maintained below 50 then wakefulness is unlikely, and BIS guidance of manual propofol infusions reduces the likelihood of over- or under-dosing.

6.5.6 Near Infrared Spectroscopy (NIRS)

Near Infrared Spectroscopy (NIRS) measures regional tissue oxygenation by measuring non-pulsatile oxyhemoglobin and deoxyhemoglobin saturation. Cerebral oxygen saturation (cSO_2) assesses the brain venous compartment, and is correlated with jugular venous saturation. A sensor emitting light in the near infrared spectrum is applied to the forehead. Light takes a banana-shaped path through a tissue volume of about 10 mL to sensors 3–5 cm away, giving a composite measure of arterial and venous blood. The light follows two paths—superficial through the bone and cartilage of the skull, and deeper through the cerebral parenchyma. The

absorption from the two paths is subtracted to estimate cortical oxygenation. The probes are age-specific and assume the cortex is at a certain depth below the probe. The lower weight limit for neonatal probes is 2.5 kg, and if the probe is used on smaller babies, it will measure oxygenation of deeper brain rather than cortex. Proprietary algorithms are used to calculate regional tissue oxygenation. Some monitors display oxy-hemoglobin as an absolute value, and others as a proportion of total hemoglobin or 'index'. The value measured in the frontal cortex underneath the probe is assumed to reflect the cortex elsewhere. Normal cerebral saturation is 70%. cSO_2 must be interpreted as a measure of balance between transport and consumption of oxygen in the brain. It rises in well perfused, inactive cerebral tissue (as during cooling or irreversibly damaged cerebral tissue), and falls in well perfused excessively active tissue (as during status epilepticus). NIRS is used during cardiac anesthesia and is being investigated as a measure of cerebral perfusion during anesthesia and surgery in sick neonates with poor cardiovascular status, aiming to achieve a satisfactory neurological outcome. In children, cerebral desaturations during congenital heart surgery are associated with increased neurological morbidity. Cerebral oximetry could be a useful monitoring technique during anesthesia in preterm neonates, due to the risk of impaired cerebral blood flow autoregulation in these patients.

Review Questions

1. What factors affect the $FiCO_2$ with the T-piece circuit?
2. What characteristics make a ventilator suitable for infants?
3. What factors affect the delivered tidal volume during pressure-controlled ventilation?
4. During pressure-controlled ventilation, why does changing the fresh gas flow rate affect how far the ventilator bellows moves? What happens if volume-controlled ventilation is used instead, and does it matter if the ventilator is integrated into the anesthesia machine or free-standing?
5. What factors affect the accuracy of $ETCO_2$ measurement in children?
6. Does an adult oximeter give accurate readings on a neonate?
7. Below what age is BIS not useable?

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Resuscitation and Emergency Drugs

7

Philip Russell

Any resuscitation is stressful for the staff involved, but even more so if the patient is a child. There are many differences when a child is involved— the causes of arrest may be different, staff are usually less familiar with CPR in children than in adults, doses of drugs need to be calculated, and parents are often present at the resuscitation.

7.1 Cardiac Arrest in Children

The causes of cardiorespiratory arrest in children are different from those in adults because most pediatric arrests are secondary to decompensated respiratory or circulatory failure. Causes of respiratory failure include birth asphyxia, bronchiolitis, asthma and airway obstruction either from inhalation of a foreign body or other causes. Respiratory arrest may also occur secondary to neurological dysfunction caused by events such as convulsion or poisoning. A smaller proportion of cardiac arrests in children are the end result of circulatory failure, either due to fluid or blood loss, or maldistribution of fluid within the circulatory system. Fluid loss may be due to gastroenteritis, burns or trauma. Fluid maldistribution may be due to sepsis or anaphylaxis.

Although most arrests in children are asystolic arrests secondary to underlying cardiorespiratory failure, 5–15% of cardiac arrests in children are due to a primary cardiac event. Ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT) may be the primary event in a significant number of arrests on wards in hospitals with a cardiology or cardiac surgery unit. VF in children may also be caused by electrolyte disturbances, drug toxicity and hypothermia.

Whatever the cause, by the time of cardiac arrest there will usually be significant hypoxia and acidosis leading to cell damage and death. The initial cardiac rhythm is

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often severe bradycardia or asystole. Management of a child needing resuscitation follows guidelines published by the relevant resuscitation council, including those from Australia, New Zealand, Europe and the UK, and the American Heart Association.

The outcome for out-of-hospital cardiac arrest is better in children than in adults. The outcome in infants however, is worse than adults because of the poor outcome from sudden infant death syndrome (SIDS). Children also have a better outcome for in-hospital arrest, reflecting the underlying causes of arrest.

Keypoint
Most cardiac arrests in children are the end result of decompensated respiratory or circulatory failure. Children with cardiac disease may also arrest from these causes, but are also more likely to have a primary cardiac arrest in VF or pulseless VT.

7.1.1 Perioperative Cardiac Arrest in Children

'Wake Up Safe' is the largest study of perioperative cardiac arrest in children and included over one million anesthetics. It found perioperative cardiac arrest occurs in 5.3 per 10,000 anesthetics, and arrest directly related to anesthesia occurs in 3.3 per 10,000 (Table 7.1). The mortality rate for anesthetic related cardiac arrest was 10.9%, which was lower than arrests not related to anesthesia. Although this large study collected data from many institutions, it included data from very unwell children—half of the children who had a cardiac arrest had congenital heart disease, and 40% were receiving some form of physiologic support including oxygen, inotropes or extracorporeal membrane oxygenation. A lower incidence of arrest would be expected in healthier children not requiring tertiary pediatric hospital care. Other risk factors applicable to all children having anesthesia included age less than 6 months, ASA status 3–5, emergency surgery and after-hours surgery. The incidence of death related to anesthesia was 0.36 per 10,000 anesthetics.

Table 7.1 Etiology of pediatric cardiac arrest during anesthesia and surgery

Etiology of anesthesia-related arrest	Details
Cardiovascular (49%)	Arrhythmia (16%), hemorrhage (9%), primary cardiac failure (9%), pulmonary hypertension (6%)
Respiratory (35%)	Airway obstruction (15%) including laryngospasm, Inability to intubate or ventilate, premature extubation
Medication related (7%)	Opioid, inhaled anesthetic, muscle relaxant
Central line related (3%)	Arrhythmia, cardiac tamponade
Blood products (1%)	
Could not be determined (14%)	

Data from 'Wake Up Safe' study, Anesth Analg 2018;127: 472–7

7.1.2 Basic Life Support

Basic Life Support (BLS) algorithms for children have a greater emphasis on early management of airway and breathing. The critical first step is oxygen delivery rather than chest compressions and defibrillation (A-B-C in children, rather than C-A-B for adults). After opening the airway, if the patient is not breathing (or only gasping), two rescue breaths are given (Fig. 7.1). In adults, chest compressions are started before ventilation, and an automated external defibrillator (AED) is applied as soon as available, reflecting the greater incidence of a primary cardiac cause of arrest.

Cardiopulmonary resuscitation (CPR) should be started when cardiac arrest is suspected on the basis of lack of signs of circulation, which include lack of responsiveness (unconsciousness), lack of breathing, lack of movement, pallor or cyanosis. It is not necessary to attempt to feel a pulse before starting CPR as pulse detection by palpation is unreliable in children, even when performed by healthcare personnel. If an attempt is made to palpate a pulse, CPR should be started if a pulse has not been felt within 10 s or if there is uncertainty about its presence. Chest compressions should be commenced if the pulse is less than 60 per minute in an infant or less than 40 per minute in a child.

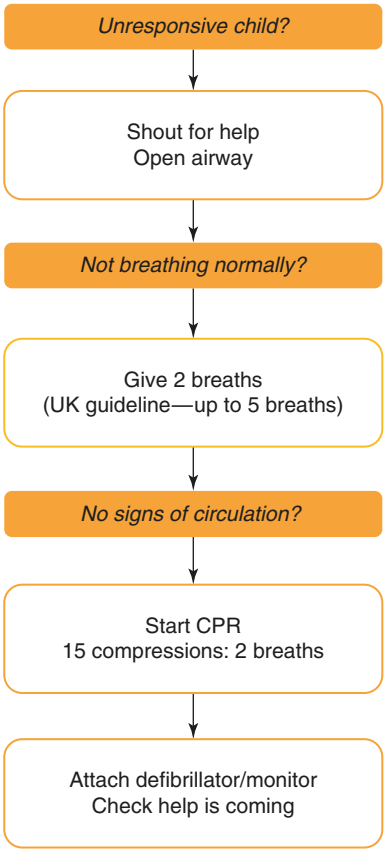

Fig. 7.1 Pediatric BLS for health care providers

Note
Palpating for a pulse is unreliable in children, even when performed by health-care personnel. However, the most accurate sites for palpation in a child are the brachial and femoral arteries.

High quality CPR includes minimal interruption to chest compressions and ventilation. The compression rate during CPR for all ages is between 100 and 120 per minute. The ratio of compressions to ventilations is 15:2 for health-care rescuers.

Chest compressions should compress the lower half of the sternum by approximately one-third the depth of the anterior-posterior diameter of the chest (5 cm in children, 4 cm in infants). For infants (a child less than 1 year of age) a two-finger technique or two-thumb (hand-encircling) technique should be used (Fig. 7.2). For children greater than 1 year of age, compress the lower half of the sternum with the heel of one hand (Fig. 7.3). For larger children, a two-handed technique can be used. Children have a much more compliant chest wall compared with adults, therefore less force is required for chest compression.

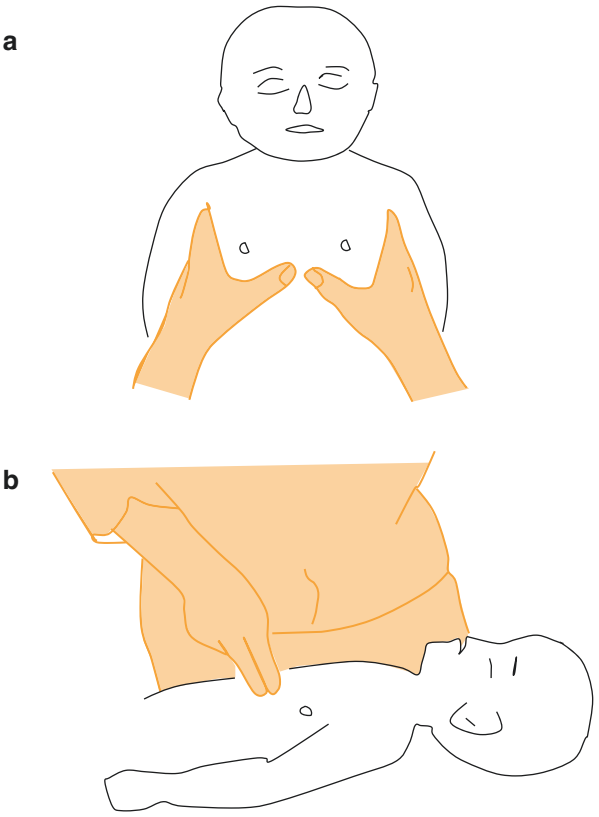

Fig. 7.2 (**a**) Infant chest compression using encircling technique. (**b**) Infant chest compression using two-finger technique

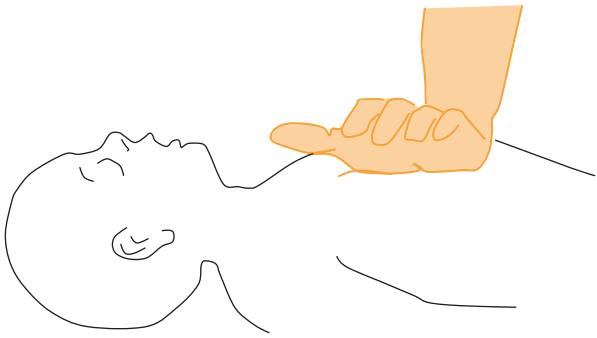

Fig. 7.3 Child chest compression using one-hand technique

Compression-only CPR from bystanders produces no survival benefit in out of hospital cardiac arrest in children, whereas standard ventilation-compression CPR does result in a survival benefit. Compression rates of less than 100 per minute or greater than 140 per minute, and inadequate compression depth are associated with lower rates of survival. Apart from an interruption to summon help, BLS must not be interrupted unless the child moves or takes a breath.

7.1.3 Advanced Life Support

Advanced life support is the management of an arrested or peri-arrest patient by a team of health care providers. It builds on BLS by adding monitoring of cardiac rhythm and treatment with defibrillation or drugs, and the use of an advanced airway such as the LMA or tracheal tube for ventilation.

As in adults, the management of cardiac arrest is divided into shockable and non-shockable rhythms (Fig. 7.4), and defibrillator and monitor should be attached as soon as possible to assess rhythm.

An advanced airway (LMA or ETT) improves ventilation compared with mask ventilation, and reduces interruptions to chest compressions, which in turn improves cardiac output. Endotracheal intubation provides better protection of the airway and control of ventilation, however insertion of an LMA is quicker and may be performed by those with less experience in airway management.

During CPR with an advanced airway in place, chest compressions should be continuous at a rate of 100–120 per minute, and ventilation at a rate of 10–12 per minute. If spontaneous cardiac output returns, a ventilation rate of 12–20 per minute is used. Capnography can be used to confirm ventilation and optimize the quality of CPR. If exhaled CO_2 ($ETCO_2$) is not detected, the position of the ETT should be checked by direct laryngoscopy. Although the absence of CO_2 may reflect tube misplacement, it may also be caused by very low pulmonary blood flow (such as immediately following adrenaline administration). If the $ETCO_2$ is consistently less than 10–15 mmHg (2 kPA), efforts should be made to improve chest compressions. Hyperventilation should be avoided due to the risk of reducing cerebral blood flow. An abrupt, sustained increase in $ETCO_2$ may occur just before the return of spontaneous circulation.

Note
A capnogram and detectable $ETCO_2$ are present during effective CPR in cardiac arrest in children. Absence of $ETCO_2$ usually suggests the ETT is not in the trachea. Avoid hyperventilation and optimize the quality of chest compressions, aiming to keep $ETCO_2$ above 15 mmHg (2 kPA).

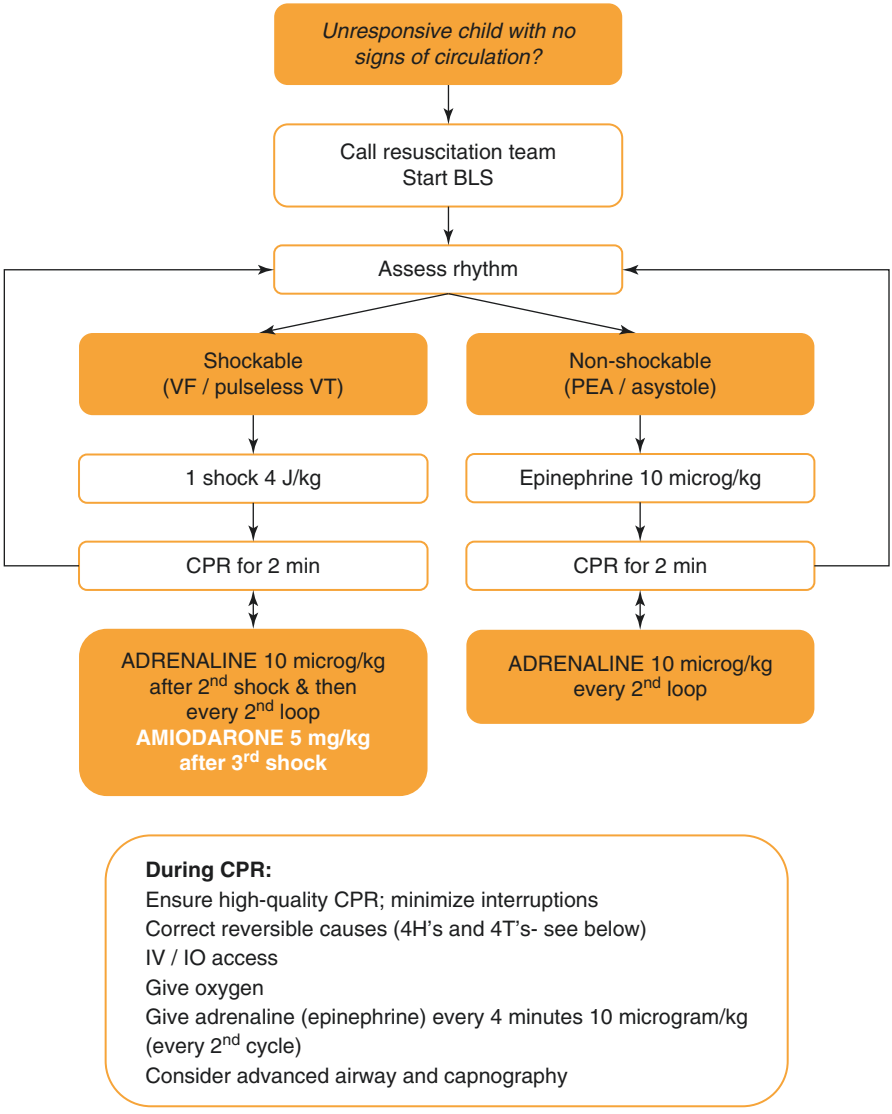

Fig. 7.4 Pediatric advanced life support algorithm

Hundred percent oxygen is still recommended for the arrested patient. There is no evidence to support the use of lower oxygen concentrations during resuscitation, but the inspired oxygen concentration is titrated to limit hyperoxia once spontaneous circulation has returned.

For both shockable and non-shockable rhythms, chest compressions are briefly paused to assess the cardiac rhythm at intervals of 2 min. If there is an organized rhythm, a pulse or signs of circulation are checked for at the end of that 2 min cycle. If there is a return of spontaneous circulation, post resuscitation care is continued.

7.1.3.1 Non-shockable Rhythms

These are severe bradycardia, asystole, and pulseless electrical activity (PEA). Effective basic life support and treatment of the underlying cause of the arrest affect the outcome of the arrest. Drug treatment includes adrenaline (epinephrine) 10 μg/kg (0.1 mL/kg of 1:10,000 solution) via intravenous or intra-osseous route every 4 min (every second cycle) until the return of spontaneous circulation. Higher doses of intravascular adrenaline in children may worsen outcome. Adrenaline (epinephrine) may be given through a peripheral line in the emergency situation, followed by a normal saline flush. If the child has no existing IV access, the intraosseous route is recommended as it is rapid and effective (see below). A central venous catheter is recommended if the child has ongoing inotrope requirements. Drug delivery via a tracheal tube is no longer recommended.

Adequate ventilation and chest compression are the best way to reverse acidosis during arrest. Alkalizing agents are not used routinely in resuscitation care. However, in prolonged arrest, severe metabolic acidosis may be treated with sodium bicarbonate 1 mmol/kg. Sodium bicarbonate inactivates adrenaline, therefore the line must be flushed with saline if adrenaline is going to be given. Atropine has no role in the routine management of cardiac arrest.

7.1.3.2 Shockable Rhythms

These include VF and pulseless VT. They are treated with a single asynchronous DC shock of 4 J/kg (either monophasic or biphasic). External chest compression is then immediately restarted and continued for 2 min before re-analyzing the cardiac rhythm. All subsequent shocks should be 4 J/kg and interruptions to chest compression minimized. Chest compression is only paused to check the child's pulse if there has been a change in cardiac rhythm, or if the child shows signs of life such as spontaneous movement or resumption of normal breathing. The risk of harm from unnecessary chest compressions is minimal, whereas interruption of chest compressions reduces the chance of a successful outcome.

Three 'stacked' shocks of 4 J/kg may be used in special circumstances such as witnessed arrests in the cardiac catheter lab, and ICU or theatre after cardiac surgery. Synchronized shocks of 0.5–2 J/kg are used for VT when there is hypotension but a pulse is present.

Paddles and defibrillation pads are equally effective. There are two sizes of defibrillation pad or paddle:

Adult-size (8–12 cm diameter) for adults and children >10 kg (approximately 1 year); and infant-size (4.5 cm diameter) for infants less <10 kg. Their placement should follow their manufacturer's recommendations—usually antero-apical with one electrode placed below the clavicle just to the right of the sternum, and the other over the apex in the mid-axillary line. In infants, anterior-posterior placement should be used if the pads cannot be adequately separated in the standard position. If infant pads are not available then standard adult pads can be used in the anterior-posterior position. Defibrillator pads must not touch, and a gap of least 3 cm between electrodes is preferable.

7.1.3.3 Automated External Defibrillators (AEDs)

Manual defibrillators are preferred in children, however if they are not available a standard AED can be used in children over 8 years (Table 7.2). AEDs in institutions caring for children at risk for arrhythmias and cardiac arrest (eg, hospitals, Emergency Departments) must be capable of recognizing pediatric cardiac rhythms. Many manufacturers supply pediatric pads or programs, which typically attenuate the output to 50–75 J. These devices are recommended for use in children between 1 and 8 years. If a manual defibrillator or pediatric attenuation system is not available, then a standard AED can be used.

Shockable rhythms are unusual in infants (particularly in out-of-hospital arrest), and the focus of resuscitation is on high quality CPR. However, there are rare case reports of successful use of AEDs in this age group. If an infant is arrested and in a shockable rhythm, current recommendations are to use an AED (preferably attenuated) if a manual defibrillator is not available.

Keypoint

Defibrillation of infants:

Manual defibrillator preferable, 4 J/kg

Infant pads, anterior-apical or antero-posterior—left side of lower sternum and below left scapula

Defibrillation of children 1–8 years:

Manual defibrillator, 4 J/kg

Adult pads, apical (mid axillary line) and to right of sternum below clavicle

Gap of more than 3 cm between edge of the two pads

Table 7.2 Recommendations for the use of automated external defibrillators (AEDs) in children

Child's age	Advice
8 years and older	Use unmodified adult AED
Younger than 8 years	AED can be used, preferably with energy attenuation (if not available use standard AED)

Table 7.3 Formulae for weight of children based on age

Age	APLS formula	Best Guess formula	UK Resuscitation Council
<1 year	$\left(\frac{months}{2}\right)+4$	$\left(\frac{months}{2}\right)+4.5$	
1–5 years	*(2 × age) + 8*	*(2 × age) + 10*	*2 × (age + 4)*
5–10 years	*(3 × age) + 7*	*4 × age*	*2 × (age + 4)*
>10 years	*Age × 3.3*		

Children older than 10 years have a large variation in body habitus and weight, and formulae are less accurate

7.1.3.4 Anti-arrhythmic Drugs

Defibrillation is the definitive treatment of VF and pulseless VT. Anti-arrhythmic drugs are given to stabilize the converted rhythm. Amiodarone 5 mg/kg IV/IO bolus, is the first-line agent and is given once, only after the third shock. Lidocaine 1 mg/kg may be used if amiodarone is not available. Magnesium (0.1–0.2 mmol/kg) is indicated in arrest due to polymorphic VT (torsades de pointes), or in the presence of hypomagnesaemia.

7.1.4 Estimation of Children's Weight

In emergencies, it may not be practical to weigh children before starting treatment. Several methods have been devised to estimate children's weight.

Formulae based on age include the APLS and "Best Guess" methods (Table 7.3). Age-based formulae have a poor predictive accuracy, particularly in older children, and may require complex calculations in a stressful environment. However, they require no equipment and are taught in pediatric advanced life support courses.

Digital methods such as the Helix Weight Estimation Tool improve accuracy over other age-based estimates, as they allow calculations based on age in months, incorporate gender and body habitus, and reduce the risk of calculation errors. With these tools, the child's data is entered and a page of values printed and included with the hospital notes. The page of values can be referred to in an emergency, and includes information about drug doses, ETT size, DC shock energy and fluid volumes. These are useful for children being cared for in non-pediatric hospitals if prepared at admission, before any emergency situation has begun.

Length- based methods such as the Broselow tape, are more accurate in estimation of weight and do not require the child's age to be known. The tape is laid alongside the child and the length is used to estimate weight. Appropriate drug doses, ETT size and energy for DC shock are also indicated.

7.2 Reversible Causes of Cardiac Arrest in Children

During resuscitation, consider and correct precipitating causes that are reversible. These causes may be remembered as the 4H's and 4T's, as for adults:

Hypoxia is a prime cause of cardiac arrest in children and reversing it is essential to achieve a successful resuscitation.

Hypovolemia may be significant in trauma (due to hemorrhage), gastroenteritis, burns or surgical conditions such as intussusception and volvulus. Distributive shock may occur with septicemia or anaphylaxis. Initial resuscitation is with crystalloid 20 mL/kg boluses as required, followed by colloid or blood products as indicated. Most children are able to compensate very well for hypovolemia. Hypotension is usually a late and pre-terminal sign. By contrast, infants have a relatively fixed stroke volume and are less able to compensate for hypovolemia.

Hyperkalemia, hypokalemia, hypocalcemia and other metabolic abnormalities may be suggested by the child's underlying condition, such as renal failure, or by ECG and blood tests taken during the arrest.

Hypothermia may be associated with drowning or environmental exposure. A low reading thermometer must be used to detect it, and active rewarming begun. VF may be resistant to defibrillation until the core temperature is increased to above 32 °C.

Tension pneumothorax and cardiac **tamponade** causing pulseless electrical activity may occur after trauma or surgery.

Toxic substances may be the result of accidental or deliberate overdose or iatrogenic error. Specific antidotes may be required and expert advice should be sought.

Local anesthetic toxicity may cause VT and VF. Resuscitation can be difficult and VF may be resistant to defibrillation, although outcome may be favorable if good quality CPR is quickly initiated. A bolus of lipid emulsion 2 mL/kg 20% lipid (such as Intralipid) followed by an infusion of 0.2 mL/kg/h may assist resuscitation.

Thromboembolic phenomena such as pulmonary embolism are less common in children than adults, but should still be considered. Children with Fontan circulation and cardiac conduits are at high risk of clot formation Spontaneous coronary thrombosis is very rare in children.

Keypoint
Successful resuscitation requires identification and treatment of the underlying cause.

7.3 Hypoxia and Bradycardia as a Prelude to Cardiac Arrest

The commonest cause of cardio-pulmonary arrest during pediatric anesthesia is hypoxia due to an airway problem such as laryngospasm or loss of airway, or a respiratory problem causing inadequate ventilation. Severe hypoxia will lead to a progressively worsening bradycardia followed by asystole. The priority is to restore oxygenation and ventilation. External chest compressions should be started if the heart rate is less than 40 per minute in a child or less than 60 in an infant. Atropine

(20 μg/kg IV) should be given early. Bradycardia may be worsen after suxamethonium is given (eg. to break laryngospasm), so co-administration of atropine in the hypoxic patient should be considered. Adrenaline (10 μg/kg IV) should be given in severe bradycardia if there are no signs of cardiac output or asystole. Resuscitation should follow the ALS algorithm for asystole.

7.4 Parental Presence During Resuscitation

Whenever possible, parents should be given the opportunity to be present during the resuscitation of an infant or child. It is important that a dedicated staff member stays with family members to provide support and an explanation of events.

7.5 Post-resuscitation Care

Return of spontaneous circulation (ROSC) may be recognized by:

- Return of spontaneous movement or breathing
- Return of pulse or blood pressure
- Return of spontaneous arterial pressure waves with intra-arterial monitoring
- An increase in $ETCO_2$

The goals of post-resuscitation care are to preserve neurologic function, prevent secondary organ injury, diagnose and correct the underlying condition, and enable the patient to arrive at a pediatric tertiary-care facility in an optimal physiologic state.

Continuous monitoring is required to detect any improvement with therapy or deterioration. Ventilatory support is usually required and vasoactive drugs are frequently required for hemodynamic support. Hyperoxia should be avoided by adjusting the inspired oxygen concentration to the lowest that will maintain oxygen saturations above 94%.

Blood glucose should be checked frequently to avoid both hyper- and hypoglycaemia. However, tight glucose control does not improve survival compared to moderate glucose control, and increases the risk of hypoglycemia. Glucose-containing fluids should not be given during CPR except in the treatment of hypoglycemia.

For infants and children remaining comatose after cardiac arrest, continuous measurement of temperature and targeted temperature management is recommended. Currently, there is insufficient evidence to recommend routine cooling over normothermia (36–37.5 °C for 5 days). Fever (>38 °C) in the post cardiac arrest setting results in poorer neurological outcomes, and active cooling should be used if the patient is febrile. If a child is severely hypothermic they should not be actively rewarmed post arrest unless core temperature is less than 33 °C. Rate of rewarming in severe hypothermia should not exceed 0.5 °C per hour. Multi-organ failure may occur after cardiac arrest with prolonged hypoxemia or hypotension, and supportive therapy may be required for many days.

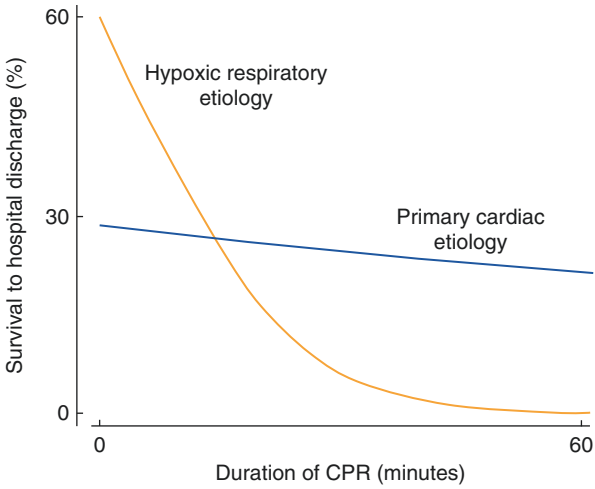

Fig. 7.5 The percentage of children surviving to discharge from hospital after in-hospital cardiac arrest. Most arrests in children are secondary to hypoxia and respiratory causes, and survival decreases markedly with prolonged CPR. Children who have a cardiac arrest due to a cardiac etiology have a worse initial outcome as a reflection of their underlying cardiac disease. Adapted from Berens RJ et al. Pediatr Anesth 2011;21: 834–40

7.6 Stopping Resuscitation

There is no single factor that predicts the likely outcome following resuscitation. Factors to consider when deciding to stop attempts at resuscitation include the circumstances of the arrest, initial rhythm, duration of resuscitation and quality of CPR, and other features such as hypothermia. Long term outcome from pediatric cardiopulmonary arrest is poor if it occurs out of hospital, but better if the arrest is respiratory alone or if cardiorespiratory arrest occurs in hospital. Perioperative cardiac arrest has significantly higher survival rates than other forms of in-hospital arrest.

The duration of cardiopulmonary resuscitation is not a reliable predictor of outcome. However, in cases of prolonged CPR, survival to hospital discharge is more likely with cardiac induced cardiac arrest, particularly in cardiac surgical patients. In the setting of respiratory failure induced arrest, survival declines exponentially after CPR duration of 15 min (Fig. 7.5).

7.7 Emergency Vascular Access

Achieving IV access in a seriously ill or arrested child is difficult, even for an experienced practitioner. The intra-osseous route has become the initial technique to use during resuscitation, or otherwise to be used if peripheral IV access cannot be obtained rapidly. Cannulation of the femoral vein using the Seldinger technique during ultrasound guidance is another useful, safe technique, though not in the arrest situation.

7.7.1 Intraosseous Access

Intraosseous (IO) access can often be achieved more rapidly than peripheral venous access. Unlike peripheral veins, bone marrow vessels will not collapse in shock or

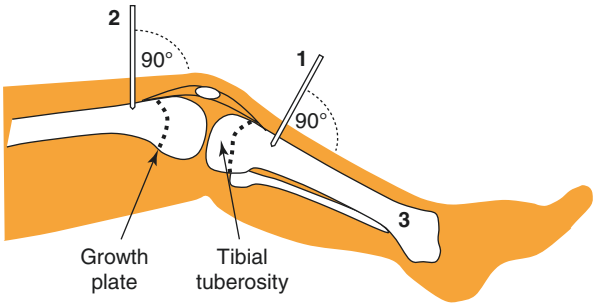

Fig. 7.6 Intraosseous insertion sites in children. (**1**) Anteromedial surface of the tibia, 2–3 cm below the tibial tuberosity. (**2**) Anterior surface of distal femur, 3 cm above the level of the lateral condyle. (**3**) Alternative site for older children on medial aspect of distal tibia about 3 cm above medial malleolus

hypothermia. An IO needle with a stylet is most commonly inserted using an IO drill or gun. The success rate is 90% or higher, but lower in infants in whom manual insertion may have a higher success rate than drill insertion.

In infants and children, the preferred site is the anteromedial surface of the tibia, 2–3 cm below the tibial tuberosity, away from the growth plate (Fig. 7.6). In young children, the tibial tuberosity may not have developed, and insertion point is about 3 cm distal and 1 cm medial to the lower border of the patella. In older children, the bone cortex can be thick and strong, and the medial side of the distal tibia, about 3 cm above the medial malleolus, can be used. An alternative site only for infants and small children is the medial side of the distal femur about 3 cm above the lateral condyle, which is above the growth plate. In any age group, the IO needle cannot be inserted into bones or limbs that are fractured.

After sterile preparation of the skin, the needle is inserted at a 90-degree angle to the skin. A loss of resistance is felt when the cortex of the bone is penetrated— this may only be millimeters from the skin in babies. Correct needle placement may be confirmed by aspiration of blood or bone marrow (although not always) or free flow of fluid by gravity. If aspiration is not possible and there is no flow of fluid with gravity, then attempt infusion of fluid by syringe. Pressurized fluids should flow without difficulty and there should be no evidence of extravasation. Fluids may be administered more rapidly by infusion with pressure, and any drugs given IO should be followed by a saline flush to speed their entry into the central circulation. Injection and infusion into the medullary cavity causes severe pain in children who are conscious and aware. IO lidocaine or opioids may reduce the pain.

In older children and adults, IO access may be more difficult because of the thicker bone cortex. At this age, the intra-medullary space also becomes less vascular and fattier, resulting in slower infusion rates. Although the technique can be used in neonates, fracture or perforation of the bone are risks because it is difficult to feel the needle enter the marrow cavity, particularly when using a drill device, and umbilical vein catheterization may be preferable.

Blood or bone marrow may be aspirated and used to measure electrolytes (although the potassium level may be higher than with venous sample), glucose

level and perform cross match. The receiving laboratory should be warned the sample is from the marrow cavity, as the marrow may block their equipment or the lab may suspect undiagnosed leukemia. The marrow sample can be used in glucometers, iSTAT® and similar point-of-care devices. All of the drugs used during resuscitation can be given via the IO route. The commonest complication is extravasation, which may cause compartment syndrome if not recognized. Infection is a concern and is related to the duration of IO access (Table 7.4). Once the child is stabilized, definitive access should be obtained and IO access removed within 24 h.

7.8 Management of the Choking Child

Airway obstruction with a foreign body should be suspected if there is a sudden onset of respiratory compromise associated with coughing, gagging and stridor. Management depends on the severity of the choking episode (Fig. 7.7). If the child

Table 7.4 Complications of intraosseous insertion

Potential complications of IO access
Extravasation and compartment syndrome
Infection and osteomyelitis
Growth plate injury
Fracture
Fat embolism

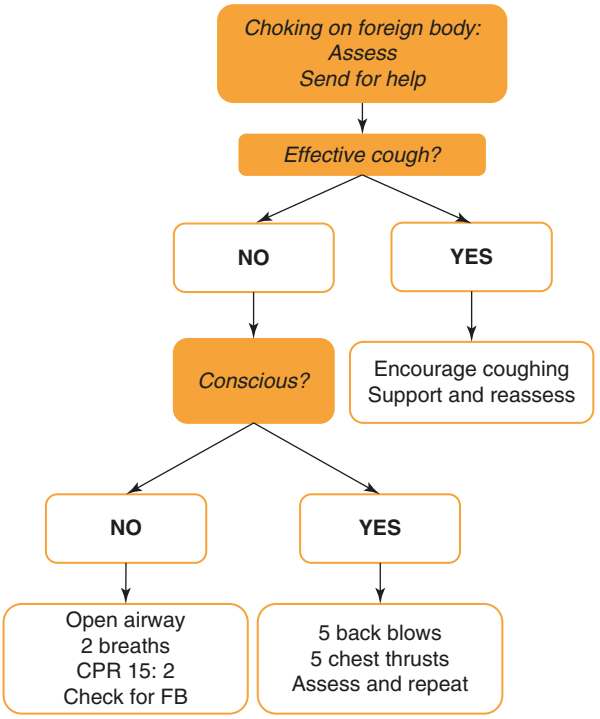

Fig. 7.7 Management of a child choking on a foreign body

has mild airway obstruction with an effective cough, then the child is encouraged to cough and monitored for signs of recovery or deterioration. If the child is conscious but has severe airway obstruction and an ineffective cough, then the child is given up to five back blows between the shoulder blades. If this is not effective, up to five chest thrusts over the lower half of the sternum (as for chest compressions in CPR) are given. If the child has severe airway obstruction and is unconscious, then CPR is begun, starting with two breaths.

7.9 Anaphylaxis

As in adults, the commonest causes of anaphylaxis (both immune and non-immune mediated) in the peri-operative setting are muscle relaxants, latex, antibiotics and radio-contrast media. The incidence of anaphylaxis appears to be increasing, especially in children and young adults. Environmental agents or over-the-counter medicines may play a role in sensitization of individuals and an increased risk of anaphylaxis with drugs such as muscle relaxants.

The management of anaphylaxis requires early administration of adrenaline (epinephrine), effective airway management, aggressive fluid resuscitation if shock is present, and escalation of therapy in refractory cases (Table 7.5). If cardiac arrest has occurred (usually PEA), then the ALS guideline for non-shockable rhythm should be followed, using the arrest dose of epinephrine (10 μg/kg IV).

Patients at known risk of anaphylaxis should carry self-administration auto-injector adrenaline pens (eg Epipen®), with two pens (twin-pack) now recommended in case a second dose is required for persistent symptoms. The standard dose pen (epinephrine 0.3 mg) is used for adults and children heavier than 30 kg, while the 'junior' pen (epinephrine 0.15 mg) is for children 15–30 kg. The recommended site for IM injection is the lateral thigh.

Table 7.5 Suggested initial adrenaline (epinephrine) treatment of anaphylaxis in children

Route	Initial adrenaline (epinephrine) dose	Notes
Intravenous	**Use 1:10,000 = 1 mg/10 mL** Moderate anaphylaxis: 1–2 μg/kg 1–2 min prn (0.01–0.02 mL/kg of 1:10,000) Life threatening: 4–10 μg/kg 1–2 min prn (0.04–0.1 mL/kg of 1:10,000)	Must be titrated carefully Increase dose if unresponsive Features of 'life threatening anaphylaxis' include: Severe hypotension Life threatening tachy- or brady-arrhythmia Oxygen saturation <90% Inspiratory pressure >40 cmH_2O
Intramuscular	**Use 1:1000 = 1 mg/mL** 10 μg/kg 5 min prn (0.01 mL/kg of **1:1000**) up to 0.5 mg If weight not known: <6 years: 0.15 mL = 150 μg 6–12 years: 0.3 mL = 300 μg	Into lateral thigh Consider if no IV access or hemodynamic monitoring, or awaiting epinephrine infusion

Based on Australia & New Zealand Anaesthetic Allergy Group guidelines, 2017

Any child who has a suspected anaphylactic reaction associated with anesthesia should be investigated fully with referral to a specialist allergy or immunology center. Blood samples for mast cell tryptase collected as soon as feasible after resuscitation has started and again 1–2 h after the onset of symptoms assist with diagnosis.

7.10 Neonatal Resuscitation at Birth

Neonatal resuscitation at birth is different to the resuscitation of other age groups because of the profound respiratory and cardiovascular changes occurring at birth. Immediate and adequate support of newborn infants who fail to adapt normally in the delivery room is critically important for their prognosis. The commonest causes of death in the neonatal period are related to prematurity, congenital malformations and perinatal asphyxia.

Neonatal resuscitation is a rapid sequence of steps to identify and manage babies with impaired breathing or circulation. Ventilation is the key. Most newborns are vigorous and do not need medical intervention. Approximately 10% require some sort of medical assistance, but only 0.1% need chest compressions or drugs for resuscitation after birth.

The neonatal resuscitation guidelines are appropriate for newborns and neonates with a transitional circulation, and in locations where the neonatal guidelines are commonly used, such as the delivery room, nursery or NICU. For neonates outside these locations and beyond the time of transitional circulation, it is reasonable to use pediatric resuscitation guidelines.

Note
Neonatal resuscitation differs from adult resuscitation in four areas:
Head position of the neonate; position of hands for cardiac compression; reassessment in 30 s blocks of time; different epinephrine dose in asystole.

7.10.1 Major Changes at Birth: From Fetal to Neonatal Circulation

In utero, the pulmonary and systemic circulations are in parallel, with mixing of blood between the two circulations at the level of the ductus arteriosus and foramen ovale (Fig. 7.8). This mixing allows oxygenated blood from the placenta to return to the right side of the heart to reach the arterial circulation. The lungs are filled with fluid, the left and right pulmonary arteries are constricted, and only about 7% of the cardiac output passes through the lungs.

Multiple stimuli initiate breathing after birth. A strong, negative intrathoracic pressure inflates the lungs for the first breath. Lung fluid is absorbed into the circulation and oxygen triggers prostacyclin release causing nitric oxide formation and a fall in pulmonary vascular resistance (PVR). Removal of the placenta from the circulation increases the systemic vascular resistance (SVR). The fall in PVR and rise

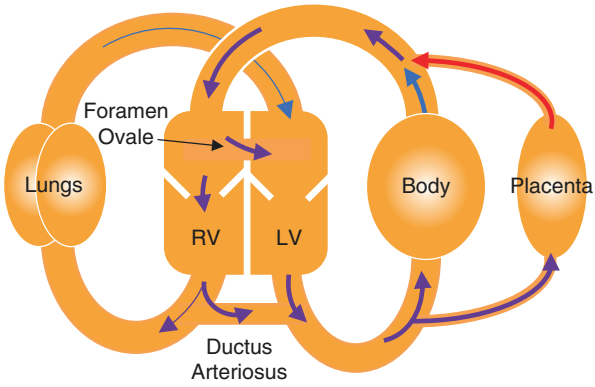

Fig. 7.8 Schematic representation of the fetal circulation with patent ductus arteriosius and foramen ovale

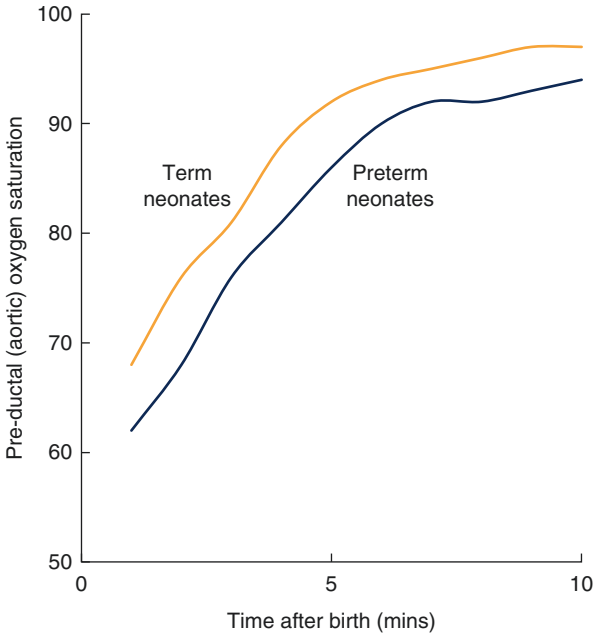

Fig. 7.9 Oxygen saturation after birth in term and preterm neonates. Oxygen saturation is 65% at birth and should reach 85–90% by 5–10 min after birth. Based on data from Wong C, Pediatrics 2010

in SVR causes functional closure of the ductus and foramen ovale, and right-to-left shunting of blood is markedly reduced and the pulmonary and systemic circulations become in-series with one another. Oxygen saturation rises shunting is reduced and lung function improves (Fig. 7.9).

7.10.1.1 Pre- and Post-ductal Oxygen Saturations

The ductus arteriosus is not fully closed immediately after birth, and there is still some blood shunting through it. This shunting may be right-to-left (as in utero) or left-to-right depending on the balance between the SVR and PVR. The oxygen saturation distal to the ductus arteriosus ('post-ductal') may therefore vary. The

pre-ductal saturation represents cerebral oxygenation and saturation is best measured in the right hand or wrist of newborns. The left hand is usually pre-ductal, but not always. The feet are post-ductal, and saturation is usually lower there during the first 15 min after birth because of R-to-L shunting across the duct. If post-ductal saturation remains lower, it suggests pulmonary hypertension or aortic lesions keeping the aortic pressure lower than the pulmonary pressure. A post-ductal saturation higher than the pre-ductal suggests transposition of the great arteries.

7.10.2 Preparation for Resuscitation

The equipment required for resuscitation of newborns (Tables 7.6 and 7.7) is assembled and checked before delivery. The presence of risk factors may be helpful in predicting the need for resuscitation (Table 7.8) and may also help determine the initial level of resuscitation. For example, if there is placental abruption and fetal bradycardia suggesting hypoxia before delivery, then immediate intubation would be considered. However, if there was no such history and the baby is born unexpectedly 'flat', then the baby might be observed for 30 s or a trial of bag-mask (or Neopuff®) ventilation given.

Table 7.6 Equipment required for neonatal resuscitation in the delivery room

Equipment item
Warm dry towels and radiant heat source
Oxygen supply and pressure-limited delivery system such as self-inflating bag, T-piece, or Neopuff® ventilator
Airway equipment including face masks, oro-pharyngeal airways, laryngoscopes, endotracheal tubes and introducer
Carbon dioxide detector (eg Pedicap®)
Suction apparatus
Stethoscope
Venous access equipment and drugs

Table 7.7 ETT sizes for newborns

Age	Uncuffed ETT size (ID, mm)	Cuffed ETT size (ID, mm)
Term baby	3–3.5	3.0
Preterm	3	Not recommended
Preterm <1 kg	2.5	Not recommended

Table 7.8 Some factors during pregnancy and delivery that may indicate a need for neonatal resuscitation

Risk factor	
Antepartum	Preterm baby
	Small for dates
	Congenital abnormality diagnosed on screening
Intrapartum	Fetal distress
	Antepartum hemorrhage
	Meconium stained liquor

7.10.3 Initial Assessment at Birth

The need for resuscitation is based on clinical observation and not the APGAR score (see later). The baby needs resuscitation if it is not vigorous and crying, or is bradycardic or not breathing adequately. Normal heart rate after birth is 110–160 beats/min. A baby at birth will initially appear cyanosed.

7.10.4 Neonatal Resuscitation

Resuscitation and assessment of the neonate is grouped into 30-s blocks. Initial actions are to assess the baby while drying and stimulating it, but also keeping it warm at the same time. Unlike resuscitation in other age groups, breathing and circulation are assessed together as heart rate is an important indicator of response. While the sequence of actions may differ from adult and pediatric resuscitation, the basic approach is still Airway, Breathing, and Circulation (Fig. 7.10). Hypothermia is a risk and is avoided by drying the baby and using an external heat source.

Keypoint
Failure of a neonate to respond to resuscitation is most likely due to inadequate ventilation.

Bradycardia is almost always due to hypoxia due to inadequate ventilation.

7.10.4.1 Airway

The baby's head should be in a neutral position or slightly tilted back to maintain an open airway. Neck flexion occasionally occurs from the neonate's relatively large head and can be overcome with a roll beneath the shoulders. Check for any obstruction of the airway such as meconium or blood. Chin support or jaw thrust may be required to achieve a patent airway.

7.10.4.2 Breathing

Assisted ventilation should be commenced by 1 min in infants who have absent or ineffective spontaneous ventilation. If positive pressure ventilation is required, chest movement during the first few breaths may be minimal as lung fluid in the alveoli is replaced with air or oxygen. Sustained initial inflation breaths may be considered in preterm infants. After these initial breaths, ventilation is continued at 40–60 breaths/min while avoiding hyperventilation. Chest movement is observed to confirm airway patency. Ventilation is continued until regular breathing is established and heart rate remains faster than 100 bpm. Ventilation via a facemask or ETT can be performed with a self-inflating bag or T-piece circuit. The latter is recommended as they more reliably deliver PEEP or CPAP. PEEP allows faster establishment of functional residual capacity (FRC) and improved oxygenation. A Neopuff®

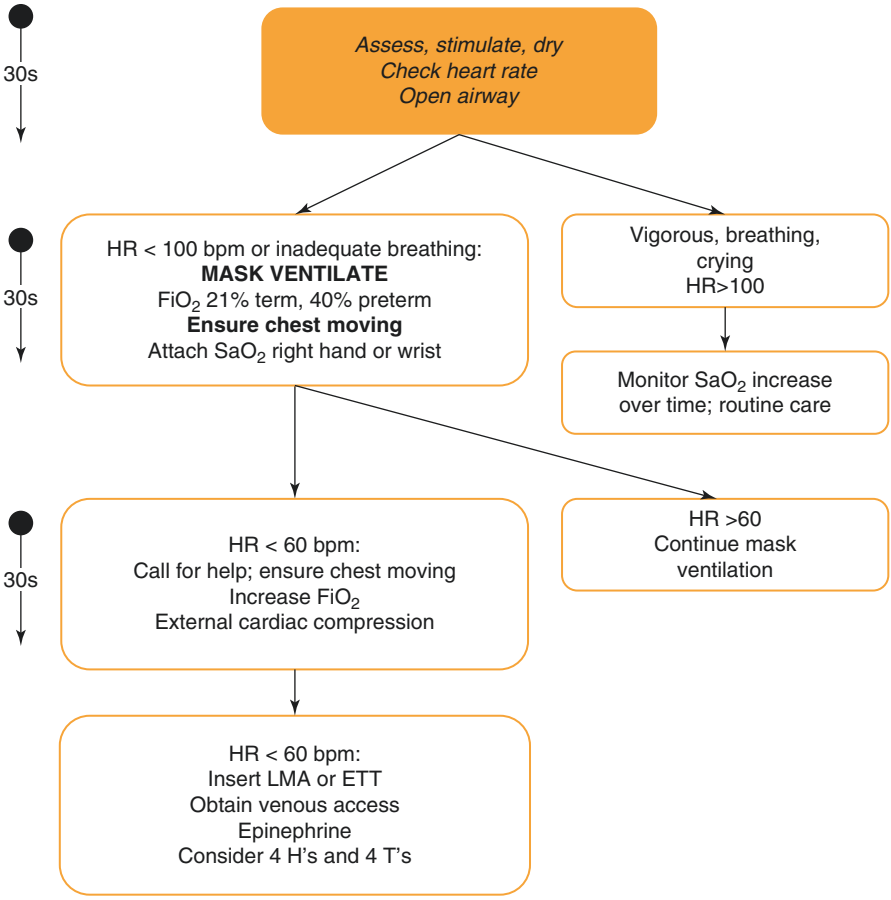

Fig. 7.10 Flow diagram of the steps during neonatal resuscitation. Infants who have absent or ineffective spontaneous breathing must have assisted ventilation begun within 1 min

ventilator is a T-piece type pressure-limited ventilator with a non-rebreathing valve at the patient connection. Suggested initial settings are 30 cmH_2O for peak inspiratory pressure (20–25 cmH_2O if <32 weeks or known lung disease), and PEEP at 5–8 cmH_2O. An oxygen-air blender is used to control the inspired oxygen concentration.

7.10.4.3 Oxygen During Resuscitation

Hundred percent oxygen is not routinely needed during neonatal resuscitation. There is no evidence that the neonate's oxygen saturation of 65% at birth needs to be rapidly increased. High concentrations of oxygen may reduce cerebral blood flow, predispose to retinopathy of prematurity and also produce free radicals and a 'reperfusion injury' to the neonatal brain. Current recommendations are to use air for resuscitation of term infants at birth. If, despite effective ventilation,

oxygenation remains unacceptable, use of a higher concentration of oxygen should be considered. Titration of oxygen concentration delivery should be guided by oximetry monitored from the right upper extremity. Saturation should reach 90% by 5–10 min.

7.10.4.4 Circulation

Heart rate is counted with auscultation at the apex (for 6 s, multiply by 10) and later pulse oximetry.

ECG is also recommended as an adjunct for monitoring resuscitation. Palpation of the umbilical pulse can be used, but palpation of peripheral pulses is not practical. Chest compression should be started if the heart rate remains less than 60 bpm despite adequate ventilation. A hand-encircling technique is the best method to deliver chest compressions, using the thumbs to compress the chest by one third of its depth. A two-finger compression of the sternum allows better access for procedures such as vascular access. Perform three compressions and one breath every 2 s. Stop and recheck the heart rate every 30 s. Chest compressions should be continued until the heart rate is above 60 bpm. The most common reason for failure to respond is inadequate ventilation.

Note
To detect neonatal heart rate: Auscultation; palpation of umbilical pulse; oximetry.

7.10.4.5 Drugs

If chest compressions are needed, vascular access should be considered to enable administration of intravenous adrenaline (epinephrine). An umbilical venous catheter is the route of choice. Endotracheal adrenaline is no longer recommended. If drugs are required for resuscitation, the outcome is often poor. The dose of IV epinephrine in neonatal resuscitation is 10–30 μg/kg. However, a gestation-based chart for dose is commonly used as it avoids the need for estimating weight and performing calculations during resuscitation (Table 7.9). Bicarbonate is no longer used, and bolus doses of dextrose are avoided. Hypoglycemia is managed with a 10% dextrose infusion. Normal saline may be used as a volume expander. Naloxone 100 μg/kg IV or IM is used only when the mother has received opioids during labor.

Table 7.9 Adrenaline (epinephrine) dose for neonatal resuscitation based on gestational age

Gestational age (weeks)	Adrenaline dose (mL 1:10,000 adrenaline)
23–26	10 μg (0.1)
27–37	25 μg (0.25)
38–43	50 μg (0.5)

Doses are absolute values, NOT per kg

7.10.4.6 Pneumothorax

Pneumothorax is not uncommon, especially in preterm babies. Diagnosis can be difficult—auscultation is unlikely to detect it and chest expansion may appear normal. Transillumination through the axilla is often the best technique in preterm babies, but is less useful in larger term babies. Emergency treatment is aspiration of the chest with a 22G needle connected to an IV extension tubing and a three-way tap. The needle is inserted through the second intercostal space in the anterior axillary line, or in the fourth space in the mid-axillary line. Have a high index of suspicion for pneumothorax and consider needle aspiration of the chest in any child not responding to resuscitation. Cardiopulmonary resuscitation of the neonate should not be stopped until both sides of the chest have been aspirated.

7.10.4.7 Meconium

Although meconium-stained liquor is common, meconium aspiration is rare. If meconium exposure has occurred and the baby is vigorous, only oropharyngeal suctioning is required. If the baby is not vigorous, not breathing or crying and has poor muscle tone, current guidelines no longer recommend the routine intubation or laryngoscopy for suctioning due to a lack of evidence of benefit in survival or incidence of meconium aspiration syndrome. Simple oropharyngeal suctioning (without laryngoscopy), and monitoring for signs of respiratory distress are recommended for these neonates.

7.10.5 APGAR Score

The APGAR score is a tool for recording an infant's condition at birth as a score out of 10 (Table 7.10), and is used as a prognostic guide for complications after resuscitation. It is recorded at 1 and 5 min after birth and for longer if the score is less than 7 or the baby is being resuscitated. An APGAR score of 3 or less beyond 10 min indicates an increased risk of hypoxic ischemic encephalopathy and long term adverse effects. It does not determine the need for resuscitation, as this is based on respiratory effort and heart rate rather than any particular score. However, the score will be low in a baby who needs resuscitation.

Table 7.10 Observations and values for the APGAR score

	Score		
Observation	0	1	2
Heart rate	Absent	Slow (<100/min)	>100/min
Respiration	Absent	Slow, irregular	Good; crying or gasping
Muscle tone	Floppy	Some flexion	Active movement of extremities
Reflex irritability (response to stimulation)	No response	Grimace	Cough, sneeze, cry
Color	Blue or pale	Pink body, blue extremities	Pink

Note
The APGAR score does not determine the need for resuscitation. Resuscitation is needed when the baby has poor respiratory effort, a low heart rate, or both.

Review Questions

1. The emergency bell in the PACU is alarming. You arrive to find a child who is not responsive, grey, apneic, and has no pulse. Nursing staff are performing CPR. They tell you that the child has just had a tonsillectomy. Describe your resuscitation of the child.
2. You are asked to provide assistance to resuscitate a baby. One minute after birth the baby has irregular respiratory effort, is blue all over, limp and has no reaction to suction. The umbilical cord stump pulse is felt at 60/min.

   Describe your resuscitation of the baby.

   This baby needs resuscitation because it has poor respiratory effort, is blue and bradycardic. The baby has already been dried, suctioned and stimulated and 1 min has gone by. A 30 s trial of mask ventilation should be the next step. If the heart rate still doesn't increase above 60, cardiac massage needs to be started and intubation considered.

   How is the Apgar score calculated, and what does it mean?

   Virginia Apgar was an American anesthetist who devised the score in 1952. This baby gets 1 for HR, 1 for respiratory effort, but 0 for tone, color and response to suction. Its score is 2. Remember—the Apgar does not determine the need for resuscitation.
3. You have performed a caudal block under GA with 1 mL/kg of ropivacaine 0.2% in a 4 year old who weighs 20 kg. One minute after completion of the block you see multiple ventricular ectopic beats. As you are checking the patient's blood pressure, the ECG changes to this VF. What is the likely diagnosis? Describe your initial management of the patient
4. The resuscitation trolley is brought into the theatre. The defibrillator is an AED but does not have pediatric pads. Can this be used? Where would you place the pads?

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Crises and Other Scenarios in Pediatric Anesthesia

8

Tom Rawlings and Tom Flett

The successful management of a crisis is a multifactorial process. A combination of clinical skills and knowledge is required as well as the application of robust and effective non-technical skills. These non-technical skills incorporate cognitive and environmental factors to enhance a successful team environment to successfully manage a crisis.

The relevant non-technical skills include:

- Leadership and follower-ship
- Communication
- Situational awareness
- Calling for help
- Role allocation
- Right people, right roles
- Avoidance of fixation error

Many experienced clinicians exhibit exceptional non-technical skills that are involuntary and learnt over time. Teaching and training in non-technical skills aim to teach 'experience' otherwise gained with time. While there is no substitute for experience, an early understanding of the multiple factors required to successfully manage a crisis allows trainees to work on their areas of weakness. Effective, targeted simulation training can help reduce the gap between the text book and reality. This training is particularly important in preparing for pediatric anesthetic crises because a child's condition can change rapidly compared to an adult, and team members may be less familiar with children and their management during a crisis.

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This chapter describes the practical management of some clinical scenarios in pediatric anesthesia. Some of the scenarios describe urgent situations, while others are less urgent but commonly seen and have the potential to become serious problems if mismanaged.

8.1 Cardiovascular Collapse During Laparoscopic Appendicectomy

An 8 year old boy is undergoing a laparoscopic appendicectomy. He has a two day history of abdominal pain, diarrhea and vomiting. He is otherwise previously fit and well and has never had an anesthetic before. There is no family history of problems with anesthesia.

The patient is intubated and ventilated and anesthesia is being maintained with sevoflurane, air and oxygen after an initial dose of fentanyl 2 μg/kg, propofol 120 mg, rocuronium 20 mg and antibiotic prophylaxis with piperacillin with tazobactam.

Shortly after the first port is inserted and insufflation of carbon dioxide begins, there is a drop in the $ETCO_2$, tachycardia, desaturation and a fall in blood pressure. Figure 8.1 shows the monitor screen at this time.

What will you do?

8.1.1 Discussion

An initial approach to this situation could be to take an 'ABC' approach and consider acute 'B' Breathing or 'C' Circulation issues. The first step would be to ask the surgeon to stop insufflating gas and release the pneumoperitoneum, placing the child onto 100% oxygen and starting manual bag ventilation.

Breathing issues can be eliminated by checking there is no obstruction in the circuit and auscultating the chest to confirm bilateral air entry and normal breath sounds. Causes such as hypoventilation, endobronchial intubation and bronchospasm will cause desaturation, but are unlikely to cause profound, acute cardiovascular collapse. The most likely 'Breathing' cause of this scenario is a pneumothorax evolving into a tension pneumothorax from gas insufflation tracking into the pleural space. Pneumomediastinum is also possible but less likely.

Once establishing there is no acute 'B' problem a 'C' (cardiovascular) issue would be considered. Whatever the cardiovascular cause, initial management should always include asking the surgeon to cease what they are doing, give a fluid bolus of 10–20 mL/kg of isotonic crystalloid, give an alpha-agonist (either metaraminol 5–10 μg/kg or phenylephrine 1 μg/kg) and consider reducing the depth of anesthesia, balancing the management of the problem with the risk of awareness. More potent inotropes such as adrenaline (epinephrine) should be considered if cardiovascular collapse is severe and rapidly evolving. Treatment is required to establish a degree of cardiovascular stability whilst simultaneously attempting to identify the

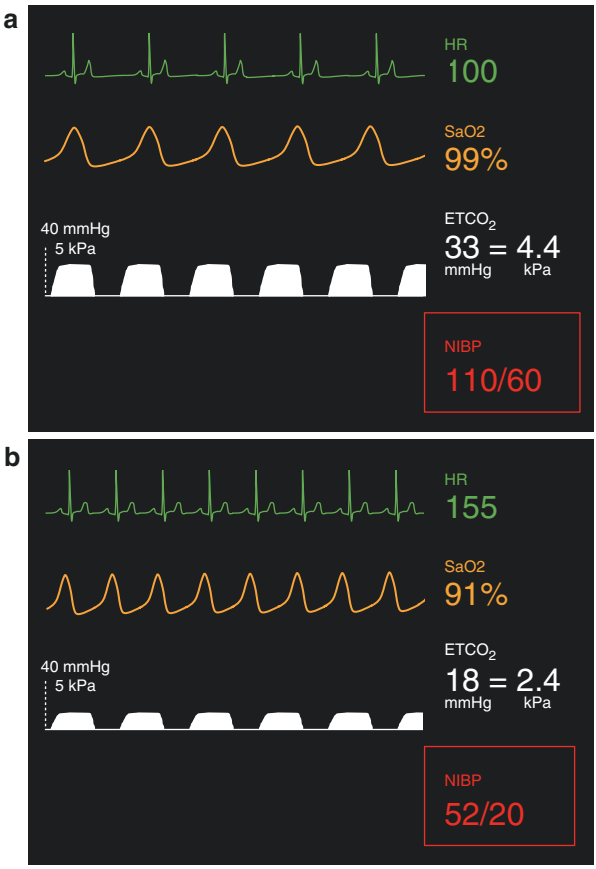

Fig. 8.1 (**a**) Screenshot of anesthetic monitor displaying vital signs during anesthesia and before surgery has started. (**b**) Shortly after insufflation of carbon dioxide and creation of a pneumoperitoneum

cause of the cardiovascular instability. If the patient continues to deteriorate despite these measures, they are likely to proceed towards cardiac arrest.

There are several potential causes of cardiovascular collapse during laparoscopic surgery. One is excessive gas insufflation and impairment of venous return, particularly if the patient is hypovolemic and has not been fluid loaded before the pneumoperitoneum. The child's condition should resolve on release of pneumoperitoneum if this was the cause. If so, the pneumoperitoneum could be cautiously reapplied with low inflation pressures (less than 12 mmHg or 1.6 kPa. If the problem persists, consideration should be given to completing the procedure open.

Another possible cause is vagal response from stretching of the peritoneum, but this would likely result in bradycardia associated with cardiovascular instability.

Undiagnosed cardiac defects should always be considered in children, especially if the clinical condition is not improving, or if large volumes of fluid are making it worse. Although unlikely in an otherwise healthy child, acute cardiac failure from an undiagnosed cardiac condition can occur under the physiological stresses of pneumoperitoneum. An echocardiogram or other cardiac investigations could be considered if the diagnosis has not become apparent.

An anaphylactic cause should also be considered. There may be other signs such as rashes and lip or facial swelling, but these are not always present. The initial management is the same as described above, including a fluid bolus, with the addition of IV or IM adrenaline (epinephrine). The dose is based on the severity of the collapse and the speed of its progression (see Chap. 7, Sect. 7.9). Intravenous adrenaline is potent and is best used in a very low dose initially until establishing how the patient will respond. In practice, adrenaline will also need dilution before being given. It is important be clear in your mind how to do this dilution, as it will likely be done under time pressure and stress, and a ten times dose error could have catastrophic consequences. A technique to dilute adrenaline is to take 1 mL of 1 in 10,000 adrenaline (100 μg/mL) and add 9 mL of normal saline to it in a 10 mL syringe. This now creates a concentration of 10 μg/mL. For infants, diluting again by a factor of 10 to create 1 μg/mL is often advised. IV adrenaline has a short half-life and repeat doses may be required. An infusion could be started if there is an ongoing requirement.

Another potential cause of this cardiovascular collapse is gas embolism from carbon dioxide used for insufflation of the pneumoperitoneum. This is another reason for stopping insufflation if is associated with any change in the child's condition. Gas embolism occurs because the trocar is in an abdominal vein. If possible, the suspected entry site of the gas embolism is flooded with saline, and the patient placed head down. Accessing the heart via the right internal jugular vein to aspirate intracardiac gas can be considered, but is unlikely to remove a significant amount of gas. If gas embolism has been caused by this mechanism there is likely to be significant acute hemorrhage from the associated vascular injury.

Insertion of the trocar and port into the abdomen can also damage a major vascular structure such as the inferior vena cava or the aorta or iliac vessels. There may be blood coming up the port, or blood visible on the laparoscopic camera but it can be concealed and not immediately obvious. If concealed or contained in the retroperitoneal space, the abdomen will continue to distend despite deflating the pneumoperitoneum. An acute, major hemorrhage from these vessels will create a large, ongoing crisis. The abdomen will need to be opened to identify and stop the source of bleeding and to stop it. The role of the anesthetic team is to maintain the patient's circulating volume and promote coagulation. This will require multiple team members and support, as this is likely to be an ongoing crisis. Activation of the hospital's critical bleeding pathway will facilitate the rapid supply of blood products.

When it becomes apparent this is the cause of the child's cardiovascular collapse, several crisis resource management principles become important in managing this scenario:

8.1.1.1 Calling for Help

This should be done early and result in many people to assist you, especially in the initial stages.

8.1.1.2 Leadership and Follower-Ship

Establish a leader or leadership group to assign roles and manage the clinical situation as it evolves. Ideally this person or persons should not be distracted by having to do any tasks during this crisis, although this is not always possible in reality.

8.1.1.3 Communication and the Ability to Communicate

Communication is vital, but the ability to communicate is usually the problem. Too many people, too much noise and excitement can stop vital parts of the process being communicated. This is not an easy problem to solve. Options are:

- Asking people to only communicate important information and to be quiet at other times
- Politely asking people who have no particular role to leave the theatre
- Establish an approach to major hemorrhage scenarios based on action cards. This prevents the need for loud, time consuming role allocation as each individual's role is on the card; it speeds role allocation, and helps those without a role card to leave the theatre.
- Have regular pause and discuss moments. At an appropriate moment silence the theatre and summarize where things are up to. This helps to bring some control and calm to the room and reduces noise; it gets everyone up to date on the clinical situation, and it invites useful suggestions from the room to the leadership group.

8.1.1.4 Use of Cognitive Aids

Bring out the massive transfusion protocol and assign someone to work their way through it. The chances of the leader or leadership group remembering everything on the protocol under pressure is unlikely. This frees up the cognitive load of the leadership group to concentrate on other things.

8.1.1.5 Role Allocation

Several roles are needed, and these roles will include people assigned to:

- A, B, D—Airway, Breathing and 'D' anesthesia (This can all usually be done by one experienced person).
- The patient essentially has a circulation issue but an airway, adequate ventilation and keeping the patient asleep still need to occur. Ketamine with or without midazolam may be appropriate. Muscle relaxation to facilitate ventilation and surgery is important.
- C—Almost all the other team members will be focused on supporting circulation.
- This will involve personnel assigned to insert lines for transfusion, monitoring and administration of vasoactive agents as well as preparing giving sets and monitoring equipment. The equipment required would include large bore IV catheters,

an arterial line and central venous access. Team members could remind each other to gain IV access in the upper limbs when the IVC in the abdomen is damaged, or blood products and medications will extravasate into the peritoneal cavity.

A team should be assigned to ordering checking and giving blood products as well as medications useful for maintaining circulating volume, such as inotropes and calcium. Other members of the team could be assigned to keeping the patient warm, organizing cell salvage, running blood tests or ROTEM studies and communicating with the laboratory.

8.1.1.6 Right People, Right Roles

Make sure you get the best available people in the right roles. For example, assigning someone skilled in the insertion of difficult pediatric lines in that role is a good option.

8.1.2 Summary for Management of Major Hemorrhage in the Pediatric Patient

- Get help early as this is a protracted crisis and many skilled hands will be needed
- Establish a leader or leadership group to manage the evolving crisis
- Help effective communication in the theatre by using the methods described above
- Assign roles either verbally or by an action card method to speed up vital parts of the massive transfusion protocol making sure they are the best available people for those roles.
- Use cognitive aids to free up the cognitive load for the leader or leadership group.

8.2 Primary Tonsillar Hemorrhage in a 5-Year-Old Child

You have been called by the ENT surgeon who needs to take a child to theatre to control post-tonsillectomy bleeding. The child is a 5-year-old girl who had an adenotonsillectomy for OSA 6 h ago and is now on the post op ward. The ward nurse has reported the girl is distressed, sitting up spitting out teaspoon quantities of blood and crying when anyone goes near her. The surgeon is returning to the hospital and wants to take her back to theatre. She has iv fluids running. She has drunk a chocolate milk shake and eaten some ice-cream about 2 h ago. The child's previous anesthetic was uneventful with the airway managed using an LMA. She is otherwise fit and well and there is no family history of anesthetic issues.

You arrive and she has already been transferred back to the theatre holding area. She will not let anyone near her and is sitting up spitting out large quantities of blood into a bowl. She is pale, sweaty and looks distressed. Her mother is with her and is very worried.

Her heart rate is 155 bpm and oxygen saturation is 96% in air.
What will you do?

8.2.1 Discussion

Most children with post-tonsillectomy bleeding have only small bleeding point, and blood in the airway isn't a major problem. Some children however have a major bleeding point, and blood quickly fills the mouth after induction and blocks the view of the glottic opening.

8.2.1.1 Preparation

There are a number of issues here to plan for.

- You have to go to theatre, essentially straight away
- Acute bleeding in the airway in an unfasted child, and the bleeding may fill the mouth and obscure the glottis opening during laryngoscopy
- The level of bleeding at this age is difficult to assess as she may be swallowing blood, but it is potentially significant and might even require transfusion.
- Distressed patient not letting people near her and distressed mother
- Possible hypovolemia

Despite the urgency of the situation, a discussion is needed with the theatre team about the plan for the child, particularly the anesthetic induction plan. A rapid sequence induction with cricoid pressure would be the preferred technique, but there are several concerns around induction:

- Inability to pre-oxygenate the child due to their distress
- The child won't lie flat
- Possibility of a 'can't intubate can't oxygenate' scenario
- High aspiration risk

The first step is a conversation with the whole theatre team about a plan for securing the airway. If intubation is not possible, it is likely face mask ventilation won't be possible due to the volume of blood in the airway. The difficult airway algorithm should be discussed with the team in case it is required, with the final step being front of neck access (FONA) by the surgeon. Although this step is unlikely to be required, having the discussion before the case gets the team's mind focused it could occur, and to prepare for it. On most occasions when FONA should have happened but has not been attempted, the team has been unable to shift their mindset in that direction as the crisis evolved.

The major failure in non-technical skills in the can't intubate, can't oxygenate scenario is fixation error and not being able to move forward through the algorithm.

A robust discussion about the plan will help the lead anesthetist should this scenario occur. The person attempting to secure the airway is almost always the most fixated person, and empowering others to help that person move forward is a vital part of crisis resource management.

Keypoint
Don't underestimate the calming effect on your theatre team achieved by a discussion about a plan for when things don't go as planned. You may feel stressed, but they are probably feeling more stressed. The more stress you can remove from the team environment the better they are likely to perform.

8.2.1.2 Induction

Attempting pre-oxygenation is important and will buy you vital time in these circumstances. If the child patient refuses to accept the mask, a small dose of fentanyl or propofol for anxiolysis might help—the child can still sit upright and the dose should not be large enough to cause apnea. Without preoxygenation, the child is likely to desaturate almost immediately after induction.

A fluid load of 10 mL/kg of isotonic crystalloid and a co-induction technique to reduce the dose of propofol would be reasonable, because it is possible the child is hypovolemic. Inducing the child on the side is a possible option, but laryngoscopy may be made more difficult with this unfamiliar position for intubation.

The key part of the difficult airway algorithm that may be overlooked in acute tonsillar bleeds is the use of the laryngeal mask. If intubation is not possible with two attempts, as much blood as possible can be suctioned from the airway and an appropriately sized flexible (reinforced) LMA inserted while maintaining cricoid pressure. The LMA will sit distal to the bleeding point and should maintain the airway. The surgeon can then insert the mouth gag and control the bleeding, and then the LMA can be changed to an ETT to complete surgery. The LMA retrieves the airway, and although there is a risk of aspiration, and some blood will inevitably enter the airway, a small volume of blood is not terribly harmful to the lungs and retrieving the airway is more important.

Although focusing attention on the airway is appropriate, it must not be at the exclusion of attention to the cardiovascular status of the child. Assigning a separate, experienced anesthetist to manage this is useful, but if not available the case should not be delayed.

A fluid load of 10 mL/kg of isotonic crystalloid and a co-induction technique to reduce the dose of propofol would be reasonable, and if the bleed is large enough, use of vasoconstrictors and potentially transfusion. There may not have been time to arrange a blood typing sample before theatre. It could be collected and urgently sent after induction if the bleed seems large enough to warrant transfusion. If bleeding hypovolemia are life-threatening, uncross matched O negative blood can be transfused. The practicalities of obtaining this blood could be discussed with the team before the case. Although blood loss may look quite dramatic in post-tonsillectomy

bleeds, transfusion is not often required. A calm appraisal of the child's clinical state and laboratory or point-of-care tests by the team will guide decision making. Mild post-operative anemia is often acceptable, particularly if bleeding has stopped and the child is otherwise well.

8.2.2 Summary of Management of a Large Post-tonsillectomy Bleed

- Prepare the whole theatre team for the possibility of a 'can't intubate, can't oxygenate' scenario, including FONA.
- If necessary use a flexible LMA while the surgeon controls bleeding, and change to an ETT to finish the procedure
- Make sure the anesthetic assistant knows about the possible use of a flexible LMA—they can suggest this if you have become fixated on intubation
- Do not lose focus on the cardiovascular status of the patient particularly during induction and assign others to manage this if available.

8.3 Loss of the Airway During a Routine Tonsillectomy

A 4 year old is undergoing adenotonsillectomy for obstructive sleep apnea. The child is generally well, but had an upper respiratory tract infection 2 weeks ago. Surgery is progressing—the adenoids have been removed and removal of the first tonsil has begun. Anesthesia is maintained with 1.2% sevoflurane in 66% nitrous oxide. The child has a size 2 flexible LMA in place and spontaneous ventilation is being assisted with pressure support ventilation at a pressure of 10 cmH_2O.

The case has been proceeding uneventfully, but now the capnogram has disappeared. Oxygen saturation is normal (Fig. 8.2).

What will you do?

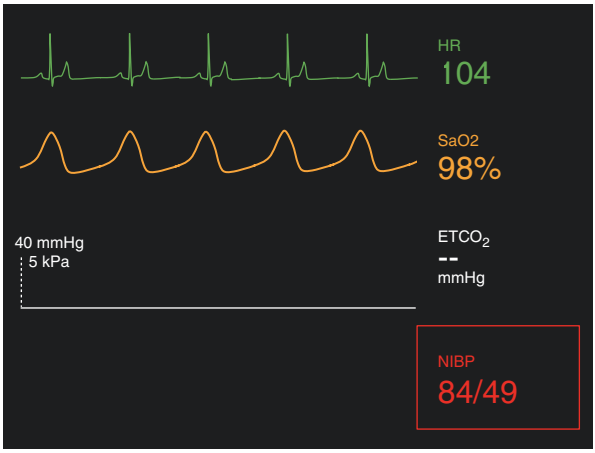

Fig. 8.2 Absent $ETCO_2$ waveform during anesthesia

8.3.1 Discussion

This could be a mechanical problem related to the LMA—it might have shifted or been compressed by the mouth gag used during tonsillectomy. Airway obstruction like this can occur with the LMA and is a reason some anesthetists prefer to intubate children having tonsillectomy. Other circuit problems are unlikely to arise midway through the case, although a rebreathing filter can become blocked with blood or regurgitated stomach contents and would stop ventilation—a quick look at the filter will eliminate this cause. Bronchospasm is a possibility, but suddenly losing all ventilation seems unlikely.

This child is at risk of laryngospasm—there's been a recent URTI and anesthesia is fairly 'light' with 1.2% sevoflurane in nitrous oxide. An LMA is a common and acceptable anesthesia technique for tonsillectomy, but it doesn't stop laryngospasm from happening, and mechanical obstruction is more likely with an LMA than an ETT.

The first step is to change to manual ventilation and decide if a pressure can be generated in the circuit and so exclude disconnections or leaks. Let's assume a pressure can be generated, but the bag is 'tight' and difficult to squeeze, suggesting an obstruction or poor lung compliance. It would be best now to change to 100% oxygen while continuing to deal with the situation. There's some urgency now because although the saturation is normal, there's no ventilation.

This finding suggests either a mechanical problem—the LMA could be obstructed by the mouth gag (either the lumen of the shaft occluded or the blade of the gag forcing the LMA against the larynx) or it could be rotated or shifted. Alternatively, there could be laryngeal spasm.

With ventilation feeling tight and no $ETCO_2$ trace, it is best to simultaneously diagnose and treat. A bolus of propofol 2–3 mg/kg is given while asking the surgeon to stop operating and release the mouth gag to see if this solves the problem. If it does, the bolus of propofol will deepen anesthesia and cause apnea, which isn't a problem. If releasing the gag doesn't help, laryngospasm is now more likely, although a mechanical problem is still possible.

8.3.2 Further Information

While you have been doing these things, the child's condition has worsened because there's been no ventilation, and now the child is hypoxic (Fig. 8.3).

What will you do now?

This is an urgent situation and a decision has to be made about the likely cause. There may be some clues the problem is mechanical— the LMA doesn't look like it's sitting correctly, or looks like it has flipped over. The surgeon will have the LMA on view and may help. Laryngospasm can't be excluded, and even if the initial problem was mechanical obstruction, this might have contributed to lightening of anesthesia and laryngospasm. Lack of response to the earlier propofol bolus does not exclude laryngospasm.

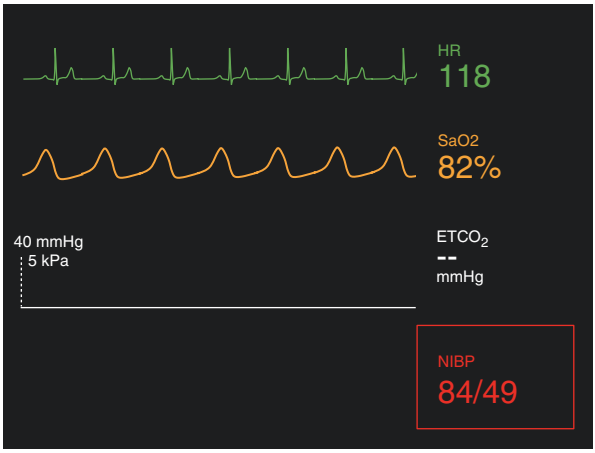

Fig. 8.3 Hypoxia and absent $ETCO_2$ waveform during anesthesia

Unless there's an obvious mechanical problem with the LMA, it would be reasonable to assume this has been caused by laryngospasm and begin appropriate management. Other possibilities can be considered concurrently or if there is not rapid resolution. There is hypoxia and the saturations will become very low, very quickly now that the child is on the steep part of the oxygen-hemoglobin dissociation curve. It's too late for propofol to treat this laryngospasm.

The next step in this scenario is IV suxamethonium 1–2 mg/kg. Although a smaller dose may be effective (the aim is to relax the vocal cords, not provide ideal intubating conditions) there may then be doubt about whether enough has been given if the saturations are still not rising. By giving a larger dose of suxamethonium, this doubt is removed and the duration of paralysis is still only a few minutes. There is no bradycardia and atropine does not need to be given with the suxamethonium.

Note
If the child is hypoxic from laryngospasm, it is too late to try a bolus of propofol.

After giving suxamethonium 1–2 mg/kg, concentrate on watching the chest for expansion. Make sure that the chest is rising and falling and that the tidal volume is adequate. The saturation may stay low for a short while, but the displayed reading is averaged over the last 12–15 s and will not record the higher saturation immediately.

After the saturations have improved, some lung recruitment breaths are given, anesthesia deepened and surgery restarted. Other options depend on the stage of surgery—the LMA probably can't be removed because blood from the surgical

dissection of the tonsil will enter the trachea. Although the LMA could be changed for an ETT, this probably isn't necessary if anesthesia is deepened for the rest of the case (especially with propofol which suppresses laryngeal reflexes more than sevoflurane). Changing to an ETT might result in soiling of the airway with blood during intubation, and might require further paralysis to facilitate it.

Although there are concerns about the possible side effects of suxamethonium as discussed in Chap. 2 Sect. 9.3, the risks from suxamethonium are rare compared to the risks from severe hypoxia in this situation. If this scenario is not managed well, the child will become severely hypoxic and close to cardiac arrest.

8.3.3 Summary of Management of Lost Ventilation During Pediatric Tonsillectomy

- Manual ventilation with 100% oxygen, assessing compliance and leaks
- Ask surgeon to release mouth gag
- Bolus of propofol 2–3 mg/kg
- Consider LMA malposition, bronchospasm, circuit or filter problem, laryngospasm
- If no other cause apparent, assume laryngospasm and give suxamethonium 1–2 mg/kg as soon as SaO_2 falls
- Lung recruitment breaths as SaO_2 improves
- Deepen anesthesia, continue surgery

8.4 Severe Asthma in the Emergency Department

You are called to the emergency department to assist with the management of an 8 year old with asthma who is in respiratory failure. The child has received appropriate treatment for severe bronchospasm but has not improved and is now exhausted and obtunded. The Emergency Department registrar intubates the child, and 45 s later the monitor appears as in Fig. 8.4.

What will you do?

8.4.1 Discussion

The monitor suggests the ETT is in the trachea, but the child is still hypoxic.

The most likely causes (assuming the oximeter reading is accurate) are:

- ETT malposition or obstruction
- Ongoing bronchospasm and dynamic hyperinflation, with suboptimal ventilation strategy)
- Inadequate ventilation-perfusion matching (relative hypovolemia or excessive dose of induction drug)

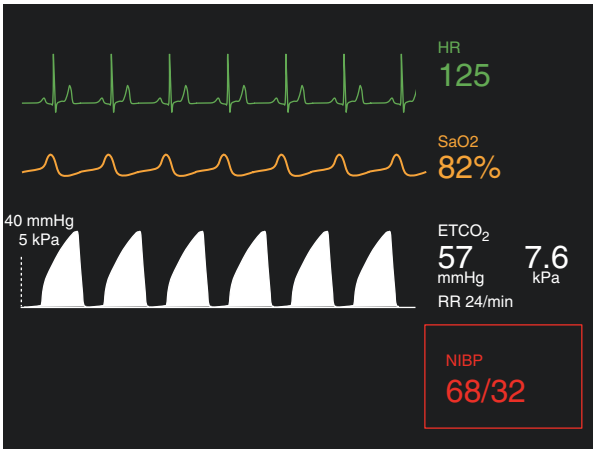

Fig. 8.4 Screenshot during monitoring of intubated 8 year old child with asthma

Table 8.1 Optimal ventilator setting for child with acute severe asthma

Ventilator settings
FiO_2 1.0
PEEP 0–5 cmH_2O
Volume controlled, tidal volume 6 mL/kg
Rate 10/min, short inspiratory time and I:E ratio > 1:4
High inspiratory flow rate (80–100 L/min) so peak airway pressure is high but plateau pressure is low (decreased risk barotrauma)
Permissive hypercapnia (requiring sedation and paralysis while ventilated)

- Tension pneumothorax
- Anaphylaxis
- Inappropriate inspired oxygen concentration

The first step is to ventilate the child with 100% oxygen and assess lung compliance whilst auscultating the chest. Several other steps would then follow:

- Confirm muscle relaxation (residual tone may affect compliance if the child has a high $ETCO_2$ and attempting to breathe spontaneously)
- Confirm the ETT position with direct laryngoscopy
- Gently 'sound' the ETT with a suction catheter or bougie to exclude obstruction
- Connect to a ventilator, auscultate chest, optimize ventilator settings (Table 8.1)
- Clinically assess for pneumothorax or anaphylaxis
- IV fluids and blood pressure support, continue bronchospasm treatment
- Arrange chest X-ray to exclude complications and confirm ETT position whilst optimizing sedation and considering invasive arterial BP monitoring

8.4.2 Further Information

You diagnose endobronchial intubation, withdraw the ETT, and the child's condition improves. Perhaps this occurred due to the inexperience of the Emergency Department registrar and the stress of the clinical situation. If this was missed for a longer time, it would likely cause rapid progression to dynamic hyperinflation, hypotension and progressive hypoxemia. If the unilateral air entry was incorrectly managed as a tension pneumothorax, then there could have been a fatal iatrogenic outcome.

There are several strategies to facilitate a safe intubation and prevent complications. These include:

- Anticipating and discussing potential complications with the team present before intubation
- Preloading the child's circulation with IV fluid to reduce the risk of hypotension
- Planning appropriate induction drugs and doses, ETT size and expected depth and ventilation after intubation
- Trouble-shooting considerations

8.4.3 Summary of Management

Ideally an early request for help with the management would enable a team discussion before intubation and a decision about which member will be responsible for airway management in this child who would have been hypoxic before induction and likely to have become more hypoxic quickly during intubation. All efforts should be made to avoid ventilation, as it is carries significant risks of hemodynamic changes at induction and then complications from positive pressure ventilation. Adrenaline (epinephrine) is a potent bronchodilator, and a low dose at this time of crisis may be life-saving by granting extra time to prepare for emergency airway management. Hypotension occurs predictably at induction, and fluid loading is needed before induction with ketamine.

8.5 A Toddler in PACU with Stridor

An 18 month old child is awake in the PACU after surgery to repair a dog bite to the face. The child was previously well, and during the 70 min of surgery, was intubated with 4.0 cuffed oral (south facing) RAE tube. The ETT was removed with the child awake about 10 min earlier. The child now has a high pitched inspiratory noise, and tracheal tug. The attached monitor is alarming (Fig. 8.5). What will you do?

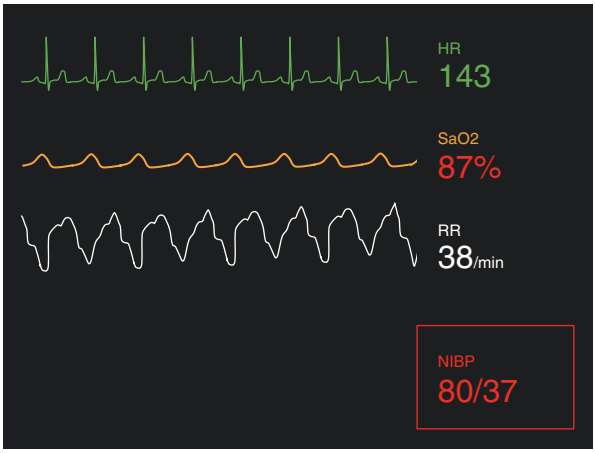

Fig. 8.5 Monitor screenshot of child with stridor in PACU

8.5.1 Discussion

This child has stridor after having been intubated. An assessment of the degree of upper airway obstruction helps make a diagnosis, judge the severity of the obstruction and the type of treatment needed.

The most likely causes are:

- Soft tissue obstruction at the level of the tongue or supraglottic area
- Retained blood, surgical pack, mucus or vomit in the upper airway
- Laryngospasm or glottic pathology
- Subglottic inflammation and edema from the ETT.
- Residual muscle relaxation
- Anaphylaxis

The upper airway obstruction is significant because the child is hypoxic along with the signs of obstruction. The management depends on the likely cause and may include:

- High flow oxygen by mask. Gently assisting inspiration (CPAP) if tolerated by the child
- Considering the need for reversal of neuromuscular blocker
- Nasal or oral airway if supraglottic obstruction if able to tolerate
- Giving propofol and performing suctioning and laryngoscopy to examine the airway for foreign bodies
- Nebulized adrenaline (epinephrine)
- IV steroids
- Considering reintubation with smaller-sized ETT if refractive to treatment

High-flow nasal oxygen could also be considered if available within a safe period of time. A helium-oxygen mixture (Heliox®) is only a temporizing measure, restricts the inspired oxygen concentration to 40%, is time consuming to set-up and has limited evidence to support its use. If this child is awake, and a retained surgical throat pack is not the cause, then the stridor is most likely caused by intubation and edema of the subglottic region.

This child is hypoxic and should be given oxygen if not already receiving it. Because of the signs of upper airway obstruction and significant hypoxia and, nebulized adrenaline (epinephrine) should be given, as a fast onset of action is needed for this child. Either the IV preparation of 1:1000 can be used, or the more concentrated nebulizer solution (1:100) (Chap. 1, Sect. 1.9.2). Sometimes, children have milder stridor, without signs of upper airway obstruction or hypoxia. Nebulized adrenaline (epinephrine) could be used, but an alternative is IV dexamethasone 0.6 mg/kg (up to 12 mg). The onset of this is adequate in this non-emergent clinical setting—within 20 or 30 min based on work using oral prednisolone for treatment of croup in the Emergency Department (Chap. 1, Sect. 1.9.2).

8.5.1.1 Could Post-extubation Stridor Have Been Prevented in This Child?

There was always a chance the 4.0 ID cuffed ETT used for this child would be too large. The formulae for ETT size are for children 2 years and older. A child this age needs a 3.5 ID cuffed ETT. A Microcuff brand has a smaller outside diameter, and the 4.0 cuffed size of that brand might have been appropriate (see Chap. 4, Table 4.9). If an uncuffed ETT was used, then a size 4.0 ID would have been appropriate as first choice, changed to 4.5 ID if there was an excessive leak. There is some judgement in selecting the ETT size for any individual child, no matter whether the ETT is cuffed or uncuffed—some children are larger than average, some smaller, and sometimes when their age is used in a formula, the result is an in-between size. When the ETT is passed through the glottis, an assessment is made whether the tube is tight. Sometimes the tube passes through the cords easily, but resistance can be felt beyond, at the level of the cricoid ring. If this resistance is more than slight, then the tube should not be passed, and the next size smaller used instead. Other important strategies are:

- Monitor cuff pressure and keep below 20 cmH_2O, especially during prolonged intubation
- Consider possible effects of pre-existing airway pathology that might narrow the subglottic region (Trisomy 21, recent tonsillectomy, recent intubation, recent URTI)
- Avoid airway trauma from multiple intubation attempts or self-extubation

8.5.2 Summary

Post-extubation stridor is uncommon, but can be a serious sign of upper airway obstruction in the PACU—perhaps the frequent use of dexamethasone for PONV prophylaxis has reduced the incidence. Careful thought is required in selecting ETT sizes in children, especially smaller ones, and the anesthetist needs a gentle technique during intubation to assess the suitability of the size of the ETT chosen.

Acute Pain Management in Children

9

Priya Thalayasingam and Dana Weber

The International Association for the Study of Pain defines pain as 'an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage'. However, the inability to communicate does not negate the possibility an individual is experiencing pain. The safe and effective management of pain in children includes the prevention, recognition and assessment of pain, the early and individualized treatment of pain and the evaluation of the effectiveness of treatment. This goal is the responsibility of all health care providers caring for children. This chapter describes the assessment of pain in children, and the management options available. Regional analgesia is also appropriate for children and is covered in Chap. 10.

9.1 Pain Assessment

Children's pain may be difficult to recognize and to measure reliably. Many pain assessment tools (PAT) have been developed to measure 'pain scores' (Table 9.1). These tools must be age and developmentally appropriate because children's understanding and ability to describe pain will change as they grow older. Additionally, the tools should be sensitive, specific and validated. There are three types of tools used for assessment of pain in children:

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Table 9.1 Examples of pain assessment tools (PAT) validated in children

Assessment tool	Age range	Assessment	Notes/limitations
Premature Infant Pain Profile (PIPP)	<33 weeks	Gestational age, behavioral state, HR, oxygen saturation, brow bulge, eye squeeze, nasolabial furrow	For procedural and postoperative pain
Neonatal Pain Assessment Tool	>33 weeks	Behavioral indicators: posture, tone, sleep pattern, facial expression, color, cry Physiological indicators: respiratory rate, HR, oxygen saturation, BP	Behavioral and physiological PAT and observation
The Faces, Legs, Activity, Cry and Consolability (FLACC) scale	0–7 years	Facial expression, leg position, activity, cry, consolability	Behavioral PAT May be adapted for cognitively impaired children
The Revised Faces Pain Scale	4–12 years	Six faces with the first face scoring 0/10 and the last scoring 10/10 pain	Self-report PAT
Visual Analogue Scale (VAS)	7–8 years to adult	A line expressing an increasing continuum of pain	Self-report PAT
Numerical Rating Scale (NRS)	7–8 years to adult	0/10 = no pain 10/10 = worst pain	Self-report PAT

1. Self-report: The preferred approach, which can be used in children older than 3–4 years who are not cognitively impaired.
2. Observational or behavioral: An objective assessment by the carer or parent of signs of distress caused by pain.
3. Physiological: measures physiological parameters of the pain arousal response. It is best combined with a behavioral assessment of pain. The measured parameters can be confounded by underlying illness (e.g. sepsis causing tachycardia) and have wide inter-individual variability

Of the available tools, the revised faces scale is commonly used for school aged children, whereas the FLACC scale is commonly used for preschool aged and cognitively impaired children. Although these are generally used, different institutions may have their own preferred tools. Pain scores form only one component of pain assessment. Holistic pain assessment accounts for factors influencing a child's perception of pain, which contribute to different pain experiences in different children undergoing the same procedure (Table 9.2).

Keypoint
Pain assessment appropriate to the child's age needs to be performed regularly so pain is treated early and effectively. Because pain is dynamic, regular pain assessments provide a trend for the patient's progress.

Table 9.2 Factors influencing a child's perception of pain

Physiological factors—site or severity of surgery
Psychological and cognitive factors— age, gender and maturity
Behavioral factors—child's coping style and parental response
Socio-cultural beliefs
Past health and hospitalization experiences

9.2 Management Strategies

Anesthetists most often encounter children with acute pain related to surgery, medical conditions, cancer or trauma. Acute pain management includes a combination of pharmacological and non-pharmacological strategies.

9.2.1 Non-pharmacological Strategies

These strategies are techniques used to supplement analgesic drugs and are especially useful for procedural pain. They can be as simple as comforting an injured child, while others include physical methods such as massage, heat therapy and transcutaneous electrical nerve stimulation (TENS). The most important psychological technique is distraction with toys or electronic games and devices, while others include breathing techniques, imagery, play therapy and hypnosis. These techniques need to be appropriate to the child's development, personality and circumstances, and ideally should be familiar to the child before they are used.

9.2.2 Pharmacological Strategies

Drug treatment is modelled on the 3-step analgesic ladder, starting with simple oral analgesia and progressing to opioid and regional analgesia if required. As in adults, simple analgesics reduce opioid use and side effects. Systemic analgesia is usually given by the oral or IV routes, but rectal, transdermal, intranasal, transmucosal or inhalational routes are alternatives. Intramuscular injections are avoided in children because of pain and erratic drug absorption.

Postoperative pain relief and side effects should be discussed preoperatively with the parents, child (if plausible) and surgeon. It should be safe, efficacious, titratable and appropriate for the surgery and patient age (for example, an ilio-inguinal block may be preferable to a caudal in an ambulating 5 year old for inguinal hernia repair). Regional techniques are useful but an alternative plan is needed if they fail, and parental education about analgesia when the block wears off is important.

Children's analgesic needs fluctuate during the day—more analgesia is required whilst mobilizing, participating in physiotherapy or undergoing therapeutic

procedures such as dressing changes. Thus, effective analgesic regimens need background analgesia and a pro-active plan for managing break-through pain, especially in preverbal or cognitively impaired children.

9.3 Analgesic Agents

9.3.1 Paracetamol

Paracetamol has a central analgesic effect mediated through activation of descending serotonergic pathways. The analgesic and antipyretic plasma concentration in children is the same as adults and is 10 mg/mL. Higher plasma concentrations only modestly increase efficacy but increase the risk of hepatotoxicity.

9.3.1.1 Metabolism

Paracetamol undergoes glucuronidation and to a lesser extent, sulfation, in the liver. In neonates, sulfation is the main mechanism. Clearance increases with post menstrual age, but in a term neonate it is still only about a third that of an older child (Fig. 9.1). Unconjugated hyperbilirubinemia is a crude measure of hepatic conjugating ability and is a reason to reduce the dosage of paracetamol.

Keypoint
Children taking maximal doses of paracetamol for several days are at risk of hepatotoxicity. The risk is even higher if they are malnourished or dehydrated.

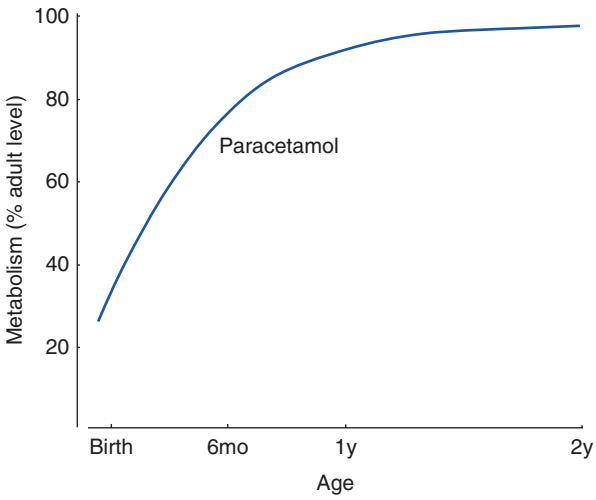

Fig. 9.1 Schematic representation of metabolism of paracetamol with age. Metabolism of paracetamol in neonates is only 30–40% of the adult level, but reaches nearly 80% by 6 months of age as the enzymes responsible for glucuronidation mature. Modified from Anderson and Holford, Pediatr Anesth 2018

9.3.1.2 Oral Administration

Paracetamol is most often given orally. Absorption is rapid in children, though slower in neonates. Oral paracetamol undergoes 10–40% first pass elimination. Plasma concentration is maximal 30–60 min after oral administration, but the brain concentration rises slowly. Maximum analgesia develops up to 2 h after administration. Doses at various ages are shown in Table 9.3. The manufacturer's dose of 60 mg/kg/day in children is often replaced by a dose of 90 mg/kg/day for the first 48 h, either by using a larger loading dose or using 20 mg/kg 6 hourly.

9.3.1.3 Intravenous Administration

IV paracetamol is more effective than oral paracetamol because there is no first pass metabolism or delay in absorption. The dose in children is 15 mg/kg infused over 15 min. The dose is reduced in neonates and is adjusted in obese children based on their ideal body weight (Table 9.4).

9.3.1.4 Rectal Administration

Rectal administration has slow and variable absorption, with typical doses failing to give a therapeutic plasma level. The smallest suppository commercially available is 125 mg, but cannot be cut to reduce the dose because the paracetamol may not be evenly distributed through it. IV paracetamol is preferable in clinical practice.

Table 9.3 ORAL paracetamol dose in neonates and children

Age	Oral dose (mg/kg)	Interval (h)	Maximum daily dose (mg/kg)	Maximum duration at maximum dose (h)
28–32 weeks PMA	10–15	8–12	30	48
32–52 weeks PMA	10–15	6–8	60	48
3–6 months	15	6	90[a]	48
>6 months	15	6	90[a]	48

Some suggest a loading dose of 20 mg/kg in children older than 32 weeks. Dose adjustment is required in overweight and obese patients. Paracetamol dose must be reviewed every 48 h; beware of risk factors for paracetamol toxicity. If treatment >1 week, use minimum dosing interval of 6 h, and consider lowering maximum daily dose and monitoring LFT's. *PMA* Post menstrual age
[a]Maximum 4 g in 24 h for 48 h. After 48 h reduce dose to 60 mg/kg/24 h

Table 9.4 INTRAVENOUS paracetamol dose in neonates and children

Age	Maintenance dose	Maximum daily dose (mg/kg per day)
32–40 weeks PMA	7.5 mg/kg 8 hourly	30
40–44 weeks PMA	10 mg/kg 6 hourly	40
44 weeks PMA–18 years	15 mg/kg (up to 1 g) 6 hourly	60

9.3.1.5 Toxicity of Paracetamol

A small amount of paracetamol is oxidized by the cytochrome P450 CYP2E1 enzymes to the reactive metabolite NAPQI. This metabolite binds to glutathione and is excreted. As sulfation and glucuronidation pathways become saturated, more paracetamol is shunted into the oxidative NAPQI pathway. However, once glutathione stores are depleted, hepatotoxicity develops from unbound NAPQI. Neonates have reduced P450 oxidation, but they can still form the reactive metabolite. This reduced oxidation paired with increased glutathione synthesis protects them from hepatotoxicity and gives paracetamol a high therapeutic ratio in neonates. The effect of liver disease on paracetamol metabolism is variable and difficult to determine in any given patient. Paracetamol may still be used in hepatic impairment, usually as a single dose or smaller, infrequent doses.

Although safe when used alone or in combination with other analgesics, severe or fatal hepatotoxicity can occur with analgesic doses of paracetamol. Children at risk are those who are malnourished, dehydrated, obese (and dosed with actual rather than ideal body weight), or have been receiving maximal doses for several days. Such conditions may exist in children after surgery who are not well hydrated and have been taking regular, maximal dose paracetamol for several days. In these groups of children, the dose must be reduced after a few days, and liver function tests performed regularly. When neonates and infants are given IV paracetamol, the volume of drug is small and they are at high risk of a ten times overdose. Prescribing in both mLs and mGs has been suggested as a way of avoiding overdose. It has also been recommended by the Safe Anesthesia Liaison Group to use 50 mL vials (where available) for children weighing less than 33 kg. The dose of IV paracetamol should be drawn up in a syringe and given, rather than hanging a full bag of paracetamol.

Paracetamol toxicity is treated with IV N-Acetylcysteine (NAC), which restores hepatic glutathione. The nomograms used for the management of paracetamol toxicity refer to oral overdose. The UK National Poisons Information Service advises NAC after a single IV dose of paracetamol larger than 60 mg/kg, and advise against waiting for a serum paracetamol level before NAC is started. If the dose of IV paracetamol is unknown, a level should be taken 4 h after the IV paracetamol dose and NAC started if the plasma paracetamol level is above 50 mg/L.

9.3.2 Non-steroidal Anti-inflammatory Drugs (NSAIDs)

NSAIDs are effective analgesics and antipyretics in children. As in adults, they reduce morphine requirements by approximately 30%. Although many NSAIDs are available for use in adults, few are marketed in a liquid form or in a suppository dose suitable for children. NSAIDs uncommonly exacerbate asthma in children younger than 10 years, and can be used in young asthmatic children unless there has been

past sensitivity. Renal dysfunction is also uncommon in children, although dehydration is a predisposing factor as it is in adults. NSAIDs are not recommended for neonates—they reduce GFR by 20% and may affect cerebral and pulmonary blood flow. Aspirin is rarely used in children because of its association with Reye's syndrome.

Ibuprofen is the most commonly used oral NSAID in children. The dose is 10 mg/kg every 6–8 h in children greater than 3 months old. It is not recommended for children under 3 months of age. It does not need to need to be taken with food in children. Ibuprofen is unlikely to increase the risk of bleeding after tonsillectomy and provides useful analgesia, however its use in this setting is surgeon and institution specific. An intravenous form of Ibuprofen is available and is dosed at 10 mg/kg (max daily dose 40 mg/kg or 2400 mg whichever is less) in children younger than 17 years. It must be diluted before administration and infused over 10 min. It may cause hemolysis if given undiluted and cannot be given intramuscularly.

Diclofenac is available orally, rectally and intravenously. The doses are 0.3 mg/kg IV, 0.5 mg/kg rectally and 1 mg/kg orally, usually 8–12 hourly. It is rapidly and well absorbed from the rectum with peak levels reached faster than either oral or rectal paracetamol. Parecoxib has not been extensively studied in children and is not approved for use in children younger than 16 years. However, its pharmacokinetics in children have been reported, and it is an effective analgesic in children after tonsillectomy.

9.3.3 Opioids

Although many different opioids are used for analgesia in adults, only a few are used in children because few have oral, liquid forms available and because experience with many opioids in children is limited. Neither transcutaneous patches nor opioid agonist-antagonist preparations are made in pediatric doses.

9.3.3.1 Morphine

Morphine is the most widely studied and used opioid in children. It is available in an immediate release elixir (dose 0.2–0.5 mg/kg, 3–4 hourly PRN) or as a controlled-release preparation (MS Contin suspension or tablets). Morphine is the only opioid with a liquid, sustained release preparation suitable for small children who can't swallow tablets. (Controlled-release tablets should never be crushed or chewed, as an unpredictably large dose of morphine is released immediately, resulting in opioid toxicity).

Morphine metabolism is reduced in neonates and infants (Fig. 9.2). Furthermore, a larger proportion of morphine is metabolized to the active metabolite M6G in neonates. These pharmacokinetic differences place neonates at risk of respiratory depression compared to children and adults—the incidence of respiratory depression from opioids is almost ten times more in neonates than

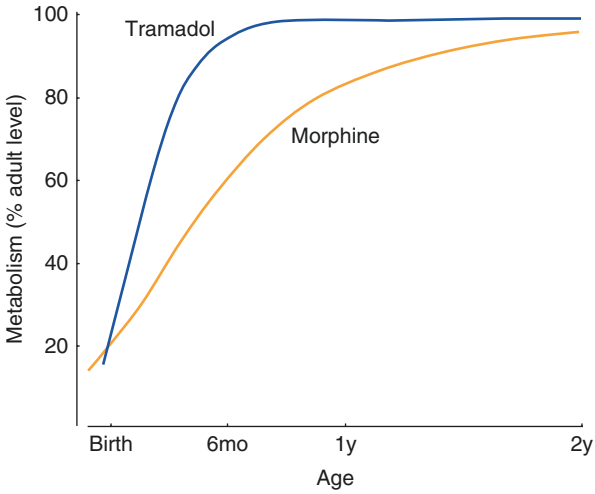

Fig. 9.2 Metabolism of morphine and tramadol in neonates and young children. Tramadol undergoes phase I metabolism by CYP iso-enzymes that mature quickly. Morphine undergoes phase II glucuronidation, which matures more slowly. Modified from Anderson and Holford, Pediatr Anesth 2018

Table 9.5 Typical infusion rates for morphine infusions in children of different ages

Age	Typical infusion rate of morphine (μg/kg/h)
Neonate	5–10
Infant	10–20
Child	10–40

The lower rates in neonates and infants reflect pharmacokinetic differences

adults. Differences in the blood-brain barrier between neonates and children are minor and unlikely to be clinically important. Respiratory depression is the same in neonates and children at equivalent plasma concentrations of morphine, but the plasma concentration is reached in neonates with much smaller doses than in children (Table 9.5).

Keypoint
The CO_2 response curve at any given morphine concentration is the same between the ages 2–570 days, suggesting neonates and infants do not have any pharmacodynamic sensitivity to morphine. Although neonates are 'sensitive' to respiratory depression from opioids, this is because of pharmacokinetic differences.

9.3.3.2 Fentanyl

Fentanyl is also widely used in children. Its relatively rapid onset facilitates dose titration in severe, acute pain compared to morphine, and it causes less pruritus. Fentanyl is very lipophilic and thus can be administered via the intranasal, transmucosal and transdermal routes.

Intranasal Fentanyl

Intranasal fentanyl is an effective analgesic that is non-invasive and needle free, suitable for children older than 1 year for procedural and post traumatic pain. Onset of analgesia is within 2–10 min. It is delivered as a concentrated solution (300 μg/mL) via an atomizer to minimize volume. The dose is 1.5 μg/kg to a maximum of 100 μg, and it may be repeated after 5 min if analgesia is inadequate. The use of a conscious sedation protocol is recommended to monitor children given intranasal fentanyl.

Oral Transmucosal Fentanyl Citrate (OTFC)

OTFC is a flavored fentanyl lozenge that was initially developed for break-through pain management in opioid tolerant adult oncology patients and is not licensed for pediatric use. It is used in some tertiary pediatric centers.

Transdermal Fentanyl ('Fentanyl Patches')

Fentanyl patches should only be used in children who are opioid tolerant, have a stable analgesic requirement and are being cared for in a tertiary pediatric center. They are not suitable to treat postoperative pain, for which oral morphine is preferable because it is titratable and clinically more familiar.

9.3.3.3 Hydromorphone

Hydromorphone is a semi-synthetic derivative of morphine. It has a prolonged duration of action (4–6 h) and half-life (3–4 h). Oral hydromorphone has a bioavailability of 50–60% and more than 90% is converted in the liver to an inactive metabolite. It has less metabolites than morphine and can be used in children with renal insufficiency. It results in lower pain scores and less pruritus compared with morphine. Hydromorphone is now the preferred second line opioid for infusions when the initial opioid provided inadequate analgesia or excessive side effects. It is also becoming the first line opioid in complex pain patients in the tertiary setting.

9.3.3.4 Codeine

Codeine is now rarely used in children. The death of several children who had ultra-rapid metabolism of codeine to morphine prompted European, Australasian and North American agencies to restrict its use. It is now listed as contraindicated in all children having tonsillectomy, and for any reason in children younger than 12 years.

9.3.3.5 Oxycodone

Oxycodone is popular for the treatment of moderate to severe pain and as a step-down from opioid infusions because it has a high bioavailability and a palatable and concentrated syrup formulation that requires only small volume to be ingested. Its bioavailability has less inter-individual variation compared to oral morphine, but it is not licensed for children in many countries. Although it has less affinity for the mu-opioid receptor than morphine, it is actively transported through the blood-brain

barrier so its concentration in the brain is higher than the plasma. For this reason, oxycodone has a greater potency than morphine. Its metabolism to an active metabolite is subject to genetic polymorphism, but the metabolite is not particularly active and differences in its concentration have little clinical effect.

Oral formulations include an immediate release (syrup, tablet or capsule) and a controlled release preparation. Immediate release oxycodone at an oral dose of 0.1–0.2 mg/kg 4–6 hourly PRN may be recommended for the treatment of acute pain. Oxycodone is prescribed at lower doses (0.05–0.1 mg/kg 4–6 hourly PRN) in infants, and is avoided under the age of 3 months due to delayed clearance and greater inter-individual pharmacokinetic variability.

Controlled release tablets are suitable to give background analgesia in older children, but they must not be chewed or crushed due to the potential for dose-dumping and toxicity. They are dosed 12 hourly with up to 40% of the dose being released in the first hour after ingestion. Controlled release preparations may be combined with naloxone in a tablet (Targin), reducing common opioid side effects including constipation and itch. For children who are "stepped" down onto extended release oxycodone formulations it is important to ensure that they are sent home with a strict weaning plan for these medications. An IV form of oxycodone is available, but little used in the pediatric setting because it does not offer an advantage over morphine.

Keypoint
Prescription of post-operative opioids (especially if discharged home) should be based on the previous analgesic requirements of the child and the expected severity and duration of their pain. Opioids should be dispensed only for children expected to have moderate to severe pain. A limited quantity of opioid may be dispensed after a thorough discussion with parents about appropriate use and side effects. A weaning plan and a cease date is recommended.

9.3.3.6 Tramadol

Tramadol is used alone for mild to moderate pain in children and is also useful in the management of neuropathic pain or as an adjunct to stronger opioids. It has a lower incidence of respiratory depression and constipation than other opioids and is valuable in children with respiratory compromise from neuromuscular disease or severe obstructive sleep apnea.

Tramadol is converted to an active metabolite by a CYP iso-enzyme that matures earlier than the enzymes responsible for glucuronidation of morphine (Fig. 9.1). Genetic polymorphism of the iso-enzyme includes an ultra-rapid metabolism form. There have been three deaths and several events in children receiving tramadol, prompting a FDA warning in the United States. Overdosing however, was the likely cause—the oral form of tramadol was intended for palliative care of adults and is extremely concentrated. Because there is no suitable liquid preparation, tramadol is not a first line analgesic agent in young children. Slow release tramadol tablets

1 mg/kg bd are usually well tolerated by adolescents (who can swallow tablets). It provides a background level of pain relief, which may be useful when stepping down from parenteral opioids and to reduce the need for break-through analgesia. Tramadol is not licensed for children younger than 12 years. Its dose in children is 1–2 mg/kg (max 400 mg) 6 hourly PRN up to a maximum daily dose of 8 mg/kg.

9.3.3.7 Buprenorphine

Buprenorphine use has increased in the adult setting due to its low abuse potential, favorable immunological profile and lower risk of diversion. It is not licensed in children, however its use is increasing in the pediatric setting for similar reasons as in adults. It is mainly used for chronic and complex pain, such as cancer, long term opioid use and opioid rotation. Due to its potency, its use in very young patients is limited and there have been case reports of respiratory depression following opioid rotation to even very small morphine-equivalent doses of buprenorphine. As a result, the use of buprenorphine is restricted to tertiary pediatric centers with specialist oversight.

9.3.4 Ketamine

As in adults, ketamine may be used as an adjunct to opioid analgesia. It is useful for children who are opioid tolerant and in pain despite maximal doses of opioids, or who are sensitive to the sedative and respiratory effects of opioids. It may be given intra-operatively (0.5–1 mg/kg) and then as an infusion at 100–240 μg/kg/h. Low doses of ketamine generally do not cause troublesome dysphoria or hallucinations. Ketamine may also be used for procedural analgesia for fracture reduction or burns dressings, with an oral dose of 3–10 mg/kg, or intravenously (0.5–2 mg/kg). Use the lower end of the dose range if combining ketamine with other sedatives. Children receiving ketamine sedation should be appropriately fasted and appropriately monitored.

9.3.5 Adjuvants

9.3.5.1 Alpha 2 Agonists

Clonidine and dexmedetomidine act on alpha 2 receptors pre-synaptically in the brain stem to reduce sympathetic outflow. Dexmedetomidine is more alpha 2 selective than clonidine. Their effects include anxiolysis, analgesia, behavioral modification and hemodynamic modulation. Dexmedetomidine is used in the intensive care setting, neuro and cardiac surgery. Some centers have utilized the intranasal formulation in the radiology suite for sedation in MRI.

Clonidine is widely used in the perioperative setting in children for premedication. Clonidine is used intra- and post- operatively as an adjuvant to analgesia in

regional techniques such as caudal or epidural blocks at doses of 1–2 μg/kg. At this dose, it prolongs caudal analgesia by up to 4 h. Clonidine is also effective in facilitating weaning and prevention of withdrawal in children who have been on long term infusions of opioids, such as the intensive care setting, oncology patients or major burns.

9.3.5.2 Gabapentenoids

Gabapentin and pregabalin are calcium channel neuromodulators and are used as anticonvulsants. In the acute pain setting they are indicated for prevention and treatment of neuropathic pain and anxiolysis. They can cause dizziness, delirium and sedation. They have been shown to reduce overall opioid consumption. However, the results are mixed in preventing post-surgical neuropathic pain and reduction of opioid side effects. Gabapentin is usually commenced at 5 mg/kg daily and titrated up to 5 mg/kg three times a day. It is also an effective premedication at 5 mg/kg. Patients are not usually discharged home on this medication and if so they are followed up to ensure the medication is weaned and ceased.

9.3.5.3 Tricyclic Antidepressants

Amitriptyline and nortriptyline are used for the treatment of neuropathic pain. They act by inhibiting serotonergic and noradrenergic reuptake in the areas of the brain responsible for pain perception and modulation. Caution needs to be exercised as they can result in long QT. They also result in increased appetite, improved sleep when taken before bedtime and improved mood which are all factors that contribute to the pain experience. The usual starting dose is 5 or 10 mg at night. These medications need to be monitored closely and their use outside of a tertiary pediatric setting is limited.

9.3.5.4 Melatonin

Melatonin acts on the M1 and M2 receptors in the anterior hypothalamus and is indicated in primary insomnia with poor sleep quality. Studies on the efficacy of melatonin at 1–2 mg have been performed in patients over the age of 55. As a result, its use is restricted to specialist prescription. It is utilized in chronic pain, palliative care and oncology.

9.4 Practical Use of Analgesics

9.4.1 Management of Analgesia in PACU

Children may be distressed in the PACU (recovery) for a variety of reasons, including anxiety, hunger, emergence delirium and pain. Experienced PACU staff are usually able to differentiate pain from other causes of distress using an age-appropriate PAT and indicators such as posture, type of cry and response to pacifiers. Moderate to severe pain in PACU is best treated with intermittent IV opioid boluses (Table 9.6), with subsequent adjustment to the ward analgesia regimen if required (for example, increasing opioid infusion rate or checking extent of epidural block).

Table 9.6 Suggested dilutions and doses for intermittent IV opioid boluses in PACU

Intermittent PACU opioid bolus protocol		
	Morphine	Fentanyl
Composition	2.5 mg morphine diluted to 5 mL of normal saline	100 μg diluted to 20 mL with normal saline
Concentration	0.5 mg/mL	5 μg/mL
Bolus dose	0.05 mL/kg = 25 μg/kg	0.05 mL/kg = 0.25 μg/kg

Bolus doses can be given at 3–5 min intervals if the child is in pain, provided observations and conscious state are satisfactory. A review of the child's pain is needed if five doses have not been adequate

Table 9.7 Intermittent IV ward morphine bolus protocols

Ward morphine bolus protocol	
Age/weight	Morphine dose
Infant 6–12 months	0.05 mL/kg = 25 μg/kg
Child older than 12 months and weighs under 40 kg	0.05–0.1 mL/kg = 25–50 μg/kg
Child weighs more than 40 kg	2–4 mL = 1–2 mg (2 mg max dose)

The boluses may be administered at 15 min intervals to treat pain providing the conscious state and observations are satisfactory. A review of the child's pain is needed if five doses have not been adequate, as the child may benefit from a continuous infusion

9.4.2 Management of Intravenous Analgesia on the Wards

Intravenous opioids are the preferred route for the management of severe pain. They allow rapid titration for effect and may be administered as intermittent boluses, nurse controlled infusions or patient controlled analgesia (PCA). Intravenous opioid infusions should only be used in hospital ward settings with appropriate staffing, nursing education, patient monitoring and an around-the-clock contact for the Acute Pain service.

9.4.2.1 Intermittent IV Ward Morphine Bolus Protocols

Intermittent IV ward morphine boluses are suitable for children older than 6 months. Indications include the management of severe, short-term pain or as a rescue for children recently weaned off continuous infusions (Table 9.7).

9.4.2.2 Continuous, Nurse-Controlled Opioid Infusions

Continuous intravenous opioid infusions are used in children who cannot use a PCA because of young age, cognitive impairment or physical disability. The baseline rate of the infusion is titrated to the level of pain, with additional nurse-initiated boluses (at intervals of 15 min or more) to cover breakthrough pain. Fentanyl, morphine, hydromorphone and tramadol may be delivered as a continuous infusion after appropriate loading doses have been given. Lower opioid infusion rates are used in children younger than 1 year because of the pharmacokinetic differences compared with older children. Typical infusion rates at this age for morphine are 5–20 μg/kg/h, about half that of older children.

Infusions are made with a dose of opioid varying according to the weight of the child (Table 9.8). This is done so the concentration in the syringe varies with the weight of the child, but the volume administered is similar regardless of age. There are three important reasons for doing this. Firstly, it standardizes volume independent of age and weight. For example, regardless of age, a child receiving a morphine infusion at 2 mL/h with a prescribed bolus of 1 mL, will receive 20 μg/kg/h of morphine by infusion, with a bolus of 10 μg/kg. Staff can see the infusion rate and are able to place that dose into context of the dose range usually given to children. Secondly, varying the concentration with weight avoids the problems of administering tiny volumes for small babies with subsequent issues of pump inaccuracy during delivery such of small volumes, and difficulty in overcoming the dead space of IV lines. Finally, the dilute concentration minimizes complications in the scenario of the IV becoming blocked and the IV-line filling with opioid solution, which is then infused as a bolus when the IV line is unblocked.

To further reduce complications in this last scenario, the opioid infusion is always connected to the IV line as close as possible to the cannula to minimize the amount of opioid that can accumulate in the IV tubing, and an anti-reflux valve is inserted in the IV line to prevent opioid backtracking and accumulating in the tubing if the IV stops running.

Keypoint
The drug concentration in the syringe for opioid infusions varies with the weight of the child. This ensures that independent of weight, children receive a standard dose (μg/kg/h) at prescribed infusion rates. (e.g.: 1 mL/h always equals 10 μg/kg/h of morphine).

Table 9.8 A suggested protocol for intravenous opioid infusions on pediatric wards

Intravenous opioid infusion guidelines			
	Morphine	Fentanyl	Hydromorphone
Dose to add to 50 mL saline	0.5 mg/kg	20 μg/kg	0.1 mg/kg
Concentration of solution relative to weight	10 μg/kg/mL	0.4 μg/kg/mL	2 μg/kg/mL
Loading dose	50–100 μg/kg	0.5–1 μg/kg	10–20 μg/kg
Infusion rate	0–4 mL/h[a] (10–40 μg/kg/h)	0–4 mL/h[a] (0.4–1.6 μg/kg/h)	0–4 mL/h[a] (2–8 μg/kg/h)
Bolus dose	1–2 mL 10–20 μg/kg	1–2 mL 0.4–0.8 μg/kg	1–2 mL 2–4 μg/kg

Varying the dose added to the infusion syringe results in a fixed concentration relative to the weight of the child, and subsequently the same infusion rate in mL/h for every child. The start rate for infusions should be in the lower half of the dose range

[a]Lower infusion rates are used for infants

Table 9.9 PCA dosing guidelines in school aged children

PCA dosing guidelines			
	Morphine	Fentanyl	Hydromorphone
Loading dose (μg/kg)	50–100	0.5–1	10–20
PCA bolus dose	1–2 mL (20 μg/kg)	1 mL (0.4 μg/kg)	1–2 mL (2–4 μg/kg)
Maximum bolus dose	1 mg	20 μg	200 μg
Lockout interval (min)	5	5	5
Background infusion rate (μg/kg/h)	0.5–1 mL/h (5–10 μg/kg/h)	0.5–1 mL/h (0.2–0.4 μg/kg/h)	0.25–0.5 mL/h (0.5–1 μg/kg/h)

Syringe concentrations are the same as for continuous, nurse-controlled infusions

9.4.2.3 Patient Controlled Analgesia (PCA)

The use of a PCA pump requires a cooperative, awake child who is able to comprehend analgesic delivery depends on pushing a button, and who is also physically able to push a button. Children aged from 6 years are usually able to use a PCA. Mature, younger children may be coached to use a PCA, but may forget to press the button and receive inadequate analgesia. The safety of PCA relies on an awake child being able to press the button independently and for this reason parents must be warned not to press the button if their child falls asleep.

Opioids for PCA are prepared in the same way as continuous, nurse controlled infusions and the concentration of the prepared infusion varies with the weight of the child (Table 9.9). Unlike adults, background infusions are commonly used in children, particularly in younger children, within the first 24–48 h after major surgery, in oncology patients and in opioid tolerant patients. Low dose background infusions improve analgesia, promote sleep and do not increase adverse effects in children with severe and constant pain.

9.4.2.4 Transition from Parenteral to Oral Analgesia

Successful transition to oral analgesia may proceed when the child's pain is mild to moderate in severity and without sudden or severe episodes of pain, and when a reliable oral route has been established with good absorption. If opioid use has been large and for a prolonged duration, then the parenteral requirement during the previous 24–48 h is converted to an equivalent oral dose of slow and immediate release drug. If opioid use in the previous 24–48 h has been low and there is no risk of withdrawal, then oral opioids are given as required along with regular non-opioid analgesia.

9.5 Management of Opioid Toxicity and Adverse Effects

Approximately one third of children will experience adverse effects from opioid infusions. These include pruritus, nausea and vomiting, ileus and constipation, urinary retention, sedation and respiratory depression (Table 9.10). Although these

Table 9.10 Opioid side effects, mechanisms and treatment

Side effect	Treatment
Sedation	
– Sedation occurs before respiratory depression and should be monitored using a sedation scale (e.g.: University of Michigan Sedation Scale)	– Stop opioid & other sedative drugs – ABC – IV naloxone 1–2 μg/kg bolus, 1–2 min (max 5 doses) – Re-sedation once naloxone wears off – Reduce subsequent opioid dose – Maximize use of non-opioid analgesics – Exclude other causes of sedation
Unrousable and/or respiratory depression/ arrest	
Opioids reduce minute ventilation (slow RR and tidal volume), reduce ventilatory response to hypercapnia and hypoxia and suppress the cough reflex	– Stop opioid & other sedative drugs – ABC – IV naloxone 10 μg/kg bolus, 1–2 min (max 5 doses) – Re-sedation once naloxone wears off, consider naloxone infusion – Avoid routine oxygen supplementation, as it will hide opioid-induced hypoventilation
Nausea/vomiting	
Children are at increased risk of PONV compared to adults Risk factors: – Age: risk progressively increases from 3 years to adolescence – Post pubertal girls higher risk than boys; consider prophylactic antiemetics – History of previous PONV – Specific surgery: strabismus, adenotonsillectomy, otoplasty etc.	– Ensure adequate hydration, analgesia and exclude other causes of nausea – Stop/reduce opioid if adequate analgesia or rotate opioid – Chart antiemetic protocol for children more than 2 years old receiving continuous opioid and use 2–3 antiemetics from different classes in children at high risk – Consider low dose naloxone infusion (0.25 μg/kg/h IV)
Opioid induced pruritus	
– A frequent and early side effect seen with IV opioids (10–50%) and centro-neuroaxial opioids (20–100%) – Face, neck and upper chest – Mainly by activation of central μ opioid receptors. Also activation of dopamine and 5HT3 receptors and release of prostaglandins PGE1, PGE2 – Histamine release may contribute a small amount to OIP after systemic opioids	– Switch or cease opioid – Low dose naloxone IV infusion (0.25 μg/kg/h) effective for treatment and prevention – Prophylactic 5HT3 antagonist may reduce incidence and severity of pruritus from neuroaxial opioids – Antihistamines poorly effective. No longer used as risk of over-sedation with concurrent opioids
Constipation	
Common & persistent	– Increase fiber & fluid, mobilize patient, stool softeners & laxatives.
Urinary retention	
Opioid related; exclude pain, bladder spasm, anxiety, epidural blockade	Treat retention, reduce opioid dose, low dose naloxone infusion

Table 9.11 The University of Michigan Sedation Scale (UMSS)

Score	Observation of sedation level
0	Awake and alert
1	Minimally sedated, tired, appropriate response to verbal stimulation/sound
2	Moderately sedated, sleepy, aroused with light tactile stimulation or verbal stimulation
3	Deeply sedated, aroused only with deep physical stimulation
4	Unrousable

side effects are common, they are often mild and may be tolerated or treated. Occasionally, adverse effects require opioid cessation or substitution. The addition of a low-dose naloxone infusion may reduce pruritus and nausea in children receiving an opioid PCA.

Children particularly at risk of sedation and respiratory depression during opioid infusions include:

- Infants younger than 6 months, and especially younger than 1 month
- Children with serious co-morbidity (cardiorespiratory, central/obstructive sleep apnea, syndromes associated with airway obstruction, hepatic/renal insufficiency, neurodevelopmental disorders)
- Those also receiving other sedative drugs (such as benzodiazepines, sedating antihistamines, clonidine, gabapentin)

Side effects in these groups can be minimized by adding non-opioid analgesics, reducing the opioid dose, vigilance, and monitoring for sedation and respiratory compromise using continuous oximetry and at least hourly assessment of heart rate, respiratory rate and sedation level. The depth of sedation can be assessed using an observational scale such as the University of Michigan Sedation Scale (UMSS) (Table 9.11).

Keypoint
Sedation occurs before opioid-induced respiratory depression. Respiratory depression (bradypnea and hypoxia) are late signs of opioid toxicity.

9.6 Opioid Withdrawal

Children on prolonged infusions of opioids for pain or sedation will develop tolerance and require increasing doses to achieve the same effect over time. Abruptly stopping opioids in these children may lead to a withdrawal syndrome

causing CNS stimulation (irritability, tremors, seizures, uncontrolled crying), gastrointestinal disturbance (abdominal cramping, diarrhea, poor feeding) and sympathetic arousal (tachycardia, hypertension, tachypnea, fever, sneezing). Withdrawal symptoms and signs are easy to overlook unless specifically monitored with a validated withdrawal assessment scale. Withdrawal is minimized by controlled weaning (reducing the opioid dose no more than 10–20% per day) and using drugs such as clonidine or benzodiazepines to treat symptoms of withdrawal. Concurrent use of other sedatives, such as benzodiazepines for children who have had a prolonged stay in the intensive care unit, may also contribute to withdrawal.

9.7 Management of Pain After Ambulatory Day Case Surgery

Most pediatric surgery is performed on an ambulatory, day case basis with effective analgesia at home an important part of care. More than 30% of children will have moderate to severe pain at home after day surgery, and especially surgeries such as tonsillectomy and orchidopexy. Pain at home is often under-appreciated and undertreated by both families and medical staff. Strategies to improve analgesia at home after discharge include:

- Parental education about the regular use of simple analgesics and when to begin them (especially if the child has had a regional technique that will wear off after discharge)
- Parental education about the signs of pain
- Providing analgesics at discharge in the correct dose and form for the child.
- Dispelling misconceptions about the side effects of strong analgesics

If opioid analgesia after discharge is necessary, parents must be educated about dosing, side effects and safe and early disposal of unused drugs to their local pharmacy. Restricting the volume dispensed to only 10 or 20 doses is one strategy to improve safety regarding opioids that are taken at home.

9.8 Neonatal Pain

Neonatal pain pathways are present before birth, but are not mature and differ from adults. In neonates, pain produces specific behavioral changes, activates the somatosensory cortex and induces physiological and neuroendocrine stress responses. Initially, there is an excess of excitatory mechanisms, as the descending inhibitory pathways do not mature until later. Therefore, neonates (especially preterm neonates), may not be able to discriminate between noxious and non-noxious stimuli and may respond with a generalized and exaggerated response to low intensity stimuli—they may actually be more sensitive to pain than older children. The

long-term consequences of untreated pain in the newborn period include exaggerated responses to future noxious stimuli that outlast the initial injury, hypervigilance and adverse neurological sequelae.

A number of pain assessment tools are validated for use in neonates. The appropriate selection depends on the age of the infant, the type of pain (procedural or postoperative) and the purpose of the measurement (clinical care or research). Examples of validated tools include the premature infant profile (PIPP), neonatal facial coding scale (NFCS) and children's revised impact of event scale (CRIES).

Reducing discomfort and reducing pain in neonates use strategies such as swaddling, breast feeding, tactile or aural stimulation and eye contact. Sucrose is an effective analgesic for stressful and painful procedures in neonates, possibly through endogenous opioid release. It is effective within 2 min of administration. In practice, the "dummy" is dipped in 12–24% sucrose, giving a dose of about 0.2 mL. A maximum of 2 mL can be used for term babies, less for preterm. Sucrose may cause coughing, choking and desaturation in very premature neonates. Sucking a pacifier without any sucrose (non-nutritive sucking) also causes analgesia through stimulation of oropharyngeal tactile and mechanoreceptors. Sucrose is not effective outside the neonatal period.

9.8.1 Pharmacological Management of Neonatal Pain

Doses of all analgesics are lower in neonates compared to children because of reduced metabolism. For example, the infusion rate for a morphine infusion in a neonate is 10–25% of the standard pediatric rate (Table 9.12) Even with lower doses, neonates are at high risk of overdose and respiratory depression from opioids, and they require careful dose titration and close monitoring.

Keypoint

Neonates (even preterm neonates) perceive pain, and prolonged, untreated pain may result in adverse long-term consequences.

Like children, neonates need procedural pain minimized with safe and effective pharmacological and non-pharmacological strategies.

Table 9.12 Suggested neonatal opioid dosing guidelines

Neonatal opioid dosing guidelines		
	Preterm neonate	Term neonate
Morphine		
IV bolus IV infusion	10–25 μg/kg every 2–4 h 2–5 μg/kg/h	25–50 μg/kg every 3–4 h 5–10 μg/kg/h
Fentanyl		
IV bolus IV infusion		0.25–1 μg/kg every 2–5 min 0.4–0.8 μg/kg/h

Table 9.13 The roles of the APS in adult and pediatric hospitals

Roles of adult and pediatric APS	Roles unique to pediatric APS
Supervision of specialized analgesic techniques Staff education and accreditation regarding all aspects of acute pain management Development of guidelines/ protocols & provision of clinical consultation as required Teaching of junior medical staff, performance of quality assurance & participation in research	Education of parents regarding pain management particularly after discharge Promotion of non-pharmacological techniques (e.g.: physical and psychological therapies which are especially important in the management of procedurally related pain) Education of staff regarding age related differences (pharmacology, physiology, psychology) in the management of acute pain

9.9 The Acute Pain Service for Children

There is no widely accepted definition of what constitutes an acute pain service—the structure of each service varies depending on the needs of the institution (number of patients, complexity of surgery and analgesic regimens), resources available and the expertise of available staff.

Within Australia and New Zealand, 91% of hospitals accredited for anesthetic training have an APS run by the anesthetic department. The APS in most tertiary pediatric centers is multidisciplinary and involves daily clinical input from APS nursing staff, pediatric anesthetists and possibly a pharmacist (Table 9.13).

9.10 Chronic (Complex) Pain Services and Services to Reduce Anxiety Associated with Hospital

Tertiary pediatric centers are managing a growing number of children with complex pain. As oncology survival rates increase and our understanding of childhood presentations such as ‘abdominal migraines’ and ‘growing pains’ improves, the demand for these services will increase. Complex pain services include a multi-disciplinary team of chronic pain specialists, allied health, nursing and play therapy. These services treat not just the child but importantly the family in the context of childhood chronic pain. Children with a complex pain background should be flagged to the Acute Pain and Complex Pain Service if they present to hospital with illness or trauma so that they can be appropriately managed. Many tertiary pediatric hospitals have embraced programs to help children cope with anxiety, distress and trauma caused by hospitalization. This involves a hospital-wide education with an emphasis on non-pharmacological strategies (in addition to appropriate pharmacological management) to support children and parents whilst receiving treatment.

Review Questions

1. You are asked to review a 7 year old boy who has inadequate analgesia after open fixation of a fractured femur. His current treatment is with a nurse-controlled infusion of morphine. What will you do?
2. Why are smaller doses of morphine than would be used in adults appropriate for infants?
3. What are the post operative analgesic options available to manage a severe spastic quadriplegic 8 year old scheduled for elective major bilateral lower limb surgery? Discuss and justify your choices.
4. Please discuss how paracetamol may be administered to children.
5. What considerations should be given prior to prescribing procedural analgesia for ward patients?
6. A 3 year old child has a broken leg. What is the best way to assess pain in this child?

Further Reading

Key Articles

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Regional Anesthesia for Infants and Children

10

Chris Johnson and Chris Gibson

Regional anesthesia is an important part of pediatric anesthesia. A comfortable child is less likely to be agitated after surgery, less likely to dislodge dressings and drains, and less likely to be psychologically traumatized by their experience. Continuous regional analgesia is useful where pain is likely to be severe and prolonged and or difficult to assess such as in children with severe cerebral palsy and subsequent communication difficulties. This chapter will concentrate on areas specific to pediatric regional anesthesia, and it is assumed the reader is familiar with the various blocks also used in adults. Rather than repeating their description here, the focus will be on important differences when performing peripheral nerve blocks in children.

10.1 The Pharmacology of Local Anesthetic Agents in Infants and Children

As is the case with many drugs, the pharmacokinetics of local anesthetic agents are different in neonates and young children compared with adults. The three most important differences are reduced protein binding, reduced metabolism and increased volume of distribution.

Local anesthetics are highly bound to proteins in the plasma, especially alpha-1-glycoprotein. The level of this protein is low during the first year, and the concentration of free (unbound) local anesthetic is higher. Liver cytochrome P450 enzymes metabolize local anesthetics and these enzymes do not mature until 6–12 months of

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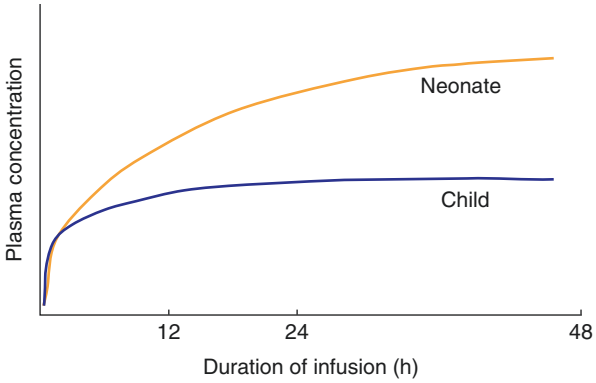

Fig. 10.1 Plasma concentration of bupivacaine increases towards toxic levels over time in neonates, but plateaus in infants and children older than 6 months. Based on Meunier et al. Pharmacokinetics of bupivacaine after continuous epidural infusion in infants with and without biliary atresia. Anesthesiology 2001;95: 87–95

age. Hence, toxicity is a high risk in neonates and infants. During an epidural infusion in smaller infants the plasma concentration of bupivacaine increases over time, but plateaus in children (Fig. 10.1). To avoid toxicity, the infusion rate or concentration of the local anesthetic is reduced in neonates, and the infusion is stopped within 24–36 h. The risk of toxicity after bolus doses is counteracted by the increased volume of distribution for local anesthetics in neonates and infants—a high plasma concentration is prevented by the anesthetic distributing into a relatively larger volume. In clinical practice, the volume in mL/kg of a single, bolus dose is the same across all ages.

Keypoint
There is a high risk of local anesthetic toxicity in neonates and infants during infusions because protein binding and metabolism are reduced. Regional infusions should be stopped after 24–36 h in neonates and infants. The dose of a single, bolus injection is similar in all ages.

Other developmental changes affect local anesthetics in children. Nerve fibers at birth are thin, about half the diameter of adult nerves, and they are less myelinated during the first several years. As a result, low concentrations of local anesthetics in children achieve a block of similar duration and intensity to higher concentrations in adults. The volume of local anesthetic needed is however relatively large due to increased tissue blood flow and tissue spread, and more rapid local clearance.

The maximum dose of bupivacaine in children has been extrapolated to L-bupivacaine and ropivacaine (Table 10.1). Although the newer local anesthetic agents have less cardiotoxicity, the maximum doses were extrapolated because they have been found safe and effective in clinical practice and result in safe plasma

Table 10.1 Maximum doses for single injection blocks and infusions of ropivacaine, L-bupivacaine and bupivacaine in neonates and children

Age group	Maximum bolus injection dose (mg/kg)	Maximum infusion dose (mg/kg/h)
Neonate and infant <6 months	2.5	0.2
Child	2.5	0.4

Based on Berde C. J Ped 1993; 122: S14–20

levels after a variety of regional blocks. Although some suggest a maximum dose of ropivacaine of 3 mg/kg in the setting of combined (more than one) block in the same child, the doses in Table 10.1 above should be adhered to for single shot blocks. In practice, a maximum dose of 1 mL/kg of ropivacaine 0.2% (2 mg/mL) for a single shot block is a simple method without complex calculations.

Keypoint
The recommended maximum single dose of ropivacaine or L-bupivacaine in children is 2.5 mg/kg.

10.2 Additives to Regional Blocks

Additives to regional blocks and infusions prolong the duration of the block, improve analgesia and provide concurrent sedation. In general, they are avoided in neonates and infants less than 3 months of age due to the risk of sedation and apnea.

Adrenaline (epinephrine) is now rarely used because of concerns about spinal cord ischemia, although it mildly prolongs the duration of caudal analgesia.

Clonidine provides postoperative sedation for the difficult toddler group, as well as analgesia. It can be added to a single shot caudal (1–1.5 μg/kg) or to epidural infusions. A simple mix is to add 1 μg/mL of clonidine to the local anesthetic infusion and run it at the usual rate. Clonidine should be used with caution in infants under 12 months as they can become very sedated, but is otherwise free of side effects apart from occasional mild bradycardia. It prolongs and improves the quality of peripheral blocks in adults, but there is not strong evidence of these effects in children. Small studies in children have not always shown a significant benefit of clonidine, and a large review of a regional block database in Philadelphia found benefit only when very dilute local anesthetic solutions had been used.

Opioids may be added to epidural infusions just as with adults. An alternative is to use opioids by the oral or IV routes to supplement the epidural as required. Some centers do not allow nursing staff to titrate epidural infusion doses. By combining epidural and systemic analgesic techniques, the epidural can provide background analgesia, and opioids can be titrated by nursing staff as required. Dexamethasone is not recommended as an additive in children because safety and efficacy have not yet been established. Ketamine prolongs caudal analgesia, but is not used due to possible neurotoxicity.

10.3 Ultrasound Guidance of Local Anesthetic Blocks

Similar to adult practice, ultrasound facilitates regional anesthesia in children. Ultrasound enables smaller doses of local anesthetic to be more easily, safely and accurately placed in close proximity to nerves, whilst avoiding inadvertent damage to adjacent structures. Ultrasound based techniques are similar to those described in adults with a few exceptions. Smaller probes, depths and needle lengths are often required to optimize the image. Anatomical structures and tissue planes are generally smaller, shallower and better defined. Particular care needs to be taken not to 'overshoot' when passing through shallow elastic tissue structures. Maintaining needle visualization throughout a short tissue trajectory can be challenging. Using a sharp hypodermic needle to puncture through the tough elastic skin before inserting a blunt short-bevel needle, helps maintain needle visualization and avoid inadvertent overshoot.

10.4 Complications of Local Anesthetic Blocks

Most pediatric regional blocks are placed after the induction of anesthesia to provide post-operative analgesia. Performing blocks with the child asleep is safe, and may even be safer than with the patient awake. Several large surveys with more than 100,000 patients show complications after blocks in children are uncommon. The most recent prospective survey in 2018 from the Pediatric Regional Anesthesia Network (PRAN), showed complications were uncommon, with a similar, low incidence of complications in peripheral and neuraxial blocks.

10.4.1 Overdose and Systemic Toxicity

These complications are usually due to arithmetic error or accidental use of the wrong strength of solution. It is best to always calculate the maximum allowable amount in milligrams and never draw up more than this, regardless of the volume required. A simple and conservative rule is to limit dosage to 1 mL/kg of ropivacaine 0.2%, L-bupivacaine 0.25% or bupivacaine 0.25%, giving a maximum dose of 2.5 mg/kg (Table 10.1). Overdose with cardiac arrest or convulsion is rare, but infants are more likely to develop these complications. Real-time ultrasound guided blocks reduce the volume required by 30–50% and allow visualization and avoidance of vessels, reducing the risk of intravascular injection. In an audit of over 100,000 pediatric regional blocks by the PRAN group, the rate of severe local anesthetic toxicity was 0.76: 10,000.

Test doses containing adrenaline (epinephrine) have been extensively studied in children, but changes in heart rate, BP and T waves are not sufficiently sensitive or specific, and vary between different volatile agents and propofol. Aspiration tests are also unreliable. It is therefore prudent to give larger volumes of local anesthetic in divided doses, watching for changes in respiration, T wave amplitude, ST segments and heart rate or onset of nodal rhythm.

10.4.2 Neurological Injury

There are few pediatric series of sufficient size to draw definite conclusions, but lasting injury after major plexus and single shot caudal block appears to be extremely rare. Infants less than 4 months of age and pre-teens appear to be most at risk. In a prospective multicenter cohort of more than 100,000 peripheral nerve and neuraxial blocks in children there were no cases of permanent neurological deficit associated with regional anesthesia. The rate of transient neurological deficit was low at 2.4 per 10,000. A UK pediatric epidural audit of 10,000 epidurals reported only one incident with residual effects 12 months after surgery in a 4 month old.

10.4.3 Injury to Visceral Structures

Is a concern during blocks of the anterior abdominal wall. Rectal damage during caudal block has also been reported.

10.4.4 Minor Complications

Pressure areas during continuous blocks in children are not uncommon, usually manifesting as heel redness or rarely skin loss. Urinary retention is common with continuous epidural blockade and warrants catheterization at all ages. Lower limb weakness and delayed ambulation may occur after caudal blockade with high concentrations of local anesthetic, or after Iliohypogastric block with inadvertent spread to the femoral nerve. Block failure is usually due to depositing the local anesthetic too deeply, as most peripheral nerves are quite superficial. Accurate visualization of nerves using ultrasound may reduce the incidence of this to zero.

10.5 Neuraxial Blocks

There are important anatomical and physiological differences of the neuraxis between children and adults:

- The anatomical curves of the spine are absent at birth and not fully fixed until puberty, altering the spread of spinal and epidural local anesthetics.
- There is less variation in the angulation of the spinous processes in children, allowing easier access to thoracic and lumbo-sacral epidural spaces.
- The spinal cord ends at L3 at birth and moves to the adult position around L1 by 12 months of age.
- The sacrum is not fully ossified with intervertebral spaces still present, allowing sacral epidural access.
- The dural sac ends at S3-4 in the neonate, moving to the adult level around S2 by 12 months of age. This is variable and it occasionally extends to the sacral hiatus in infancy.

- The line joining the two superior iliac crests (the intercristal line) is through L5 in children and L5-S1 in neonates.
- Hypotension, even with extensive block, is uncommon under 8 years of age unless hypovolemia is present. (Related to reduced resting sympathetic tone).

10.5.1 Caudal Epidural Blockade

Caudal blocks are best used as a single shot block for procedures below the umbilicus in infants and small children. The inferior termination of the epidural space can be approached via the sacral hiatus which is covered by skin and the sacrococcygeal membrane (the continuation of the ligamentum flavum). There is usually a clear loss of resistance or 'pop' as the membrane is penetrated. The relationship between volume of solution injected and extent of the block are reasonably predictable since only cephalad spread is possible. Recent studies show the anatomical spread of local anesthetic seen on ultrasound is less than the clinical block obtained, perhaps suggesting the mechanism of epidural blockade is still not fully understood.

10.5.1.1 Technique

Placing the child slightly beyond the lateral position with the top leg over (rather than strictly at 90°) stabilizes the pelvis and slightly stretches the skin, making it easier to feel the sacral hiatus. This is located either at the apex of an inverted equilateral triangle using the two posterior superior iliac crests (Fig. 10.2), or by placing the tip of the index finger on the tip of the coccyx—the hiatus lies opposite the second inter-phalangeal skin fold for those with average hand size. This distance from coccyx to hiatus does not change from around 4–6 months of age and remains the same for life. For this reason, the hiatus appears to be very cephalad in neonates and infants, and failure usually relates to aiming too low. The apex of the hiatus should be carefully located with an index finger and the needle inserted as cephalad as possible within the apex—this is where the sacral canal is deepest and the needle is less likely to impinge on the anterior wall of the canal. Reversing the needle bevel so it faces anteriorly (away from the anesthetist) also reduces this possibility.

Tip
If you are having trouble finding the sacral hiatus, you are probably too low on the back.

The sacrum is a flat structure in infants and children and the technique of needle puncture, flattening and advancing is inappropriate and may cause bloody tap or dural puncture. The needle should be advanced at an angle of 45–60° to the skin at the apex of the hiatus and not advanced once the sacrococcygeal membrane is penetrated, as the dural sac may be very close, particularly in babies. Extreme care is needed to prevent needle dislodgement during aspiration and slow

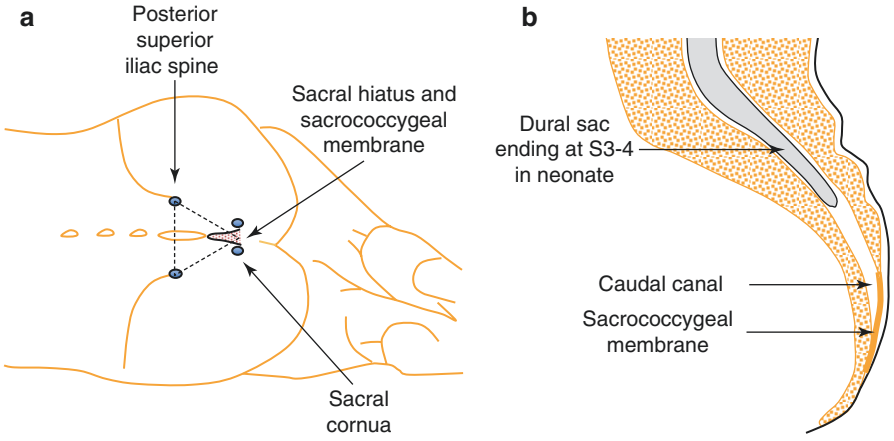

Fig. 10.2 Anatomy of the caudal block. Injection is through the sacral hiatus, located in the lower sacrum between the two sacral cornua. (**a**) The sacral hiatus is at the apex of an equilateral triangle formed by it and the two posterior superior iliac spines. (**b**) The caudal canal is largest cephalad rather than caudally, and the needle is best inserted towards the top part of the triangular sacral hiatus

injection. This is best done by stabilizing the needle with a hand resting along the child's back and either making a window between your thumb and index finger or an underhand technique to allow for early visualization of subcutaneous sacral swelling during injection, a warning of incorrect needle placement. Importantly, there should be minimal resistance to injection. If injection is difficult it is invariably an indication of incorrect placement. Many would advocate always using a similar sized syringe to get a consistent feel for injection.

10.5.1.2 Anatomical Difficulties

The anatomy of the sacral hiatus and caudal canal is highly variable. Sacral variations such as absent cornua, a bony septum or a presacral fat pad can make locating the hiatus technically challenging. Difficulty in locating the sacral hiatus has been reported in at least 11% of children under 7 years of age. Occasionally the sacral hiatus extends one or two segments more cephalad than usual, making dural puncture more likely if needle placement is in the most cephalad point of the long, slit-like hiatus. The correct site for needle placement can be judged using the above two methods. Some advocate ultrasound guidance to aid placement, particularly if there are concerns regarding the anatomy, although routine use of this practice is not widespread.

Cutaneous anomalies including sacral angioma, hairtuft, nevus or dimples near the puncture site may indicate abnormalities of the underlying spine. Midline sacral dimples are found in 2–4% of children and are usually of no significance. Rarely, they are associated with an occult spina bifida. Warning signs of an underlying abnormality include multiple dimples, or high on the back (should be below caudal insertion site, less than 2.5 cm above the anal verge), or more than 5 mm diameter, or associated with an underlying lump or a deviated or double gluteal cleft. Ultrasound can be used

to clarify the underlying anatomy, or the block can be abandoned and a pediatric opinion obtained after surgery. Finally, if the sacral hiatus doesn't feel normal, it might be safer to use different analgesia rather than persisting and causing problems.

10.5.1.3 Needles for Caudal Epidural Blocks

The short-bevel styletted regional or spinal needles have the lowest risk of actual and theoretical complications. They give an obvious sensation or 'pop' passing through the membrane, and venous and dural puncture is less likely than with standard needles. The 22G needle is suitable for all ages. Fine gauge needles introduce the risk of unrecognized intra-osseous injection in neonates and infants. Intravenous needles (bloody tap rate 10%) and cannulae (require advancement into epidural space and may kink) still remain popular. Needles without stylettes introduce a small theoretical risk of implantation dermoid which most practitioners do not regard as significant.

10.5.1.4 Local Anesthetic Agents and Doses for Caudal Block

The Armitage formula (Table 10.2) is simple and reliable for infants and pre-school children, but the doses and volumes must be reduced for older children. Older children are also more likely to be troubled by leg numbness or weakness, and hence peripheral blocks are often a better alternative.

The duration of analgesia varies with the site of surgery and the patient's age. For example, 1–2 h after infant herniotomy, compared with around 5 h after a perineal procedure in a pre-school aged child. Block regression is quickest in the most cephalad dermatomes. Adding clonidine 1–2 μg/kg can prolong the block duration in younger children by 50–100%.

10.5.1.5 Complications and Safety

Caudal analgesia is one of the commonest pediatric blocks and has a very low risk. Several series demonstrate the risks of a major complication (seizure, cardiac arrest, total spinal) are around 1–6 per 10,000. The incidence of death, persistent neurological injury, epidural abscess and meningitis was zero. Motor block (inability to walk unaided) is usually the most troubling side effect in school aged children. Urinary retention is rare despite sacral blockade, as children invariably pass urine later once home.

Table 10.2 Relationship between volume and block height for caudals in children, based on the classical paper: Armitage EN, Anaesthesia 1979;34: 396

Volume of local anesthetic	Height of caudal block	Example surgical procedure
0.5 mL/kg	Sacral block	Circumcision
1 mL/kg (maximum 20 mL)	Block to umbilicus (T10)	Herniotomy, orchidopexy, orthopedic procedures
1.25 mL/kg[a] (maximum 20 mL)	Block to mid-thoracic	Upper abdomen (but care with mg/kg dose, upper block first to wear off)

[a]Dilute local anesthetic solutions are used so the dose is below the maximum recommended dose

Caudal catheters may be threaded to thoracic levels with a reasonable degree of certainty in infants under 9–12 months. The catheter entry site in the 'nappy zone' appears to be a theoretical rather than actual infection risk. Incomplete vertebral ossification allows ultrasound to be used to confirm catheter tip position in most infants up to this age. Ultrasound also reliably demonstrates epidural space expansion with single shot blocks in children up to 2 years of age.

10.5.2 Sacral Epidural Blockade

The sacrum is only partly ossified and there are still discrete sacral vertebrae with intervertebral spaces in pre-school children. The S1-2 interspace lies above, and the S2-3 space below, the line joining the posterior superior iliac spines. An epidural catheter can be placed for continuous analgesia as an alternative to either a caudal or lumbar approach, particularly for urological or foot surgery. This is a technically simple block to perform, with good landmarks and wide, easy spaces. Equipment, technique and postoperative infusion rates are as for a lumbar approach. Initial bolus doses are the same as for caudal blockade.

10.5.3 Lumbar Epidural Blockade

This technique is often used to provide pain relief after major urological and lower limb surgery.

10.5.3.1 Technique

Pediatric epidural kits containing short (5 cm), 18 or 19g Tuohy needles are suitable for all ages, although some centers use 22g needles for infants. Technical problems including kinking, occlusion, leakage and failure are common with smaller diameter catheters.

Precision is required as it is easy to stray from midline, the ligaments are soft and the distance to the epidural space is short. A useful guide for epidural depth in the lumbar area is around 10 mm in newborns and infants and around 1 mm per kg in older children, reaching the adult range around 10–12 years of age. Loss of resistance to saline is used as it usually gives a more definite end point. It is best to rely on loss to resistance with limited injection of saline in order to minimize confusion with dural puncture.

For children up to about 8 years, an initial bolus dose of 0.5 mL per kg reliably blocks to T12 (watch dose in mg/kg). This is a conservative maximum bolus dose for a well-sited effective epidural. Older children require smaller volumes, with a maximum of 1 mL per segment blocked by 10–12 years. Analgesic duration is about 90 min and the same volume but at half the strength should be repeated before this time to maintain intra-operative blockade. With repeated top-ups

during long operations the total dose of ropivacaine/L-bupivacaine should not exceed 2 mg/kg per 4 h. This rule is also useful for calculating maximum postoperative infusion rates.

10.5.4 Thoracic Epidural Blockade

Thoracic epidural block is a sub-specialist technique with real risk of cord damage and is reserved for major thoraco-abdominal procedures. Although the needle angulation is less than required in adults, penetration of the ligamentum flavum may be quite subtle. For children up to around 8 years, an initial bolus dose of 0.2–0.3 mL/kg gives an extensive thoracic block. Again, older children require less.

10.5.5 Postoperative Epidural Infusions

The absolute maximum infusion rate for epidurals in children is 0.5 mg/kg/h of L-bupivacaine or ropivacaine. This dose must be halved in neonates and small infants because of reduced clearance in these age groups. A requirement to run maximum rate suggests that the catheter is sited at the wrong dermatome or the technique is marginally successful and may need supplementation with alternative analgesia. Typical infusion rates are shown in Table 10.3.

10.5.6 Spinal Anesthesia

Awake spinal anesthesia avoids the difficulties of managing the neonatal and infant airway, but its use is limited by the technical difficulties of lumbar puncture and the short duration of spinal anesthesia in infants (Table 10.4). It is used in many parts of

Table 10.3 Infusion rates in mL/k/h of local anesthetics in children and neonates

Agent	Child infusion dose (mL/kg/h)	Neonate infusion dose (mL/kg/h)
L-bupivacaine or bupivacaine 0.125%	0–0.3	0–0.15[a]
Ropivacaine 0.2%	0–0.2	0–0.1

[a]An alternative bupivacaine dose for neonates is half strength bupivacaine 0.0625% 0–0.3 mL/kg/h

Table 10.4 Advantages and disadvantages of spinal anesthesia in infants

Advantages	Disadvantages
Avoids volatile anesthetic that may be neurotoxic to developing brain	Technically difficult (failure rate over 10%)
Avoids airway problems	Short duration—less than 40–60 min
Reduces early postoperative apnea in former preterm infants	More difficult to perform lumbar puncture and surgery if infant larger and older than 6–12 months

the world as an alternative to general anesthesia for procedures in children of all ages, often with sedation. In contemporary western practice, its main role is for infant herniotomy in preterm infants. Although spinal anesthesia was thought to avoid the risk of postoperative apnea, recent work suggests it does not reduce the risk of apnea compared to general anesthesia. However the number of early apneas in PACU and amount of stimulation needed to resolve apnea are less with spinal than general anesthesia.

10.5.6.1 Technique

Trained assistance is essential to maintain the infant in an optimal flexed position but with neck extension to prevent airway obstruction and desaturation. Either the sitting or lateral decubitus position is used. A 22g or 25g short neonatal spinal needle is inserted in the midline below where the spinal cord ends at L3. Lumbar puncture at the level of the intercristal line will always be below the spinal cord in infants. The distance from the skin to the dural sac varies with weight: distance = 7 + (weight in kg × 2) mm. Ultrasound gives a reliable estimate of depth and may help to reduce the common tendency to go too deep.

Note

The spinal cord ends at L3 in neonates and infants and the intercristal line is at L5-S1 in neonates.

During lumbar puncture, the needle can be inserted at L5-S1 or L4-5. Some suggest L3-4 is too high, but others suggest it can be used—probably best to avoid L3-4 unless not successful at lower levels.

The per-kilogram dose of local anesthetic is much larger in infants compared with adults. Recent MRI studies in neonates and older children have shown that the differences in CSF volume per kg in the spinal canal below T1 (relevant to LA dilution) and CSF turnover are much less than previously believed, so there are likely to be pharmacodynamic or other factors to account for this requirement for high doses. Spinal CSF volume correlates closely with weight in both preterm and term infants, but duration is significantly shorter in preterm infants for unknown reasons. A dose of 0.2 mL/kg (1 mg/kg) of hyperbaric or isobaric 0.5% bupivacaine is injected using a 1 mL syringe without compensation for needle dead space. No attempt is made to aspirate CSF at the beginning or end of injection. Infants have no spinal curvature to restrict the spread of local anesthetic, and high block is the biggest concern. To control local anesthetic spread, the infant is turned supine and slightly head up immediately after injection. The block can be accidentally extended cephalad if the legs and torso are lifted to attach the diathermy plate.

Motor block occurs within seconds as a sign of a successful spinal block. There is minimal change in blood pressure with spinal blockade in infants—the low resting sympathetic tone of infants is not changed by the block. Even total spinal

anesthesia is associated with hemodynamic stability in neonates, although it always causes apnea and sometimes bradycardia. The intravenous line can be placed in a foot after onset of blockade to minimize distress and the BP cuff should also be placed on a leg. The baby's arms can be kept away from the operative field by clipping the surgical drapes onto the operating table sheet near the baby's axillae.

With minimal stimulation and deafferentation from the block, babies often sleep. A dummy or soother with or without glucose may also help. Block duration is a maximum of 45–60 min so the surgeon needs to be scrubbed and ready as the block is inserted. All advantage of reducing early post-operative apnea is lost if supplemental sedatives are required. Spinal anesthesia compared with general anesthesia does not appear to reduce the risk of apnea in the first 12 h in at-risk infants. For this reason, post-operative apnea monitoring is still necessary after unsupplemented spinal anesthesia in at risk former preterm infants.

Awake caudal anesthesia can be used as an alternative to spinal anesthesia, but requires high doses of local anesthetic. With large, difficult herniotomies in preterm babies, the best surgical conditions may still be provided by general anesthesia.

Keypoint
Infants need a larger weight-based dose of local anesthetic for spinal anesthesia compared with adults, but their block is brief and does not cause hypotension.

10.6 Upper Extremity Blocks

The techniques for upper limb peripheral nerve blocks used in pediatrics do not differ significantly from those in adults. Ultrasound has improved the confidence and safety in performing brachial plexus blocks in children. Complications include hematoma, intravascular injection, nerve injury and pneumothorax. Ultrasound should always be used when performing brachial plexus blocks to reduce these risks. The interscalene approach is not commonly used due to limited indications and the increased incidence of complications in pediatric patients. The supra and infraclavicular approaches can both be safety performed by those experienced with ultrasound guided blocks. The supraclavicular approach is preferred as the brachial plexus is generally more superficial and easily accessible. Both approaches can be used for most procedures on the arm below the mid humeral level. The axillary approach can be safely performed as both a landmark and ultrasound guided technique and can be used for procedures of the forearm and hand. Recommended local anesthetic doses of 0.2% ropivacaine or 0.25% bupivacaine are 0.2–0.4 mL/kg.

10.7 Blocks of the Anterior Abdominal Wall

These blocks provide analgesia to the anterior abdominal wall, muscles and parietal peritoneum but do not block visceral (peritoneal) structures. They are useful alternatives to caudal or epidural blocks, particularly for minor day case procedures such as inguinal and umbilical hernia repair. Numerous landmark-based blocks are described although ultrasound techniques are becoming the mainstay.

10.7.1 Iliohypogastric and Ilioinguinal Nerve Block

This is a simple and generally effective somatic block, providing analgesia for herniotomy and orchidopexy. Separate scrotal infiltration is also required for orchidopexy. The incision for pediatric herniotomy and orchidopexy is higher and more medial than for adult herniorrhaphy, and lies in the iliohypogastric nerve distribution. The ilioinguinal is incidentally blocked but this is not required to provide analgesia. About 50% of children having unilateral herniotomy require no further postoperative analgesia following successful iliohypogastric nerve block. Both caudal block and wound infiltration at the end of surgery are equally effective, but the latter does not provide intraoperative analgesia.

This block was traditionally carried out using short-beveled needles and a loss of resistance technique, introducing the risk of intraperitoneal injection.

Ultrasound-guided techniques have been shown to provide better quality intra and post-operative analgesia with smaller volumes of local anesthetic. A linear transducer is placed medial to and against the anterior superior iliac spine (ASIS), oriented on a line joining the ASIS with the umbilicus. The three muscle layers are identified—external oblique, internal oblique and transversus abdominis. The nerves are often but not always seen as hypoechoic ovals in the plane between the internal oblique and transversus abdominus muscles. A short-beveled needle is advanced in plane from medial to lateral. Two ‘pops’ are often felt passing through the external and then internal oblique aponeurosis. Following aspiration, an initial 1–2 mL bolus is injected, which should be easy to inject and be seen to spread along the plane between the internal oblique and transversus abdominus muscles. If the local anesthetic appears to be intramuscular the needle should be advanced or withdrawn 1–2 mm and another small bolus injected until spread along the plane is seen. This is repeated until the correct needle position is achieved. Total dose can be reduced to 0.1–0.2 mL/kg.

Inadvertent femoral nerve block occurs in up to 10% of patients secondary to diffusion of solution when larger volumes are injected. Intraperitoneal injection and bowel injury are possible (and described) however this risk is reduced with real time ultrasound guidance (Fig. 10.3).

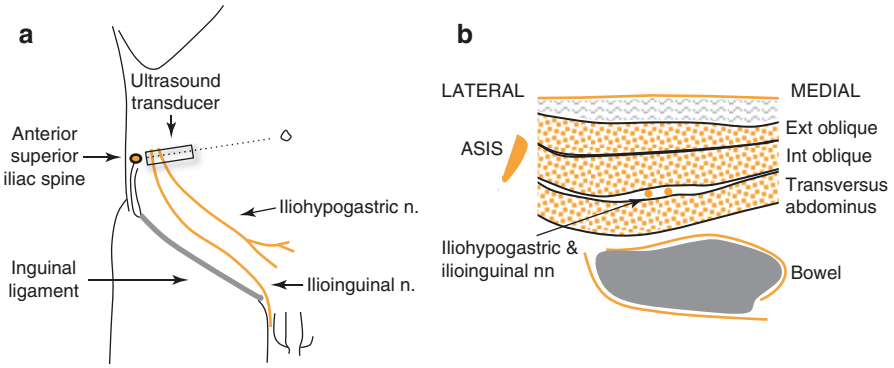

Fig. 10.3 (**a**) Schematic of Ilioinguinal and iliohypogastric nerves. The ultrasound transducer is positioned just medial to the anterior superior iliac spine (ASIS), parallel and below a line between the ASIS and the umbilicus. (**b**) Transverse plane at the level of the transducer showing abdominal wall muscles and location of Ilioinguinal and iliohypogastric nerves below the internal oblique and above the transversus abdominus muscle, below which is the peritoneal and bowel. The external oblique often appears as a hyperechoic aponeurotic layer during ultrasound

10.7.2 Rectus Sheath Block

This simple block provides effective pain relief for umbilical or epigastric hernia repair and other surgical incisions of the midline abdominal wall. Direct infiltration of local anesthetic can obliterate landmarks and make surgery difficult.

The anterior cutaneous branches of the ninth, tenth and eleventh thoracic nerves can be blocked distally in the space between anterior rectus sheath and rectus abdominus muscle where they pass before exiting to supply sensation to the anterior abdominal wall. Spread is limited in this space by three fibrous intersections between the sheath and muscle and medially by the linea alba, but only a limited spread is required. The injection point is at the apex of the bulge of rectus abdominus, slightly cephalad to the hernia at right angles to the skin using a 22G short-bevel needle. A small volume is also injected subcutaneously to cover the anatomical variant of subcutaneous passage of the nerves. A definite pop is felt as the needle passes through the anterior rectus sheath and a volume of 0.2 mL/kg is injected on both sides. The anterior sheath is a clear landmark making it difficult to inadvertently penetrate into the abdominal cavity.

An alternative technique aims to block the thoracic nerves (T7-T11) where they run posterior to the rectus abdominus muscle just anterior to the posterior sheath. Here spread is not limited by the fibrous intersections. This technique appears to be more effective but there is poor correlation between child size and depth to the space, leading to an increased risk of penetrating the peritoneal cavity. This block should only be performed using real time ultrasound. A linear ultrasound probe is placed lateral to the umbilicus and the rectus abdominus muscle is identified. Using an in-plane technique a 22G short bevel needle is advanced in a lateral to medial direction to deposit local in a potential space between the rectus abdominus muscle and its posterior sheath. Injection between the two layers of the posterior rectus sheath will result in block failure. This is an effective technique with children

requiring no additional analgesia in the perioperative period. 0.2–0.3 mL/kg is adequate to provide excellent analgesia for umbilical hernia repair.

10.7.3 Transversus Abdominus Plane (TAP) Block

The TAP block provides analgesia to the anterior abdominal wall from T8 to L1. The nerves lie in the plane between the internal oblique and transversus abdominus muscles. TAP block has been used for laparoscopic procedures to provide analgesia for port placement sites as well as for larger abdominal incisions. Few studies have looked at the efficacy and safety of TAP blocks in children and its use among pediatric anesthetists remains limited. Landmark and ultrasound-based techniques are the same as those used in adult practice. The dose is 0.2–0.4 mL/kg to a maximum of 20 mL.

10.8 Dorsal Penile Nerve Block (DPNB)

The dorsal nerve of the penis is the terminal branch of the pudendal nerve (S2-4). Dorsal nerve block is used for circumcision, hypospadias repair and other penile procedures. Both landmark and ultrasound guided techniques are commonly used. A large randomized controlled trial in children comparing the effectiveness of the ultrasound-guided and landmark-based dorsal nerve block found no differences in pain scores or analgesia requirements after circumcision. No adverse events were noted however ultrasound guidance may reduce the risk of deep puncture and damage to the neurovascular bundle within Buck's fascia.

10.8.1 Landmark-Based Technique

The block is performed in the sub-space between the pubic symphysis and corpora cavernosa (Fig. 10.4a). At this level, the left and right dorsal nerves, veins and arteries are enclosed within Buck's fascia, on top of the corpora cavernosa and shaft of the penis. Superficial to Bucks fascia is the pear-shaped sub-pubic space, divided by the midline suspensory ligament of the penis (Fig. 10.4b). Local anesthetic is injected into this space, which is deep to the membranous layer of the superficial fascia (Scarpas fascia). By injecting into this space rather than deeper (through Buck's fascia), damage to the accompanying vessels and penile ischemia is avoided.

The base of the penis is retracted caudally and a short-bevel needle inserted in the midline a few millimeters cephalad of the junction between the penile shaft and abdominal wall. The needle is gently touched onto the pubic bone for depth orientation and then redirected vertically and to one side by 10–20° and advanced until it pops through Scarpa's fascia. This is often surprisingly deep. There should be no resistance to injection. After injection, it is withdrawn to just under the skin and redirected in the mirror image to the other side. L-bupivacaine 0.5% is used with a volume for each side of 1 mL + an extra 0.1 mL/kg—a total of 2 mL for neonates, 10 mL for adults. Adrenaline (epinephrine)-containing solutions must not be used. This relatively large volume ensures block of the nerves that supply the ventral side

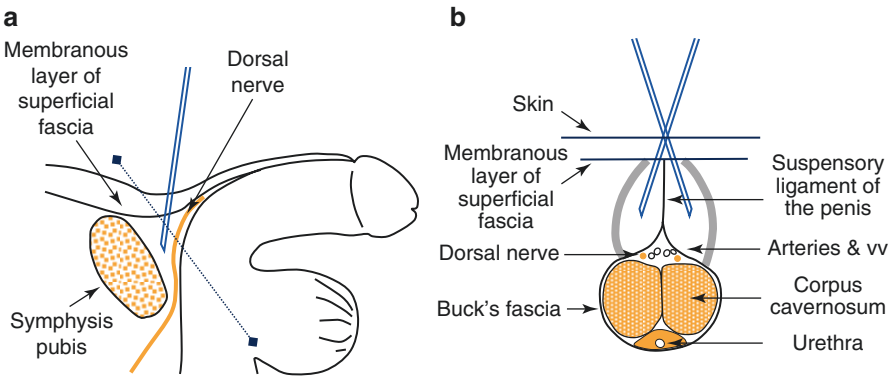

Fig. 10.4 Landmark-based technique for dorsal nerve block of penis. (**a**) Sagittal section through pelvis and penis showing needle inserted through membranous layer of superficial fascia within potential space between it and buck's fascia of penis. (**b**) Cross section of base of penis (through dotted line in **a**) showing needle directed first one side and then the other of the midline suspensory ligament, deep to the superficial fascia. Local anesthetic diffuses through Buck's fascia to block dorsal nerves. Based on Brown et al., Anaesth Intens Care 1989;17: 34–8

of the foreskin. These ventral branches can also be blocked with a subcutaneous injection of local on either side of the midline at the peno-scrotal junction.

10.8.2 Ultrasound-Guided Technique

In the technique described by Sandeman, the ultrasound probe is positioned to give a sagittal view of the penile shaft and subpubic space. The needle is inserted on each side of the into the triangular sub pubic space and local anesthetic injected until either the space is filled or the calculated volume (as above) injected. The probe is rotated into the transverse plane to confirm bilateral spread. An alternative approach is described using a transverse ultrasound position as described above. Local anesthetic is injected into each side of the subpubic space, using either an in plane or out of plane approach. The description of both techniques includes a separate injection of local anesthetic to block the ventral branches, as described with the landmark-based technique.

10.9 Lower Extremity Blocks

Many of these blocks used in children are the same as used in adults, and detailed descriptions will not be given here.

10.9.1 Fascia Iliaca Block

This reliably blocks the femoral and lateral femoral cutaneous nerves where they run under the fascia iliaca. It is commonly used for burn graft donor sites, femoral shaft fracture or osteotomy, quadriceps muscle biopsy and surgery to the patella, distal

femur and anterior part of the knee. It is a volume-block and relies on local anesthetic spreading in the plane between the fascia iliaca and iliacus (iliopsoas) muscle.

Performing this block with ultrasound increases ease, reliability, and safety by allowing visualization of the needle path, fascial planes and local anesthetic spread. A linear probe is placed transversely, immediately below the inguinal crease. The femoral artery is identified then the transducer is moved laterally to identify the triangular looking femoral nerve, the fascia lata, fascia iliaca and the iliopsoas muscle. A short-beveled needle is used and the block can be performed with an in plane or out of plane approach. Two fascial 'pops' are often felt as the needle tip passes though the fascia lata then iliaca. This brings the needle tip under the fascia iliaca and lateral to the femoral nerve. On injecting the local anesthetic, the fascia iliaca should be seen to separate from the iliopsoas muscle with local spreading both medially towards the femoral nerve and laterally to block the lateral femoral cutaneous nerve. If above the fascia iliaca or in the iliopsoas muscle the needle will have to be adjusted before further injection. A volume of 0.5 mL/kg is required to a maximum of 30 mL. A catheter can be reliably passed into the space for prolonged postoperative analgesia, infusing at 0.2 mL/kg/h. Leakage is common but does not usually impair efficacy.

10.9.2 Femoral Nerve Block

Femoral nerve block can be safely performed as a landmark-based technique, however real-time in plane or out of plane ultrasound has become the new standard. The ultrasound-guided technique is similar to the fascia iliaca technique described above, but smaller volumes of local anesthetic (0.2–0.3 mL/kg) can be placed around the triangular femoral nerve. Block duration is around 6 h. Parents and children should be warned that weight bearing activities must be avoided until resolution of the blockade.

10.9.3 Saphenous (Adductor Canal) Block

The saphenous nerve is a purely sensory terminal branch of the femoral nerve which innervates the anteromedial aspects of the lower leg from the distal thigh to foot. This block is used to provide analgesia without causing quadriceps weakness for knee and tibia surgery, and in combination with a sciatic nerve block for major foot surgery to cover the medial aspect of the ankle and foot. It is commonly blocked using an ultrasound-guided technique in the mid-thigh, where it runs in the adductor canal underneath the sartorius muscle, directly lateral to the superficial femoral artery and vein. The technique is the same as in adult practice and 0.1–0.2 mL/kg of local anesthetic is used.

10.9.4 Sciatic Nerve Block

Landmark and ultrasound approaches at both the gluteal and popliteal areas are similar to adult techniques and provide analgesia to all superficial and deep structures below the knee, apart from the medial aspect of the calf and foot. This block is

useful as an alternative to epidural analgesia in major foot surgery (talipes, tarsal osteotomy), combined with femoral or saphenous nerve block if surgery involves the medial side of the foot. The volume required is 0.3–0.5 mL/kg to a maximum of 20 mL.

10.10 Peripheral Nerve and Wound Catheters

Peripheral catheters are popular in pediatric anesthesia to provide prolonged analgesia for surgery associated with moderate to severe postoperative pain. They are used primarily for major limb surgery but can also be used for truncal blocks or as wound catheters. Catheters offer a longer duration of analgesia over single shot blocks, improving postoperative pain management and facilitating early rehabilitation. They are also used for various chronic pain states. Peripheral catheter techniques are considered safer than neuraxial techniques as the sequelae from complications such as bleeding and infection are likely to be less severe. Minor complications such as catheter dislodgement, occlusion and leakage are common. A prospective study of over 2000 peripheral nerve block catheters in children by the PRAN group showed a complication rate 10.7–13.5%, similar to adult practice. There were no reports of persistent neurological problems, serious infection or local anesthetic systemic toxicity. Catheter tip position should be confirmed with ultrasound and generally no more than 2–3 cm of catheter needs to inserted beyond the tip. Tunneling the catheter helps to minimize the risk of accidental dislodgement and application of tissue glue at the puncture site reduces leakage under the dressing. The catheter should be flushed once it has been tunneled and secured as catheters can easily become kinked. Recommended rates using ropivacaine 0.2% (2 mg/mL) or levobupivacaine 0.125% (1.25 mg/mL) are 0.1–0.2 mL/kg/h to a maximum of 5 mL/h.

Review Questions

1. Describe anatomy and technique to perform caudal epidural block for postoperative pain relief for circumcision in a 3 year old. What volume and concentration of agents will be required?
   Why isn't a fluid load required before performing the block?
2. What factors need to be considered when running local anesthetic infusions in neonates?
3. What are the local anesthetic options to provide pain relief after bilateral inguinal hernia repair in a 2 year old? What are the risks and benefits of each technique?
4. You are about to perform a caudal block for a 8 month old baby and you notice a midline indentation in the skin in the sacral region. How will you decide if it is still safe to proceed with the caudal?

5. You plan to perform a spinal block in 3 month old baby. What level will you insert the needle? What local anesthetic will you use, and how much will you inject? How long is this block likely to last? If the baby becomes apneic, what might this indicate?

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Respiratory Illnesses and Their Influence on Anesthesia in Children

11

Britta von Ungern-Sternberg and David Sommerfield

Respiratory disease is a frequent co-morbidity in children, and is the commonest reason for hospital admission in children aged 4 years and younger. Illnesses of the upper airway and respiratory tract are often the cause of adverse events during pediatric anesthesia. Approximately two thirds of critical incidents and one third of cardiac arrests in pediatric anesthesia have a respiratory cause. Whilst arrests due to a cardiovascular problem occur mainly in children with known cardiac disease, critical incidents or cardiac arrests with an underlying respiratory cause are seen in children who were previously healthy. This is particularly important in younger children since the risk for respiratory events decreases by about 10% for each year older the child becomes. Many of the risk factors for respiratory events are associated with airway inflammation and subsequent hyper-reactivity of the airway and bronchi, such as asthma, recent upper respiratory tract infection (URTI) or passive smoke exposure. These risk factors are common in the pediatric population and easily detectable by thorough history taking. They are cumulative and the risk of adverse events correlates with the number of risk factors better than with tests of airway inflammation such as blood markers of allergy or exhaled nitric oxide.

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Table 11.1 Risk factors for respiratory events during anesthesia

Key points from history associated with risk of respiratory events during anesthesia
Young age
History of prematurity, chronic lung diseases including asthma or cystic fibrosis
Recent upper respiratory tract infection
Symptoms associated with bronchial hyper-reactivity: wheeze, nocturnal cough, purulent nasal discharge, fever
Symptoms of sleep disordered breathing: snoring, apnea, mouth breathing
Personal or family history (>1 first degree relative) of atopy (asthma, eczema, hay fever)
Exposure to passive (parental) smoking

11.1 Bronchial Hyper-Reactivity

Recent upper respiratory tract infection (URTI), passive smoke exposure, chronic lung diseases such as asthma or cystic fibrosis, and atopy are associated with bronchial hyper-reactivity and increased airway reflexes (an 'irritable' airway). Mechanical stimuli during procedures such as laryngoscopy, intubation and suctioning of the airway can lead to bronchospasm or laryngospasm, particularly in those with increased reactivity. These reflex responses are mainly under vagal control and are more active in younger children. Thus, induction and extubation are the commonest periods for these problems to occur. This section highlights how to identify and manage at risk children.

Atopy, a general tendency to allergic hypersensitivity, may be present in children with eczema, hay fever, asthma or environmental allergies. Eczema, and to a lesser extent hay fever, are early risk factors for development of recurrent wheeze and asthma. These conditions or even a family history of them, is associated with a higher risk of respiratory events during anesthesia. A history of eczema is of importance in the younger child as symptoms of bronchial hyper-reactivity might not yet have become apparent. Additionally, about 10–15% of parents report respiratory symptoms such as nocturnal cough, wheezing, or wheezing with exercise even when asthma has not been diagnosed. These symptoms usually reflect underlying bronchial hyper-reactivity and increased risk (Table 11.1).

11.2 Asthma

For unknown reasons, the incidence of both allergy and asthma have increased in recent decades, with the prevalence of asthma around 20% in western societies. The rise appears to be levelling off.

11.2.1 Background

Asthma is a chronic inflammatory disorder of the airway associated with variable airflow obstruction and airway re-modelling. Wheezing is the main symptom, but there is underlying airway inflammation and increased airway reactivity. Children without a history of allergy tend to outgrow their asthma, making asthma more

Table 11.2 Commonly used medications for treatment of asthma in children

Group	Agent	Example product	Route	Role
Beta-2 agonists:				
– Short acting	Salbutamol	Ventolin	Inhal/ Neb	Treatment of bronchospasm Pre-op optimization
– Long acting	Salmeterol	Serevent		
Inhaled steroids	Fluticasone Budesonide	Flixotide Pulmicort	Inhal	Treatment of airway inflammation Prevention of bronchospasm
Leukotriene modifiers	Montelukast	Singulair	Oral	Anti-inflammatory and b/dilator effects. Reduce frequency exacerbations
Cromolyns	Cromolyn, Nedocromil	Intal, Tilade	Inhal	Prevention of bronchospasm
Prednisolone			Oral/ IV	Rescue therapy for acute exacerbation

common in children than adults. Of children aged 3 years who wheeze, 60% will stop wheezing by school age, and even more by adolescence.

Treatment is directed at the airway inflammation and resulting bronchospasm (Table 11.2). All children should use metered dose inhalers (MDI) via a spacer device and facemask, rather than the inhaler directly. The spacer is a tubular container placed between the inhaler and mask. The inhaler dose mixes with air in the spacer, and is then inhaled over several breaths. The combination of an MDI with a spacer gives better deposition of the inhaled drug into the bronchioles compared to a nebulizer. If no spacer is available, a nebulizer is better than an MDI with no spacer. Although the dose in the nebulizer bowl is much larger than an MDI dose, only a tiny proportion of the nebulizer dose is inhaled, and most is lost to the atmosphere. Nebulizers are also noisy and may frighten young children.

Oral steroids are only used in short courses to control an acute flare in symptoms, as long-term systemic steroids affect growth. Most children have mild asthma that is well controlled and characterized by infrequent episodes, perhaps only related to URTIs in the winter months. Children particularly at risk are those with recent hospital admissions, escalating therapy or use of oral steroids, and those who have had episodes of sudden, severe asthma requiring intensive care.

Note
Although asthma causes wheezing, the underlying chronic airway inflammation is the focus for long-term treatment. This is why bronchospasm may occur from a stimulus that would not normally cause bronchospasm.

11.2.2 Anesthesia and Asthma

Airway instrumentation during anesthesia is a potent stimulus that can trigger bronchospasm. Perioperative management of asthmatic children aims to optimize

asthma treatment and minimize the effects of increased airway reactivity. Although asthmatic children have an increased risk of respiratory events, the risk of bronchospasm and morbidity is low in the child with stable asthma.

Keypoint
Audible wheeze at the time of preoperative assessment indicates a high risk of intraoperative respiratory adverse events. The child should be wheeze-free at induction.

11.2.2.1 Preoperative Treatment for Asthmatic Patients

Children with stable asthma should continue their regular medications. Children who have had recent symptoms or are undergoing tonsillectomy benefit from preoperative salbutamol. Children who are wheezing at the time of the preoperative assessment are at high risk for respiratory complications and should therefore always be given inhaled salbutamol preoperatively. If the child's symptoms are poorly controlled, a short course of oral steroids could be discussed with the child's physician. Steroids need to be given at least 24 h before surgery because their effect on airway reactivity begins after 6–8 h and is maximal after 12–36 h. Children taking long-term inhaled steroids do not have suppression of the hypothalamic-pituitary axis and do not need perioperative steroid supplementation, unlike the rare child taking long-term oral steroids.

Note
An inhaler used with a spacer is the best way to give salbutamol to young children. If this combination is not available, use a nebulizer. The nebulizer dose for salbutamol in children is 0.05 mg/kg (minimum 1.25 mg, maximum 2.5 mg) in 3 mL saline.

11.2.2.2 Intraoperative Management of Asthmatic Children

Bronchospasm can be avoided by choosing appropriate anesthetic techniques (Table 11.3). It is most likely to occur with airway manipulation such as the insertion or removal of an airway device, and particularly an endotracheal tube. A bolus dose of propofol 1–3 mg/kg suppresses airway reflexes and should be considered in the absence of contraindications. Although there is little difference between the effect of sevoflurane and isoflurane on the airway, desflurane increases airway resistance in all children and should be avoided. IV induction with propofol is also protective compared with an inhalational induction with sevoflurane—although inhalational agents are bronchodilators, airway obstruction and other respiratory events are common during the slower induction with them. Agents that may blunt reflex bronchoconstriction or cause bronchodilation such as clonidine, ketamine or propofol are preferred. Atracurium and morphine and are associated with histamine release, although usually only cutaneous histamine release occurs in children and

Table 11.3 List of factors during anesthesia that may contribute to incidence of bronchospasm in children with bronchial hyper-reactivity

Less likely to trigger	More likely to trigger
Preoperative inhaled salbutamol	
α2 agonists, clonidine	Inhalational induction with sevoflurane
IV induction with propofol	
Ketamine	Desflurane
Fentanyl	Morphine
Maintenance with Propofol, sevoflurane or isoflurane	Atracurium and neostigmine
Face mask or LMA	Endotracheal intubation
Deep removal of airway device	Awake removal of airway device
Specialist pediatric anesthetist	

these drugs are often used in asthmatic children. Non-steroidal anti-inflammatory drugs can worsen bronchospasm by increasing leukotrienes. However apart from children with nasal polyps or severe, uncontrolled asthma, the risk from NSAIDs is low (2% compared to 7% in adults) and generally easily treated.

Tip
A bolus of propofol 1–3 mg/kg reduces the risk of airway and respiratory events during insertion or deep removal of any airway device.

Tip
Deepening anesthesia is an important step because infants and young children often cough, breath hold, develop rigidity of the chest and abdominal muscles and become very difficult to ventilate as anesthesia is lightened. This is often confused with severe bronchospasm.

11.2.2.3 Treatment of Bronchospasm During Anesthesia

As soon as a bronchospasm is suspected, 100% oxygen is given and anesthesia deepened. Deepening anesthesia is an important step because infants and young children often cough, breath hold, and develop rigidity of the chest and abdominal muscles as anesthesia is lightened. Repeated doses of salbutamol are given until bronchospasm is relieved. Less than 3% of aerosolized drug given through a supraglottic airway or endotracheal tube reaches the patient. Many factors reduce the delivery of the drug, and the disease itself will favor delivery to areas of the lung that are already better ventilated. Only very limited drug delivery is achieved with 'home made' devices such as a 50 mL syringe delivering into the angle piece or trachea, and the devices are not without risk. The most effective method during anesthesia is to use an MDIs with an inline spacer (Fig. 11.1). Second best is directly connecting the outlet of the aerosol canister to the airway device. If repeated doses of salbutamol from an MDI are insufficient, then give IV salbutamol 10–15 μg/kg IV bolus over 10 min and consider infusion 1–5 μg/kg/min. In severe resistant cases

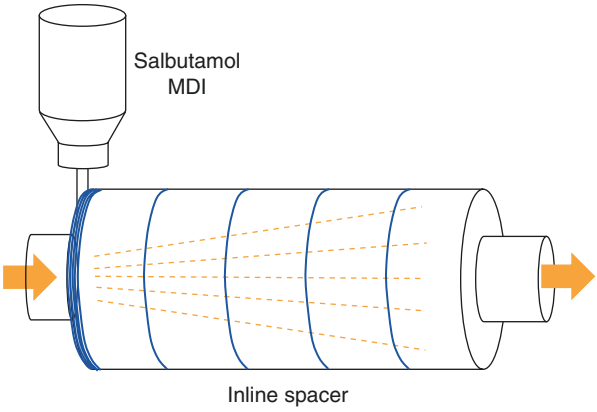

Fig. 11.1 An inline inhaler as close as possible to the ETT or LMA is the best method to deliver salbutamol into the anesthetic circuit

ketamine, magnesium sulfate (40 mg/kg/IV over 20 min) and adrenaline (epinephrine) (0.01 mg/kg IV) can be considered. Neuromuscular blockade may also help.

Consider that suctioning of airway secretions via the ETT is a powerful stimulus that may worsen bronchoconstriction. Ventilation with slow breaths, a long expiratory time and plateau pressures less than 30 cm–35 cmH_2O all aim to allow full expiration and reduce air trapping. Flow-time loops can be monitored to ensure expiratory flow has finished and avoid raising intrinsic PEEP.

11.3 Upper Respiratory Tract Infection (URTI)

Over 200 viruses are associated with the common cold, or URTI, and there is often superimposed bacterial infection. Rhinoviruses account for about 80% of URTIs and have a predilection for the nasal mucosa and upper respiratory tract. Respiratory syncytial virus (RSV) can cause cold-like symptoms but causes a more severe infection particularly affecting the bronchi. The viral infections causing URTIs also cause airway inflammation, increased secretions and hyper-reactivity of the airway and bronchi, much like asthma. It can be difficult to decide whether or not to proceed with elective surgery in a child with a recent URTI. Between a third and a half of children presenting for surgery have had an URTI in the preceding 6 weeks. Preschool-aged children undergoing ENT surgery have an average of six to eight URTIs per year, potentially leaving only a few weeks of the year when the child is well and not recently had an URTI.

Note
Although called upper respiratory tract infections, the lower respiratory tract is often affected, causing bronchial hyper-reactivity and a susceptibility to atelectasis.

11.3.1 Risks of Anesthesia After a Recent URTI

The risk of adverse respiratory events are two to three times more likely with a current or recent URTI. Increased reactivity of the airway can persist for 6 weeks or longer, well beyond clinical symptoms. The risk for adverse events is highest 2 weeks after an URTI. During the acute URTI itself, the incidence is increased compared to healthy children but is still less than the risk 2 weeks after the URTI. By 4 weeks, the risk for respiratory adverse events is similar to, or even lower, than in healthy children—probably due to endogenous mechanisms counteracting the hyper-reactivity.

A child with an URTI or recent URTI is prone to laryngospasm, coughing and bronchospasm and tends to desaturate more rapidly during disconnection for positioning or transfer (Table 11.4). They often need oxygen for an hour or two postoperatively and occasionally develop a chesty cough that was not present before surgery. Factors affecting the risk from URTI are listed in Table 11.5.

Table 11.4 List of risks and reasons to proceed with anesthesia despite recent URTI in a child

Possible risks	Reasons to proceed
Risk of laryngospasm and bronchospasm	Risk does not reduce for 2–3 weeks
Irritable airway with coughing and desaturation	URTIs frequent so difficult to find URTI free time
Possibly increased risk chest infection	Family disruption and inconvenience
Brief oxygen dependency postoperatively	Most airway problems minor and easily managed
	Maintain efficiency of theatre utilization

Table 11.5 Risk factors for developing perioperative adverse respiratory event or complications from URTI

Factor	Clinical feature
Child	Infant or young child Former preterm baby Pre-existing cardiac or respiratory disease Comorbidities, ASA 3 Clinical signs: • Green or yellow nasal secretions • Productive, moist cough • Wheezing or crepitations • Fever >38° • Headache; irritability; not feeding Lethargic or generally unwell Passive smoking
Anesthesia	Intubation required
Surgery	Major elective surgery with post-op stress response Painful wound likely to inhibit coughing Surgery involving airway
Logistics	Limited expertise in team managing child with URTI or of this age Hospital facilities (private day hospital vs tertiary center

11.3.2 Reasons to Proceed Despite a Recent URTI

There are several practical reasons to proceed with anesthesia in a child who has had a recent URTI. Airway incidents can occur in children with or without an URTI and any anesthetist caring for children should be able to manage these incidents. Although there is an increased risk, with careful management children can undergo procedures safely. Also, URTIs are frequent and it may be difficult to arrange theatre time when the child is well. Finally, cancellation creates practical problems for the family and health service. Parents may have travelled from far away, arranged time off work, and arranged child care for siblings. Time in a busy operating theatre may be wasted. Clearly the child's safety is paramount and these various practical problems can be considered, but placed into context (Table 11.4).

11.3.3 Decision on Whether to Proceed or Cancel

Anesthetizing a child with a recent URTI is sometimes unavoidable. There are however, children in whom the likelihood of problems is so high that most anesthetists would not proceed with elective surgery. Factors to help identify these children are listed in Table 11.5. In children with symptoms of a lower respiratory tract infection (productive moist cough, crackles or wheeze on auscultation or positive chest-x ray findings) or with a fever, elective surgery should be postponed for approximately 3–4 weeks. These children are usually off-color and look ill. Parents are helpful in determining the child's condition, as they are usually able to clarify the severity of symptoms and report if the child is getting better or worse. In chronically ill children with recurrent (aspiration) pneumonia it can be very difficult to assess whether the child is fit for surgery or not. Often a decision can be made based on the parent's assessment that the child is as well as possible. If proceeding, children should be observed longer post operatively or kept overnight and should be advised to seek review early if respiratory symptoms develop.

11.3.4 Management of Anesthesia in a Child with Recent URTI

If the risk-benefit ratio suggests proceeding with anesthesia, management is similar to that of a child with asthma. IV induction and avoiding intubation if possible are worthwhile steps. It is important to minimize instrumentation of the airway, ensure adequate depth during instrumentation and to maintain end-expiratory lung volume with recruitment maneuvers and PEEP to reduce atelectasis. Maintaining CPAP for a short time after extubation will also prevent atelectasis. Positioning the patient on their side with 30° head up is also useful to help maintain the airway open and reduce basal atelectasis. Removal of any airway device under deep anesthesia should be considered, or otherwise with the child well awake. However, as anesthesia lightens

the irritable airway is likely to result in a combination of coughing, breath-holding, chest and abdominal muscle rigidity and desaturation, which is often mistaken as bronchospasm.

Tip
Steps to manage coughing and desaturation during anesthesia or at extubation:

- Deepen anesthesia with propofol or volatile agent
- Confirm airway remains patent with capnography. Ventilate or assist inspiration holding CPAP with 80–100% O_2
- If desaturation, include a recruitment maneuver to reverse atelectasis. Give 5–10 slow breaths held for 5–10 s up to 35–40 cmH_2O, then restart ventilation or allow spontaneous breathing with PEEP or CPAP.
- Slow emergence with propofol or clonidine, and consider deep extubation if appropriate

11.4 Bronchiolitis

Bronchiolitis is a lower respiratory tract infection with coryza, cough, respiratory distress and wheeze mostly affecting infants. One third of children are affected in the first 2 years of life, and one in ten of these children are hospitalized, including a small number who develop respiratory failure requiring ventilation. Most cases are caused by the respiratory syncytial virus (RSV) causing bronchial inflammation with airway plugging, increased work of breathing, atelectasis and hypoxia. It may also cause apneas in neonates. Mortality is low, but young infants and those with underlying cardio-respiratory disease are vulnerable. The difficulty with bronchiolitis and anesthesia is the underlying ventilation-perfusion mismatch and increased airway reactivity. These changes persist after the acute illness and gradually improve over several weeks. The considerations are similar to children with URTI, though in this case the patient group is typically younger and the disease process more severe. When possible, postponing anesthesia and surgery for several weeks after the acute episode is best.

11.5 Passive and Active Smoking

Young children are exposed to cigarette smoke in the home, car and outdoors. Passive smoking results in airway hyper-reactivity and increases respiratory complications with anesthesia. Carboxyhemoglobin and nicotine levels are also increased in children exposed to passive smoking. Cessation of passive or active smoking 48 h before surgery partly reverses these changes, although in adults it takes 4–6 weeks after cessation to improve pulmonary function.

11.6 Chronic Lung Disease of Infancy and Bronchopulmonary Dysplasia

Chronic lung disease of infancy is a group of disorders starting in the neonatal period. Several pulmonary conditions and their treatment (high FiO_2 or ventilation) in the neonate produce airway and parenchymal inflammation and then limit development of the airways, leading to chronic airflow obstruction and airway hyperreactivity. The commonest disorder is bronchopulmonary dysplasia (BPD). BPD is defined by the requirement for supplemental oxygen at 28 days of life. Severity is graded by the oxygen requirement and respiratory support needed at 36 weeks post menstrual age. Advances in neonatal care have made BPD infrequent in infants born after 30 weeks. The commonest cause of BPD is Respiratory Distress Syndrome (RDS) of the newborn. RDS is a clinical and radiological diagnosis made shortly after birth in preterm neonates with difficulty breathing due to surfactant deficiency. It was previously known as hyaline membrane disease (HMD) based on histopathological characteristics seen in babies that died before modern neonatal care.

In normal human lung development, alveolarization begins around 36 weeks gestation, and alveoli grow in size and number until 8 years of age. In BPD, lung development limits the final branching divisions of the alveoli and the lungs have larger but far fewer alveoli available for gas exchange. Inflammation from disease or supportive treatments superimposed on the under-developed lung can lead to more reactive airways in the long term, and lower capacity lungs that will be symptomatic at an earlier stage and with a lesser reserve (Fig. 11.2).

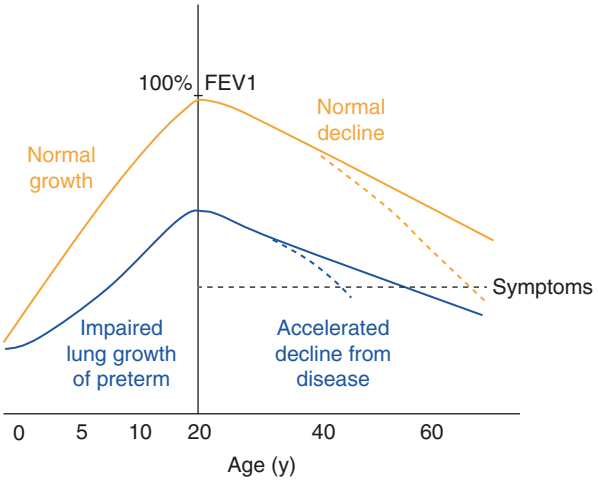

Fig. 11.2 Effect of lung disease on subsequent lung function later in life. Bronchopulmonary dysplasia in the neonatal period slows lung development, and former preterm children do not reach the same lung function at age 20 years. After that age, lung function deteriorates in all adults, but former preterm patients are starting at a lower level and develop symptoms earlier in adulthood. The decline in lung function is accelerated by other injuries, such as smoking (dashed line)

Infants with BPD may require low flow oxygen therapy at home after discharge. They are often 'chronically chesty', have lower respiratory reserve and are prone to respiratory failure from viral chest infections. Pulmonary vasoconstriction is more likely as BPD renders the pulmonary capillary network sensitive to stimuli such as hypothermia, pain or acidosis. A small number of infants with severe BPD have impaired right ventricular function which can worsen during anesthesia. Those with mild disease eventually become asymptomatic by 2–3 years, but still have abnormal reactivity and poorer function compared to the normal population through life (Fig. 11.2).

Note
Babies born very preterm and who developed BPD have abnormal pulmonary function throughout childhood. Pulmonary function improves as the child grows older but is starting from a lower reserve. Risk factors for significant BPD include being born before 28 weeks, needing more than brief mechanical ventilation, oxygen therapy after 40 weeks and re-admissions for chest infections.

11.7 Cystic Fibrosis

Cystic fibrosis (CF) is an autosomal recessively inherited, multisystem disorder predominately affecting the lungs. It has a very broad spectrum of severity but in general worsens as the patient becomes older. Molecular subtype diagnosis and therapy have improved immensely over the years and most children with CF are reasonably well. The end stages of the disease have mainly shifted into adulthood.

11.7.1 Background

The underlying problem in CF is mutation of the transmembrane conductance regulator (CFTR) gene on chromosome 7 causing abnormal chloride transport in epithelial cells. Ultimately, this affects electrolyte transport in the airway, sweat ducts, pancreas, intestine and vas deferens of males. The severity of the clinical illness is variable, but progressive, obstructive lung disease is the main cause of morbidity and death. The underlying epithelial defect causes thickening of airway mucus and abnormal clearance of secretions in the lung. This in turn causes mucus plugging, mechanical obstruction of the airway, atelectasis and recurrent bacterial infections. Thickening of intestinal secretions often leads to intestinal obstruction, including meconium ileus in newborns. Many children with CF develop progressive pancreatic disease which causes intestinal malabsorption and malnutrition. Pancreatic enzyme replacement therapy before meals is routine. Diabetes becomes common in adolescence. Hepatic

Table 11.6 Manifestations of cystic fibrosis

Organ system	Manifestation
General	Failure to thrive (malabsorption)
Respiratory	Bronchiectasis Bronchial Hyper-reactivity Eventual respiratory failure Large FRC, decreased FEV1, obstructive pattern on VFT's
Cardiac	Eventual right ventricular hypertrophy and Cor pulmonale
ENT	Nasal polyps and sinusitis
Gastrointestinal	Meconium ileus or intestinal atresia as neonate intestinal obstruction Eventual cirrhosis and portal hypertension Gastro-esophageal reflux (rarely a problem in children) Hypersplenism
Bone	Osteoporosis and uncommonly recurrent arthritis
Reproductive	Delayed puberty, infertility

Not all manifestations are present in childhood and many become apparent only as the disease progresses throughout adulthood

Table 11.7 Progression of lung disease with advancing age in cystic fibrosis

Age group	Lung pathology
Infancy to Childhood	Mucous plugging Recurrent bacterial infections Colonization with resistant organisms Progressive parenchymal disease
Adolescence to Adulthood	Bronchiectasis Cystic, fibrotic changes Emphysema Respiratory failure Cor pulmonale

dysfunction also gradually develops as the patient grows older. Abnormal mucous clearance in the upper airway causes chronic sinusitis (Table 11.6).

Multiple chest infections cause diffuse airway inflammation and damage to the airways and surrounding lung parenchyma. This leads to bronchiectasis, emphysema, fibrotic cavitations and diffuse cystic changes on chest X-ray in adulthood (Table 11.7). Inflammation and infection begin early in life and infants who have CF may have considerable pulmonary dysfunction despite appearing asymptomatic.

Proactive medical treatment has greatly improved prognosis with a median predicted survival age of nearly 38 years. Infants born now with CF would be expected to live into their 50s. The past decade has seen the development of orally bioavailable small molecule drugs that target some of the defective CFTR proteins and are disease-modifying in some patient subsets. Management aims to prevent infections causing this lung damage, either with regularly scheduled intravenous antibiotics independent of clinical status, or therapy in response to acute changes. Both approaches require anesthesia for vascular

access. Some centers also regularly perform surveillance bronchoscopy with CT scanning, which also requires anesthesia.

11.7.2 Anesthesia and CF

Anesthesia is frequently required for endoscopy, bronchoscopy, ENT and vascular access procedures. Since these children now have stratified follow-ups, perioperative therapy should be optimized by the treating specialist physician. This will usually include physical therapy and preoperative antibiotic therapy. For emergency surgery, the treating specialist physician would be involved in at least the postoperative care.

Pulmonary function is assessed through exercise tolerance, recent infections or requirement for admission, changes in sputum and oxygen saturation on air. Chest X-ray and pulmonary function tests may have been performed recently or can be requested in selected children. Arterial blood gases are rarely helpful and are painful. Children with CF have a lot to do with hospitals and they and their parents will be useful sources of information about their condition and past anesthetic experiences and preferences. CF children often benefit from premedication.

Tip
Principles of anesthesia in cystic fibrosis are:

- Maintain lung volume
- Prevent secretions drying and accumulating
- Be alert to bronchial hyper-reactivity
- Tailor anesthesia and analgesia to allow child to cough as soon as possible

Although CF is associated with gastro-esophageal reflux, aspiration does not appear to be a problem in children with CF. Pulmonary disease slows the uptake of volatile agents but inhalational induction is usually straightforward. Chronic infection and airway inflammation mean precautions similar to those taken in an asthmatic child to avoid bronchospasm and airway irritation are advisable. Other precautions taken during anesthesia are humidification to prevent further drying of secretions, maintenance of end-expiratory lung volume, avoidance of nitrous oxide to reduce atelectasis and enabling the child to cough effectively soon after the procedure. Most children tolerate anesthesia for minor surgery as well as any other child, though perhaps requiring oxygen briefly afterwards. Children at risk are mainly those who are older with more noticeable lung disease having major surgery, particularly surgery that inhibits coughing afterwards. This is a high-risk group needing special care with anesthesia and postoperative management. Recent data

suggests that CF children with mild to moderate lung disease do not experience significant deterioration in central or peripheral airway function following GA and have a low rate of complications.

11.8 Obstructive Sleep Apnea

Sleep disordered breathing encompasses a range of upper airway obstruction during sleep. The mildest form is primary snoring without other symptoms. Intermediate forms have associated symptoms or changes in $PaCO_2$ or PaO_2. The most severe form is obstructive sleep apnea (OSA). The incidence of perioperative respiratory complications is ten times higher for children with OSA compared to those without OSA.

OSA is characterized by repeated collapse of the upper airway with periods of obstructive or central apnea. Narrowing of the upper airway is not confined to a discrete region, but rather occurs in the entire upper two-thirds of the airway where adenoids and tonsils overlap. Children in the preschool and primary school years have the highest incidence of OSA, as this is the age when their tonsils are largest relative to the rest of their airway. Adenotonsillar hypertrophy is the main cause of OSA in children and tonsillectomy is the initial treatment (Table 11.8). In contrast to adults, there is little relationship between OSA and obesity in children—only 10% of children with OSA are obese and up to a quarter of children are undernourished. Teenagers with OSA, however, follow the adult pattern of causation and symptoms. Obesity is still a common reason for unanticipated readmission and residual disease after adenotonsillectomy. There are three broad reasons for OSA in children: enlarged soft tissues, small bony upper airway and poor neuromuscular control of the upper airway (Table 11.9).

11.8.1 Diagnosis

Parental history is relied upon for a clinical diagnosis. Nearly all children with OSA snore and children who do not snore are unlikely to have OSA. Primary,

Table 11.8 Comparison of features of OSA in children and adults

	Child with OSA	Adult with OSA
Most common age	2–6 years	Middle-aged
Main cause	Adenotonsillar hypertrophy	Obesity
Sleep architecture	Normal, restless sleep. Obstruction during REM sleep	Decreased REM, arousal after apnea. Obstruction during non-REM and REM sleep
Consequences	Behavioral changes, hyperactivity, enuresis. Day time somnolence may occur but uncommon	Day time somnolence
Treatment	Surgical (tonsillectomy)	Medical (CPAP)

Table 11.9 The three underlying mechanisms of OSA in children with common examples

Mechanisms	Examples
Enlarged soft tissues	Adenotonsillar hypertrophy Macroglossia Obesity
Small bony upper airway (Small midface or mandible)	Craniofacial syndromes Down syndrome Pierre Robin Achondroplasia
Hypotonia of upper airway	Cerebral palsy Neuromuscular disorders

unobstructed snoring occurs in 3–12% of preschool aged children, whereas OSA with obstructed snoring occurs in only 2% of this age group. A large number of children with OSA show behavioral changes including lack of concentration at school, hyperactivity and enuresis, which contrasts with the day time somnolence seen in adults. Long-standing, untreated OSA in older children can lead to pulmonary hypertension and cor pulmonale, though this is rarely seen in contemporary practice. History and examination do not reliably distinguish between primary snoring and OSA. Overnight polysomnography is the gold standard for diagnosis, but other modalities such as nap polysomnography or oximetry are occasionally used. A hypopnea is an episode of restricted flow in breathing. The Apnea Hypopnea Index (AHI) is the number of obstructive, central or mixed apneas and hypopneas per hour of sleep and is the parameter from polysomnography used to quantify the severity of the sleep disordered breathing. Only obstructive apneas are used to make the diagnosis, with one or more regarded as significant. Severe OSA is defined as 10 or more obstructions per hour (this would be regarded as mild disease in an adult), or saturations falling below 80%. Central apneas are common in very young children even without OSA, and AHI can be divided into central and obstructive indexes. Central apneas will also have anesthetic implications for the level of postoperative monitoring and risk from opioids.

11.8.2 Anesthetic Implications

Since tonsillectomy is the main treatment of OSA in children, these children are most likely to be encountered on ENT lists. Management of anesthesia for tonsillectomy in these children is covered in Chap. 16 Sect. 16.2. In summary, the main issues are airway obstruction in the postoperative period and sensitivity to opioid analgesia. Characteristics of children with OSA who are particularly at risk are listed in Table 11.10. Children who have had tonsillectomy are amongst the highest risk for postoperative airway obstruction. Children with OSA who are undergoing anesthesia for other procedures seem to be at much lower risk and can usually be managed as day cases. The 5 point STBUR (Snoring/Trouble Breathing/Un-Refreshing sleep) is a brief, validated preoperative questionnaire with a score >2 predicting desaturation events post operatively.

Table 11.10 Risk factors for airway obstruction after anesthesia in children with OSA

Children with OSA at higher risk after anesthesia
Age less than 2 years, and especially less than 1 year
Airway surgery (including tonsillectomy, adenoidectomy)
Facial abnormality with reduced oropharyngeal size
Downs Syndrome
Serious comorbidity (neuromuscular disease, cardiac)
Preterm birth
Obesity
Severe OSA on polysomnography or saturation <85% on overnight pulse oximetry
SpO_2 nadir of <80% or peak pCO_2 > 60 mmHg (8 kPa)

Sedative premedication can be used with caution if required. Midazolam occasionally causes airway obstruction in these children and a reduced dose of around 0.3 mg/kg may be safer. Clonidine is a better choice as it does not lead to hypercarbia or hypoxemia. Children having an inhalational induction can enter a phase with quite an obstructed airway needing CPAP, when they are still too light to accept an oral airway. Bag-mask ventilation after an IV induction may be awkward, but is facilitated by jaw thrust and by inserting an oral airway. Intraoperative management is directed at minimizing postoperative airway obstruction. The principles include maintaining a level of anesthesia that facilitates rapid awakening, minimizing opioid use and arranging appropriate monitoring postoperatively. This may include HDU/ICU for high risk children undergoing airway procedures, or additional time in the day ward before discharge home or overnight stay with pulse oximetry.

The clinical features of OSA are usually improved after tonsillectomy, although it can take a number of days to weeks after surgery. Overall 20% of children are not improved by surgery, but the improvement depends on the severity of the OSA before tonsillectomy. One hundred percent of children with mild OSA resolve their symptoms, but only 64% of those with severe OSA (AHI > 20/h) resolve their symptoms. In children with comorbid conditions such as obesity, craniofacial abnormalities, age less than 3 years, or severe OSA, the cure rate as gauged by sleep study can be as low as 40%. Thus, high-risk patients are likely to have some residual disease which accounts for much of their increased risk of respiratory adverse events post operatively. For those deemed suitable for discharge with opioids, a test dose with monitoring should be considered.

Note
OSA may not improve for several days or weeks after adenotonsillectomy and around 20% of children are not improved by surgery.

Review Questions

1. A 2 year old child is being ventilated through a 4.5 mmID ETT using a constant pressure ventilator. The $ETCO_2$ has risen, and you suspect bronchospasm.
   (a) List the common potential triggers of intraoperative bronchospasm
   (b) What other causes of increased $ETCO_2$ should you consider?
   (c) What is the management of intraoperative moderate to severe bronchospasm?

2. Why are children with OSA more likely to develop respiratory problems after tonsillectomy than those without OSA?
3. Why is a 3 year old who has an URTI scheduled to undergo tonsillectomy at greater risk of complications compared with a 6 year old who has an URTI scheduled for circumcision?
4. A 4 year old ex-preterm child presents for myringotomy and grommet insertion as a day case. On arriving you notice a nasal discharge.
   (d) What features in the history and examination are associated with an increased risk of airway complications?
   (e) Apart from history and examination what factors (surgical, social, institutional) would you consider in deciding whether this child should be deferred or not?
   (f) If the case proceeded, what anesthetic strategies could be used to reduce the risk of complications?

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Chronic Disease of Childhood

12

Alison Carlyle and Soo-Im Lim

This chapter describes several important non-respiratory diseases that may affect anesthesia in children. Optimal anesthetic management of these children requires careful planning and a collaborative approach with the multidisciplinary teams involved in their care.

12.1 Cerebral Palsy

Cerebral Palsy (CP) is an umbrella term used to describe a spectrum of neurological motor disorders that can be associated with other conditions such as seizure disorders and intellectual impairment. Most children have increased muscle tone or spasticity in one of more muscle group or limb. A minority of children have ataxia or dystonia rather than spasticity. Cerebral palsy results from pathogenic insults to the developing brain in utero or in the post-natal period. These insults include intracerebral hemorrhage, genetic disorders, fetal infection such as rubella and CMV, pre-eclampsia, peri-partum hemorrhage and maternal hyperthyroidism. Extreme prematurity and low birth weight are important risk factors. Approximately 80% of cases develop antenatally with the remainder in the first 2 years of life. The incidence is 1–2.5/1000 live births in western countries and has remained steady with the increase in survival rates of premature infants.

These children present with a broad range in the severity of their symptoms. Some have an isolated limb spasticity and normal intellect, while others have severe spasticity, limb deformity and developmental delay. The Gross Motor Function Classification System (GMFCS) categorizes the severity into mild (level 1) to severe (level 5) based on the level of movement and activity a child can perform. Children

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with the severe GMFCS 5 level often have difficulty swallowing and feeding and may require nasogastric or gastrostomy feeds. Despite this, they often have weight loss and may have nutritional deficiencies, dehydration or anemia. Chronic low fluid intake coupled with pre-operative fasting may increase the risks of developing pre-renal renal failure.

Children with cerebral palsy require a multidisciplinary approach of community and hospital care. The aims are to improve mobility and posture by minimizing muscle contractures, spasticity and spasms, as well as controlling symptoms of accompanying disorders such as seizures and gastro-esophageal reflux with pulmonary aspiration. Management includes a combination of physical therapies, surgical procedures and medical treatments to reduce spasticity such as diazepam, baclofen, vigabatrin and botulinum toxin. Anesthesia is commonly required in these children for orthopedic or dental procedures, feeding gastrostomy, fundoplication and botulinum toxin injections.

Botulinum neurotoxin is derived from clostridium botulinum bacteria and blocks the release of acetyl choline at the neuromuscular junction. An intramuscular injection produces muscle weakness lasting between 2 and 6 months, with peak effects at 4 weeks post-procedure. Treatment involves injections into multiple muscles at regular intervals, improving function across the CP spectrum. In children with mild CP (GMFCS 1 and 2) it improves movement and gait, whilst in more severely affected children (GMFCS 4 and 5) it assists with supine positioning and basic quality-of-life care by preventing limb contractures. Systemic absorption and generalized weakness are extremely rare side effects.

12.1.1 Anesthesia Management

Cerebral palsy patients present a number of challenges (Table 12.1). Communication may be difficult because of developmental delay, and children with normal or delayed intellect may be anxious because of past hospital experiences. Parents are usually a reliable source of information about past medical history and previous anesthesia. Some children have mild respiratory failure requiring CPAP ventilation at home. Premedication is often worthwhile in this patient group, taking care to minimize the likelihood of respiratory side effects.

Keypoint
Children with severe CP have many potential anesthetic problems depending on the procedure, but the most important are the potential postoperative respiratory complications and pain management issues.

Many of the children with severe cerebral palsy are at risk of reflux and aspiration, but unfortunately also often have very difficult venous access. In children who have not had multiple previous episodes of pulmonary aspiration, a careful inhalational induction is a reasonable approach. Although neck and jaw contractures can

Table 12.1 Summary of important anesthetic issues in care of children with cerebral palsy

Key anesthetic issues in children with severe cerebral palsy
Anxious; communication may be difficult
Bulbar problems and poor swallowing of saliva; postop secretion clearance
Some are at risk of reflux and aspiration
Poor cough, frequent chest infections, kypho-scoliosis; risk of pneumonia or respiratory failure
Limb contractures; positioning for surgery may be difficult; pressure area risk
Altered thermoregulation and risk of hypothermia
Pain assessment difficult; painful muscle spasms after orthopedic surgery common
Pre-existing seizure disorder

occur, airway management is usually straightforward. Suxamethonium does not cause rhabdomyolysis in children with cerebral palsy, but there is resistance to non-depolarizing muscle relaxants because of an up-regulation in the number of acetylcholine receptors. Nevertheless, a non-depolarizing relaxant would be used more often than suxamethonium for a rapid sequence induction. MAC values are reduced in the children most severely affected (GMFCS 4 and 5).

Positioning can be difficult as a result of limb contractures and spasticity. Great care must be taken to protect pressure areas and to avoid neuropraxia. Hypothermia is a significant problem. These children have abnormal thermoregulatory control and cool quickly as they have minimal subcutaneous fat and muscle mass and a high surface area to volume ratio. Active warming is needed even for short procedures.

12.1.2 Post-operative Care

Respiratory care and pain management are the major postoperative problems in children with severe cerebral palsy. These children often have a weak cough and diminished respiratory drive leading to sputum retention, atelectasis, chest infection and respiratory depression. Some may require a period of respiratory support or close observation in a high dependency area.

Pain can be difficult to assess in children with cerebral palsy, and input from their parents is useful to gauge the effectiveness of analgesia. Muscle spasms triggered by pain and anxiety are a particular problem in this patient group. They cause paroxysms of intense pain that can be difficult to prevent and treat. Post-operative analgesia is optimized using a combination of non-opioid analgesics, intravenous opioid infusion, epidural analgesia or other regional technique, and sometimes a ketamine infusion. Regional techniques are particularly useful in reducing spasms. Epidural clonidine helps reduce spasms and may produce mild sedation which is often useful in the early postoperative period. Intravenous opioid infusions are commonly used, but require caution in this vulnerable patient group who are at risk from cough suppression, sedation and respiratory depression.

12.2 Muscle Disease

Muscle diseases, or myopathies, are uncommon conditions that have important implications for anesthesia. There are three specific risks—the risk of rhabdomyolysis from suxamethonium in any child with a myopathy; the risk of rhabdomyolysis from volatile agents in a child with muscular dystrophy, and finally the risk of malignant hyperthermia (MH) in some children with rare, specific muscle disorders. With increasing age and progression of the disease, myopathies become multi-organ diseases affecting cardiac and pulmonary function.

Practice Point
Before anesthetizing a child with a known or suspected myopathy, consider the following:

- Is the health care facility suitable?
- Is there a risk of MH?
- Is there a risk of rhabdomyolysis from volatile agents?
- Is there a risk of metabolic acidosis from propofol anesthesia?
- Are there cardiac or respiratory problems?

12.2.1 Categories of Muscle Disease

There are a large number of rare, eponymously named myopathies in children, but a simple classification of the more important ones with their specific anesthesia problems is listed in Table 12.2. Some myopathies have a causative or genetic link with MH, although there is variation within these, reflecting the rarity and complexity of the disease. As the child gets older, other consequences of the underlying muscle

Table 12.2 Overview of specific anesthesia problems related to muscle diseases

Muscle disease	Specific concerns
All myopathies	Rhabdomyolysis with suxamethonium
Muscular dystrophies	Rhabdomyolysis with volatile agents Cardio-respiratory problems later in life
Mitochondrial myopathies	Lactic acidosis with fasting
King Denborough Central Core, Multi-Minicore, Centronuclear Congenital myopathy with cores & rods Nemaline rod Congenital fiber type disproportion KDS, idiopathic hyperCK-emia Native American myopathy Exercise induced rhabdomyolysis	Known association with MH

Based on Litman et al. Anesthesiology 2018;128: 159–67

fiber problem become more apparent. Cardiac muscle is often affected, leading to arrhythmias, conduction defects and cardiomyopathy. Postural and mobility changes occur with limb deformities, contractures and scoliosis. Respiratory muscle weakness causes poor swallow and cough, a propensity to chest infection and respiratory failure. Developmental delay and seizures occur with some myopathies.

12.2.2 Rhabdomyolysis with Suxamethonium

Every child with a muscle disorder is at risk of hyperkalemic cardiac arrest from suxamethonium, and it should not be used under any circumstances. Suxamethonium causes depolarization of the muscle cell membrane, causing a prolonged contraction of the abnormal muscle fiber with breakdown of the cell membrane and release of potassium. The breakdown of the muscle cell membrane destroys the muscle fiber and is called rhabdomyolysis. It is the depolarisation caused specifically by suxamethonium that is the problem, and non-depolarizing relaxants are safe to use.

Treatment of a suspected hyperkalemic cardiac arrest follows APLS guidelines but specific therapies to consider are calcium, sodium bicarbonate and dextrose-insulin. Resuscitation should continue until the plasma potassium has been normalized.

Tip
If laryngospasm occurs in a child with myopathy, suxamethonium cannot be used to treat it. Options are a bolus of propofol 3–5 mg/kg and a non-depolarizing relaxant. The dose of relaxant needed to relax the vocal cords is not known, but is likely to be small, such as 0.2 mg/kg atracurium or 0.2 mg/kg rocuronium (the latter could be antagonized with sugammadex).

12.2.3 Muscular Dystrophy (Duchenne and Becker)

The muscular dystrophies are characterized by the absence of dystrophin in the muscle fiber (including cardiac), making the sarcolemma unstable. They occur only in males. Asymptomatic female carriers have no specific risks with anesthesia. The disease usually presents during the first years of childhood, so there is small a group of yet-to-be diagnosed preschool boys with the condition. However, up to half of the children with muscular dystrophy have a positive family history. There were several deaths from rhabdomyolysis each year in the USA in this group of children when suxamethonium was routinely used for elective intubation.

Young children with muscular dystrophy are active and reasonably well but later develop multi-organ problems, most commonly during the teenage years. Limb contractures and scoliosis develop, and ventilatory failure progresses from respiratory muscle weakness and restrictive lung defects secondary to kyphoscoliosis.

Autonomic dysfunction may occur, suggested by a resting tachycardia. Dysphagia results from weakness of striated muscle in the upper pharynx and smooth muscle of esophagus which can result in aspiration and passive regurgitation during anesthesia. Cardiomyopathy becomes more of a concern over the age of 10 years—30–50% of teenagers and 100% of 18 year olds have cardiomyopathy.

Note
The muscular dystrophies are not associated with MH. The same triggers as MH may however, cause rhabdomyolysis and an MH-like clinical picture.

12.2.3.1 Anesthesia for Children with Muscular Dystrophies

There are several problems with anesthesia in these children (Table 12.3). Suxamethonium is contra-indicated. Non-depolarizing relaxants can be used, but the block is likely to be more profound and longer lasting than usual.

The safety of volatile anesthetic agents in these children is controversial. Volatile agents have been used without problems in the past, but there are regular case reports of them causing hyperkalemic cardiac arrest. Volatile agents probably trigger rhabdomyolysis under unknown predisposing factors, and their inconsistent effect has led to discussion about their safety in muscular dystrophy patients—most would completely avoid volatiles.

Practice Point
When presenting for anesthesia, young children with DMD have the problem of rhabdomyolysis with suxamethonium and volatiles; older children and adults also have the problems of cardiac and respiratory failure, and steroid dependency.

Table 12.3 Anesthesia-related problems in children with Duchenne's and Becker's muscular dystrophy

Anesthesia-related problems in DMD and Becker's
Dystrophinopathy with hyperkalemia from suxamethonium and probably volatiles
At risk of ventilatory failure from anesthesia and surgery in later childhood
Cardiomyopathy in later childhood
Dysphagia and pulmonary aspiration in later childhood
Solutions:
Avoid suxamethonium
Avoid volatile agents
Use propofol-remifentanil anesthesia and avoid muscle relaxants
Avoid post-op deterioration in respiratory function
Take precautions for cardiomyopathy and aspiration in older children

12.2.4 Malignant Hyperthermia

Malignant hyperthermia (MH) is a rare, inherited disorder of the skeletal muscle that predisposes to a life threatening hypermetabolic state after suxamethonium and volatile anesthetics. MH reactions are rare, but approximately half occur in children younger than 15 years. It is very rare in the first year of life, and an uneventful anesthetic in the past is meaningless. Most children at risk of MH are asymptomatic, with only a few myopathies known to be associated with an MH risk (Table 12.2).

12.2.4.1 Diagnosis

Intraoperative MH causes a hypermetabolic state with lactic acidosis. Masseter muscle rigidity or spasm in response to suxamethonium may be the first sign, but is not specific to MH (see Chap. 2, Sect. 2.9.3). Early signs are increased CO_2 production, tachycardia, and metabolic acidosis. Fever develops, but it is often a late sign. Subsequently, muscle cell membrane pumps fail and there is leakage of intracellular elements with hyperkalemia, myoglobinemia and disseminated intravascular coagulation. Rarely, MH may begin in the postoperative period, up to several hours after anesthesia.

12.2.4.2 Management of a MH Reaction

A brief overview of management is listed in Table 12.4, but is more comprehensively covered in the guidelines from the Australian and New Zealand College of Anaesthetists and the Association of Anaesthetists in Great Britain and Ireland. The dose of dantrolene in children is the same as in adults, 2.5 mg/kg. There is no need to eliminate the anesthetic machine because the load of volatile agent in the patient will higher than that in the machine. High flow oxygen should be used though to wash-out the volatile from the patient and machine. The role of charcoal filters is still being determined.

12.2.4.3 MH Testing of Children

The in-vitro contracture test is the gold standard test for MH susceptibility. It is not usually performed in children under 10 years or 30 kg as they do not have an adequate thigh muscle from which to obtain a muscle sample. Genetic testing is used but not as a first-line test for index cases or their relatives. MH genetics remain heterogeneous and multiple mutations are likely to be involved, although a handful of mutations can definitely be characterized as MH causative. A negative genetic test does not rule out the disease.

Table 12.4 Overview of management of suspected MH reaction in children

Management of MH reaction
Call for help
Hyperventilate with 100% oxygen
Intravenous anesthesia if clinically appropriate.
Dantrolene 2.5 mg/kg and 1 mg/kg dose can be repeated to maximum of 10 mg/kg
Start active cooling to less than 39 °C
Treat arrhythmias, hyperkalemia, acidosis
Transfer to ICU for continuing treatment and monitoring

12.2.4.4 Management of a Child with a Family History of MH

Many children who present for anesthesia have a family history of an MH reaction, but their susceptibility is not certain as they cannot be tested. Children who should be considered particularly at risk are those where the reaction was in a close relative, or more than one relative in the family. The history of an MH reaction however, is often in a more distant relative. In this situation, a pragmatic approach is usually taken and the child treated as susceptible, even though the real risk is not known but likely to be low.

Fortunately, trigger-free anesthesia is simple to achieve in most circumstances. The principles are the same as in adults: propofol-based anesthesia, volatile-free equipment and avoidance of suxamethonium. Elective cases are scheduled first on the list—anesthesia workstations can take up to an hour to prepare and flush so their residual agent concentration is less than 5–10 parts per million. Activated charcoal filters can shorten this time. There are also alternatives to the machine preparation if the circle circuit and positive pressure ventilation are not needed. One alternative is to use a disposable T-piece circuit with oxygen from a wall source. Another is to use the machine's common gas outlet, which can usually be prepared by flushing with oxygen at 10 L/min for 10 min.

Reactions after trigger-free anesthesia are rare. MH-susceptible children may be safely managed as day procedure cases with standard times for postoperative monitoring and care, although some units observe for fever for several hours before discharge. Like any other child undergoing anesthesia, these children are at risk of laryngospasm. Although a bolus of propofol is a reasonable first treatment, having a non-depolarizing relaxant drawn up and ready to use is wise in any child with a contraindication to suxamethonium.

12.2.5 Metabolic and Mitochondrial Myopathies

Disorders of fatty acid metabolism in the mitochondria affect muscle and other organs such as the brain and heart. This group of disorders is termed metabolic myopathies, or mitochondrial myopathies. These children present with neurological and muscle symptoms, cardiomyopathy, respiratory failure and metabolic disorders. Fasting may initiate fatty acid metabolism and trigger lactic acidosis, so the duration of fasting is minimized and IV fluids containing 2.5–5% glucose given. These children are considered at risk of developing propofol infusion syndrome at relatively low doses of propofol. An induction dose of propofol is safe, as is volatile anesthesia. Brief propofol-based anesthesia may also be safe, although there is debate about this technique in these children. Suxamethonium is contraindicated as with all myopathies.

12.2.6 Anesthesia for Muscle Biopsy

A muscle disorder might be suspected in infants who are hypotonic ('floppy') or have other clinical signs, and these infants might require anesthesia for muscle biopsy. Anesthetic management is tailored to the suspected diagnosis and any possible link to MH or propofol infusion syndrome, as well as any cardiac or

respiratory problem. Apart from avoiding suxamethonium, many types of anesthesia have been used without apparent problem. If the child's creatine kinase is elevated, it would seem reasonable to avoid volatile agents, and if the lactate level is elevated, minimize propofol anesthesia. Alternatives such as ketamine or regional techniques can also be considered.

12.3 Mucopolysaccharidoses (MPS)

This is a group of inborn errors of mucopolysaccharide (also known as glycosaminoglycans) metabolism. Mucopolysaccharides are long chain carbohydrates forming connective tissues and bones. An enzyme deficiency in the degradation pathway causes deposition of these molecules throughout the body. Hurler syndrome is the most severe form. The other mucopolysaccharidoses include Hunter, San Filippo and Morquio syndromes and share some or all of the Hurler characteristics in a somewhat milder form (Table 12.5). Patients with Hurler's syndrome present early in infancy with hernias, macrocephaly, recurrent respiratory infections and limited hip abduction. These children gradually develop the characteristic features and complications over time as more mucopolysaccharides deposit in tissues, and developmental delay is apparent by 1 year of age. Stem cell transplant or enzyme replacement therapy is now available for many forms of mucopolysaccharidosis. If started at a young age, it improves long term outcome and reduces the severity of airway changes. It does not however prevent neurocognitive, cardiac valvular or skeletal changes.

12.3.1 Anesthetic Management

Anesthesia for these children in infancy is relatively straightforward as airway and other changes are mild. However as the child becomes older, airway

Table 12.5 Characteristics of Hurler syndrome

System	Features
Airway	Coarse facies, macrocephaly Micrognathia and macroglossia Decreased mobility of cervical spine and TMJ Atlanto-axial instability with subluxation common Tracheal narrowing from deposition of mucopolysaccharides
Respiratory	Obstructive sleep apnea Ventilatory failure and respiratory infections related to skeletal and neurological abnormalities
Cardiovascular	Cardiomyopathy, valvular defects, arteriosclerosis, coronary artery involvement Difficult IV access
Neurological	Progressive decline in intellect with eventual severe mental and motor retardation, poor gag and swallowing reflexes
Other	Progressive skeletal dysplasia, joint contractures, kyphoscoliosis

management becomes difficult as more and more mucopolysaccharides are deposited in the tongue, oropharynx, neck and periglottic structures. Extremely difficult and failed intubations are common, and these airway difficulties generally worsen over time as the disease progresses. As the child grows older, progressive anxiety and intellectual impairment may cause increasingly difficult behavior at induction. IV cannulation also becomes difficult, sedative premeds become risky to use and inhalational induction often ends up being a hurried, 'guerilla' induction rather than a smooth, gradual descent into anesthesia. The mask airway is often difficult to manage and obstructed. The LMA is not always a reliable method of obtaining a clear airway.

A fiberoptic intubation under anesthesia with spontaneous ventilation is often attempted. Unfortunately, as the child grows older their airway becomes even more difficult to manage and they are more likely to have cardiovascular disease that makes deep, inhalational anesthesia problematic. For these reasons, this group of children is one of the most difficult and challenging for pediatric anesthetists.

Note
Children with MPS have the combination of difficult airway, difficult behavior, difficult venous access and reduced myocardial function. This group of children are one of the trickiest for pediatric anesthetists.

12.4 Sickle Cell Disease

Sickle cell disease is an inherited hemoglobinopathy originating in areas of Central Africa, India, the Mediterranean and Middle East. Patients with sickle cell disease have the abnormal hemoglobin S (HbS) that becomes insoluble in its deoxygenated form. The HbS precipitates, causing red blood cells to take on the rigid, characteristic sickle shape, obstructing the microvasculature and causing ischemia in distal tissues.

Most of the hemoglobin in patients with sickle cell disease is HbS, and sickling occurs at oxygen saturations of approximately 85%. Sickle cell patients have chronic hemolytic anemia (Hb 50–100 g/L) and may have episodes of pain related to vaso-occlusive episodes and gradually worsening organ damage. Sickle cell patients rarely survive past their fifth decade. Patients with sickle cell trait (30–40% HbS) are largely asymptomatic because sickling only occurs at sub normal venous oxygen saturation. Children with sickle cell disease rarely present before 6 months of age because of the masking effects of fetal hemoglobin. Acute pain related to a vaso-occlusive crisis is the commonest presenting symptom. Vaso-occlusive crisis can affect any part of the body and can be associated with concurrent infection, dehydration, nausea and vomiting, extreme hypothermia, fatigue and psychosocial stress. Treatment of a vaso-occlusive crisis is supportive: rehydration, antibiotic treatment if necessary and opioid analgesia.

Sickle cell disease is diagnosed by high performance liquid chromatography (HPLC). Peripheral blood films are an alternative and show target cells, elongated RBCs and sickle cells. The "Sickledex test" is a rapid test of hemoglobin solubility but does not differentiate between sickle cell disease and sickle cell trait and can give false negative results in the presence of severe anemia and fetal hemoglobin. In practice, preoperative screening is at the discretion of the individual anesthetist. It is often omitted, particularly if it delays urgent surgical management, because a well-formulated anesthetic and analgesic plan as aimed for in every patient, would minimize the chances of triggering a crisis.

Screening for Sickle cell disease before anesthesia and surgery remains controversial: guidelines such as those for NICE in the UK suggest testing should be performed in susceptible populations. Newborn screening is performed routinely in some countries including the UK, and targeted testing occurs in Australia based on the antenatal histories of parents. If screening is not performed, children will generally have had a crisis and be diagnosed by 5–10 years of age.

12.4.1 Anesthesia for Children with Sickle Cell Disease

It is important to assess the severity of the disease and identify triggers. Signs and symptoms of pre-existing organ dysfunction should be looked for and investigated if clinically indicated. Traditionally, blood transfusions were given to sickle patients to reduce the HbS concentration to 30% in an effort to minimize post-operative complications such as cerebral-vascular accident and vaso-occlusive crises. Aggressive transfusion regimens are probably unnecessary for outpatient and minor procedures, and put patients at higher risk of problems related to transfusion. The decision to transfuse an individual child before surgery should be made following consultation between the hematologist, anesthetist and surgeon caring for the child.

The anesthetic aims are to minimize RBC sickling by avoiding dehydration, maintaining normal levels of oxygen, promoting venous return through careful patient positioning and treating infection aggressively (Table 12.6). Surgical tourniquets have been safely used but carry a risk of sickling. After surgery, patients are monitored for complications related to the disease such as acute chest syndrome. Optimal pain control is vital because untreated pain can trigger sickling. Opioid requirements may be higher in sickle cell patients than the normal population.

Table 12.6 Key points for anesthesia of children with sickle cell disease (Children with sickle cell trait can be managed as normal)

Key anesthetic issues in sickle cell disease
Careful pre-op assessment of pre-existing organ damage
Plan anesthetic to avoid the conditions in which RBC sickle
Optimal post-op analgesia

12.5 Diabetes

The prevalence of diabetes mellitus in the pediatric population is increasing. Approximately ninety percent of children with diabetes present with type 1 diabetes (insulin-dependent), 10% with type 2 diabetes (non-insulin-dependent) and a few children present with rare types. The prevalence of type 2 diabetes is growing as the number of obese children increases. Insulin pumps giving a continuous infusion of subcutaneous short-acting insulin are common in pediatric practice. In contrast to adult diabetics, secondary organ damage (renal, cardiac, ophthalmic and gastroparesis) is not a major concern in pediatric patients and instead the focus is on control of glucose homeostasis in the peri-operative period. Pediatric diabetic physicians are commonly involved in the care of children undergoing surgery, and many hospitals have agreed guidelines and protocols for these children.

12.5.1 Anesthesia for the Child with Diabetes

A formal plan for diabetes management is made before admission. Careful management aims to keep the child's blood glucose level (BGL) at 5–10 mmol/L and to avoid ketosis. Scheduling surgery as the first case in the morning simplifies management (Table 12.7). Hypoglycemia is the greatest risk and it is safer to have the child's blood glucoses a little higher than normal. Consider IV fluids while the child is fasting, although this is not always necessary. If hypoglycemia develops while the child is fasting, IV glucose is given. If there is no IV access, the parent can give the child oral clear fluids containing glucose as part of their usual hypoglycemia management. This clear fluid is unlikely to affect theatre scheduling with the recent acceptance of short fasting times for children (see Chap. 6, Sect. 6.2).

12.5.1.1 Minor Surgery in the Morning

Minor surgery lasts less than 2 h, is not associated with major metabolic disturbance, and the child is able to eat soon after. It includes endoscopy and tonsillectomy.

If the child has an insulin pump the basal rate is continued or reduced by 20% at 0300 h, especially if they usually tend to a low BGL in the morning. The pump is continued during anesthesia, and can be stopped for no more than 30 min to treat mild hypoglycemia. BGL is checked every 30–60 min. Consider fluids without glucose, at least initially, if the BGL is within the target range of 5–10 mmol/L.

If the child is receiving injections of insulin, the dose of long-acting insulin on the evening before surgery is reduced by 30–50%, and the next morning's dose of short-acting insulin is omitted. IV fluid 5% dextrose with normal saline should be given at maintenance rate during surgery.

Table 12.7 Key points for anesthesia of children with diabetes

Key anesthetic issues in children with diabetes
First on morning list
Continue pump at basal or reduce by 20%
Check BGL
Aim for BGL 5–10 mmol/L and avoid hypoglycemia
5% dextrose with normal saline is a suitable fluid
Input from diabetic physician useful in the peri-operative period

12.5.1.2 Minor Surgery in the Afternoon

If the child has an insulin pump, it is continued as normal for breakfast and thereafter. Their pump will be at basal rate by the time of admission. For children receiving intermittent injections, they are given their usual dose of long-acting insulin and 50% of their short-acting insulin with breakfast. BGL is monitored and IV fluid 5% dextrose and normal saline at maintenance started before surgery.

Major surgery usually lasts more than 2 h, is associated with major metabolic changes and prevents the child eating soon after surgery. The child's diabetic physician should be involved with management, which will include admission to hospital before surgery and a dextrose-insulin infusion started at least 2 h before surgery. Most children require between 0.1 and 0.2 Units/kg/h (maximum 5 Units/h) of insulin, adapted regularly to the BGL.

BGL during surgery is monitored every 30–60 min. If the BGL is <4 mmol/L, 10% dextrose 1–2 mL/kg is given. If BGL is >14 mmol/L for longer than 1 h, subcutaneous short-acting insulin is given and blood ketones measured. The dose is the same as the child's usual correcting dose, or 5–10% of their total daily dose. Many children have continuous glucose monitors. These may be left attached to the patient, although there are some reports of inaccurate readings during anesthesia and surgery, and cross checking abnormal readings is advised.

12.6 Obesity

Obesity is an increasingly common problem in children, with 50% of obese children becoming obese adults. Apart from rare syndromes, most childhood obesity is due to diet, inactivity and behavioral tendencies. The definition of obesity in children varies, clouding research into obesity. The normal range of BMI varies with gender and age in children, although BMI is still often used for diagnosis. Alternative definitions use the 85th centile of BMI for age and gender, or the Cole definition using centile curves. There is an increased incidence of hypertension, type 2 diabetes and asthma in obese children. Additionally, functional residual capacity and forced vital capacity are reduced in obese children and the incidence of OSA is higher than in non-obese children.

Anesthesia for obese children is associated with an increased risk of minor morbidity, but care of this group of patients is not as challenging as that of obese adults. Tact and sensitivity are required in the preoperative assessment. Exercise tolerance is a useful measure of cardio respiratory function. Gastro-esophageal reflux is not increased as there is normal gastric emptying. Ultrasound guidance for IV access is useful, or inserting a fine-gauge cannula for induction and replacing it later with a large cannula is an alternative. Initial drug doses are based on ideal weight and then titrated to effect. The induction dose of propofol is based on ideal weight, but an increased maintenance rate is needed when using intravenous anesthesia. Airway management in obese children is more straightforward than obese adults. Although obese children may be more awkward to mask ventilate due to their fleshy cheeks, large tongue and flaps of soft tissue, they are not usually difficult to intubate.

12.7 Attention-Deficit Hyperactivity Disorder

Attention-deficit hyperactivity disorder (ADHD) is a behavioral disorder in which inattention, hyperactivity and impulsivity is more frequent and severe than is normal in similar aged children. It has a worldwide prevalence of 6–12% in schoolchildren compared with 1% in adults. It is much more common in boys, though no single cause has been identified. About half of children diagnosed with ADHD are medicated, although this seems to be decreasing. Treatment is usually with stimulants such as dexamphetamine, a methylphenidate or the norepinephrine reuptake inhibitor atomexetine. These stimulants enhance central nervous system catecholamine action in areas regulating attention, arousal, and impulse control. Non-stimulant agents used in children with ADHD include clonidine.

A potential issue when anaesthetizing children with ADHD is a perioperative deterioration of behavior. Children with ADHD are twice as likely to be uncooperative at induction and more likely to have maladaptive behavior postoperatively than other children. Interactions between ADHD and the drugs used to treat it are not apparent clinically, and stimulant medications do not affect the bispectral index and depth of anesthesia. Continuing or withholding ADHD medication before anesthesia is probably best decided in conjunction with the child's parent, who will know what will be best for their child's behavior. There is no evidence to support stopping or continuing these medications. Some children with ADHD may benefit from premedication. Clonidine might a reasonable choice given its use in the treatment of ADHD, but there is no data comparing it with the anxiolytic midazolam in these children.

12.8 Autism Spectrum Disorder

Autism spectrum disorder ('autism') is a group of disorders characterized by deficits in social interaction and communication, and repetitive behaviors and restricted interests. Autism varies in its severity, with some children only mildly affected, or 'high functioning'. It is more common in boys, occurring in 6/1000, and becomes apparent by the age of 3 years. Affected children find difficulty forming bonds with their parents, are upset by changes in their routines, and may have repetitive or ritualistic behaviors. They often have poor speech, refuse to cooperate, do not like being touched and refuse oral medicines. Some are treated with antipsychotic medications such as risperidone to reduce aggressive tendencies. Managing their perioperative behavior and enabling a non-traumatic induction and smooth emergence in recovery are the main challenges for anesthesia.

Admission for surgery changes the child's routine and can distress the child. Their behavior often deteriorates as a result and is upsetting for the parents, other patients and staff. Several steps can be implemented to minimize the stress on the child and family (Table 12.8). Notification before admission highlighting the child's needs allows planning of the perioperative care. The time between admission and surgery can be minimized, information regarding the child's likes, dislikes or

Table 12.8 Key points in the management of autistic children presenting for anesthesia and surgery

Important steps in perioperative care of the autistic child
Notification before admission
Coordinate multiple procedures to one anesthetic if possible
Minimize admission to surgery time
Admit to quiet room
Premedication
Flexible approach to induction
PONV prophylaxis
Remove IV cannula as soon as possible
Discharge as soon as possible

behavioral triggers can be used to tailor management in an appropriate area of the admissions ward. Parents can also be asked to bring any calming objects such as weighted blankets, noise cancelling headphones or favorite objects. Some autistic children use alternative communication devices such as picture charts. Parents are well informed and know many effective strategies for their child.

12.8.1 Premedication of Children and Young People with Autism

Preoperative assessment determines how communicative and cooperative the child is—some will not allow any form of examination. Older children with autism may exhibit extraordinary strength when under stress and restraining them can be difficult, as well as putting the child and care givers at risk of injury.

As the severity of autism increases along the spectrum, the optimal type of premedication changes (Fig. 12.1). Distraction and other behavioural techniques are useful. The parent will know their child's preferences.

Children with mild, high functioning autism might not need a premed, while some will benefit from oral midazolam or clonidine. Children with more severe autism may need more than these agents. Oral clonidine followed by oral midazolam is one such strategy—clonidine 3–4 μg/kg (maximum 150 μg) given 60 min before induction is followed by oral midazolam 0.3 mg/kg (maximum 15 mg) given 30 min later. This combination may produce deep sedation and airway obstruction, and it should be given in an area with adequate monitoring and airway equipment. Children and young people with severe, non-verbal autism may be very difficult to restrain and become violent if they become stressed or agitated. In this group of children, oral ketamine 2–5 mg/kg 30 min before induction is often more effective. Alternatively, lower doses of ketamine 1–3 mg/kg can be combined with midazolam 0.3 mg/kg mixed together 30 min before induction. This combination may produce deep sedation and airway obstruction in some children. Ketamine may contribute to postoperative vomiting. If it is used, antiemetics, IV fluids and reduced doses of opioids are suggested. The IV preparation of ketamine is used to make these premeds, and the taste is masked with the child's favorite flavoring (often cola, lemonade or apple).

The child may be reluctant to drink the premed, but parents have often developed their own strategies to enable their child to take medicines. Intranasal premeds can be used, but may be difficult to administer to a large and uncooperative child.

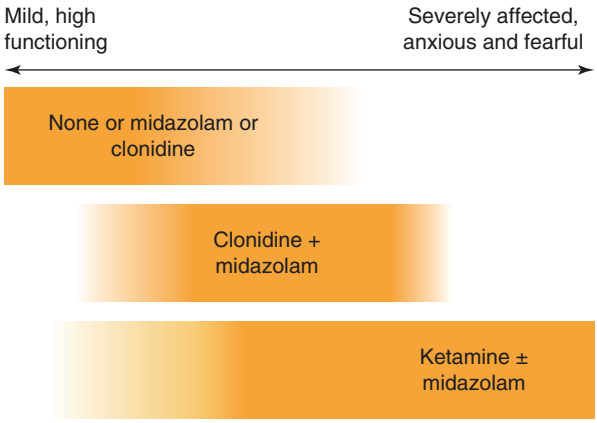

Fig. 12.1 Different types of pharmacological premeds are needed for children with different severities of autism

Intranasal premeds include dexmedetomidine 3 μg/kg, or ketamine, or midazolam. Another premed option is intramuscular ketamine 3–4 mg/kg into the deltoid muscle or thigh. Most children can be persuaded to take an oral premed if managed carefully, and fortunately IM premeds are rarely required.

An IV or inhalational induction is used, depending on the effect of the premed and child's behavior at induction. In large children who are not well sedated despite premedication, an IV induction is often easier than restraint and an inhalational induction. In this case, have all equipment ready, insert a fine cannula and inject induction agent as soon as possible. Tape or connect the giving set after induction. Thiopentone has a smaller volume than propofol and is worth considering as one of the rare uses of thiopentone nowadays.

To minimize distress in the postoperative period, the parent should be present early in recovery, and the IV cannula removed as soon as the child starts to wake. IV fluids and antiemetics are routinely given during anesthesia to minimize PONV and avoid the need to retain the IV cannula. Reducing the time that the child stays in hospital after the procedure minimizes stress on the child and helps the parents return the child to their usual environment. As soon as the child meets discharge criteria, they should be allowed to go home.

12.9 Anorexia Nervosa

Anorexia is a psychiatric disorder with multi-system physiological sequelae. It consists of reduced body weight (at least 15% below expected), weight loss that is self-induced by food avoidance or vomiting and distorted body image. It is most common in teenage girls. There are two types: restrictive anorexia, and purging/bulimic anorexia (although bulimia can also occur without anorexia). A specialist team including a psychiatrist and gastroenterologist usually looks after these patients.

There are many possible sequelae which depend on the severity of the disease (Table 12.9). Most patients are thin but generally well and pose no problems with

Table 12.9 Systemic complications arising from anorexia nervosa

Organ system	Possible problems (notes)
Cardiovascular	Hypotension, bradycardia from decreased metabolic rate ECG changes, arrhythmias (including during anesthesia) Reduced contractility via anorexia and also if abusing ipecac to induce vomiting Mitral valve prolapse (A bradycardia would suggest ECG needed. ECHO would be needed if other clinical features indicate CVS problems)
Respiratory	Pneumothorax Aspiration pneumonitis Reduced compliance from starvation (CXR not routinely performed)
Renal	Reduced GFR common Electrolyte disorders from vomiting or abuse of diuretics, laxatives or purgatives: low Mg or phosphate, low calcium
Gastrointestinal	Strict dieting appears to prolong gastric emptying time
Hematological	Leucopenia and thrombocytopenia common Anemia unusual
Endocrine	Panhypopituitarism, diabetes insipidus
Musculo-skeletal	Muscle weakness from electrolyte disturbance, osteoporosis with fractures at young age

Most patients, however, are thin but pose no major problems with anesthesia

anesthesia. Some are desperately ill and need intensive care, although this group will look ill from the end of the bed! Investigations before anesthesia would depend on symptoms, examination and previous tests, with anesthetic management adjusted according to the severity of the illness.

12.9.1 Refeeding Syndrome

During starvation, cellular metabolism slows and there is intracellular depletion of electrolytes (especially potassium, magnesium and phosphate), proteins and B vitamins. Refeeding syndrome refers to the metabolic and fluid disturbances that can occur after severe, prolonged starvation. With the initial reintroduction of nutrition, cellular metabolism increases and cells start to take up electrolytes, which can cause significant disturbance in their circulating levels with metabolic effects on organ function (and in particular, cardiac arrhythmias).

12.10 von Willebrand's Disease

von Willebrand disease (vWD) is a bleeding disorder caused by inherited defects in the concentration, structure or function of von Willebrand factor (vWF). About 1% of the population has some form of the disease.

Von Willebrand factor is released from platelets and endothelial cells and mediates the adhesion of platelets and stabilizes factor VIII. There are three categories of

von Willebrand disease. Type I makes up 70% of cases, and vWF function is mildly reduced (about 20–50% of normal levels). These children have no problems in daily life from the disease. Type II has four subtypes, but all are severe forms with significant bleeding problems. Type III is an absence of vWF and is characterized by bleeding unresponsive to treatment with desmopressin (DDAVP).

vWf levels are measured using several techniques, including ristocetin activity. The activated partial thromboplastin time (APPT) is mildly prolonged in 50% of patients with vWD due to low factor VIII. PT is normal. Bleeding time is nonspecific and does not help predict whether patients will have problematic bleeding during surgery. For all but the most straightforward minor surgeries, a pre-operative discussion with a hematologist is warranted regarding specific treatment advice for the child's von Willebrand subtype.

Desmopressin (DDAVP) is effective in 95% of children with vWD and 0.3 μg/kg IV over 30 min causes a three to five times increase of vWF in patients with Type I. The maximal effect is 30–60 min, and duration 6–10 h. It is given at 12 h intervals if needed postop. The effect of DDAVP in Type II is variable. Children with vWD not responsive to DDAVP need vWF-containing FVIII concentrates. Local antifibrinolytic activity in the oral mucosa compromises hemostasis, and antifibrinolytics such as tranexamic acid may be used peri- and postoperatively to stop breakdown of blood clots after dental extractions and oral surgery (including tonsillectomy). Tranexamic mouth washes and oral administration have been described in these settings.

12.11 Latex Allergy

Latex allergy in children is relatively common, often being detected by a history of lip swelling after blowing up balloons. There is known cross-reactivity with avocado, banana and kiwi fruits (amongst others). Fortunately, allergic reactions during anesthesia and surgery are rare. Children with spina bifida have a higher incidence of latex sensitization than any other patient group due to the frequency and duration of exposure to latex. It is possibly due to immune changes rather than direct exposure to latex. Current practice is to take latex-free precautions from birth. Children with urinary tract malformations are also at high risk due to multiple urinary catheterizations. Of children who have had multiple operations (an average of 7.7 operations), more than half are sensitized to latex independent of their underlying diseases. Standardizing on a latex-free anesthetic environment is a logical approach and nearly all equipment for pediatric anesthesia is now available without latex. Maintaining a standardized latex-free anesthetic environment is a logical approach. Chemoprophylaxis using histamine receptor antagonists in children with latex allergy is ineffective. Routine use of non-powdered gloves in most theaters has eliminated the problem of aeroallergens and order of scheduling latex allergic patients on the OR list.

Review Questions

1. Why is suxamethonium contraindicated in patients with muscular dystrophy?
2. How would you initiate treatment for suspected MH? What is the dose of Dantrolene?
3. Why do patients with Hurler's syndrome have difficult airways?
4. Why might a child with Trisomy 21 have a difficult airway?

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Congenital Syndromes and Conditions

13

Prani Shrivastava and Dana Weber

13.1 Robin Sequence

Robin sequence (formerly Pierre Robin) is a clinical triad of micrognathia, glossoptosis and airway obstruction often in association with cleft palate. Mandibular hypoplasia in the first trimester causes the tongue to be in a superior position, preventing midline fusion of the palatal shelves. Robin sequence may occur alone or in association with many syndromes, most often Stickler, velocardiofacial and fetal alcohol spectrum disorder. It occurs in 1 in 8500 births.

The baby's small jaw causes airway obstruction, sometimes even while the baby is awake. Some are nursed prone to help the tongue fall away from the back of the pharynx, and occasionally they need tracheostomy soon after birth. The jaw grows along with the baby, and eventually the amount of space within the oral cavity is sufficient to avoid airway obstruction. Other organ systems may be affected either from associated syndromes or secondary to chronic upper airway obstruction. However, the main problem for anesthesia is the airway and difficulty with intubation during infancy and early childhood.

Note
It's Robin sequence because a single event, mandibular hypoplasia, sets off a sequence causing the other signs. A syndrome has multiple, independent anomalies.

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13.1.1 Anesthetic Implications

Anesthesia may be required either during the neonatal period for intubation or tracheostomy, or during infancy for cleft palate repair or mandibular advancement. The mid face and mandible grow in the first years of life, and so by primary school age the mandibular profile may be near normal with an improved airway.

The most important aspect of airway assessment is jaw size—the smaller it is, the more difficult airway management will be. Having to nurse the child prone or use a nasal airway even while awake are indicators of more severe forms. The LMA reliably provides a clear airway as the obstruction is at the level of the oropharynx and this is bypassed by the LMA. Anesthesia management therefore usually involves inhalational induction and intubation aided with a videolaryngoscope. A scope with a curved, hyperangulated blade would be best (see Chap. 4, Sect. 4.12.3). Another technique is to use an LMA used as a conduit for fiber optic intubation. Some neonates with severe Robin sequence needing tracheostomy have the airway topicalized and the LMA inserted awake.

Keypoint
The small jaw size in Robin sequence is the key. It prevents the tongue fitting within the oral cavity, causing airway obstruction and preventing the tongue being compressed enough to visualize the larynx at intubation. As the jaw grows, the airway improves.

13.2 Achondroplasia

Achondroplasia is the commonest cause of dwarfism. Most cases are spontaneous, with autosomal dominant inheritance of a mutation of a fibroblast growth factor receptor. The features of achondroplasia are described in Table 13.1.

Table 13.1 Features associated with achondroplasia

Organ system	Feature
Appearance	Short stature, short arms and legs with relatively long trunk Macrocephaly and frontal bossing May develop scoliosis
CNS	Tendency to develop hydrocephalus, foramen magnum stenosis and craniocervical cord compression (risk factor for sudden death during infancy)
Airway	Midface hypoplasia Choanal atresia High arched palate, macroglossia High incidence of obstructive sleep apnea Dental malocclusion, crowding
CVS	May develop pulmonary hypertension if severe untreated OSD or scoliosis

13.2.1 Anesthetic Implications

Airway considerations include a potentially awkward mask fit and bag-mask ventilation, and restriction of cervical spine movement. Management of the airway in most children with achondroplasia however, is straightforward. Positioning for laryngoscopy may require planning due to the presence of hydrocephalus, foramen magnum stenosis or craniocervical cord compression. Intubation using a videolaryngoscope reduces neck movement. The size of the ETT may be smaller than predicted by an age-based formula. Planning for post-operative observation or ventilation may be necessary depending on the presence of obstructive sleep apnea or neurological problems.

Tip
Children with achondroplasia appear small but are developmentally normal—it is a frequent trap to treat them as a younger child.

13.3 Trisomy 21 (Down Syndrome)

Trisomy 21 is the most common chromosomal syndrome, occurring in 1 in 800 live births. Several different mechanisms can result in three copies of chromosome 21, so phenotypic expression is variable. Approximately 50% of pregnancies with Trisomy 21 are reported to spontaneously terminate. Risk factors include increasing parental (maternal and paternal) age. Antenatal screening with the offer of elective termination in high risk pregnancies has reduced the incidence.

13.3.1 Anesthetic Implications

The many features that may be present are listed in Table 13.2. In practice, atlantoaxial instability, obstructive sleep apnea and cardiac defects have the greatest implications for anesthesia. Despite their many airway changes, intubation is usually not difficult.

13.3.2 The Cervical Spine and Anesthesia

Craniocervical abnormalities are common in Trisomy 21 (approximately 1 in 5). Abnormalities include atlanto-axial & atlanto-occipital instability, lax transverse ligaments between C1 and C2, and hypoplasia of the occipital condyles & the posterior arch of C1. While most children have uneventful anesthesia, there are case reports of adverse neurological outcomes after surgery including rare cases of cervical cord compression. Of concern are reports of neurological

Table 13.2 Features of Trisomy 21 patients

Organ system	Feature
Appearance	Characteristic facies Brachycephaly, flat occiput Upslanting palpebral fissures Brushfield spots on iris Short hands with a single, Simian crease
CNS	Variable developmental delay, frequently social & friendly Atlantoaxial instability (approximately 15%, symptomatic in 2%) Cataracts, strabismus, refractive errors
Airway	Macroglossia (relative to midface hypoplasia) Micrognathia Subglottic stenosis in 10% (may require a smaller ETT than predicted) High incidence of obstructive sleep disorder Frequent respiratory tract infections
CVS	High incidence heart disease, classically endocardial cushion defects (atrioventricular canal—VSD + ASD), PDA, Tetralogy of Fallot Cor pulmonale/pulmonary hypertension if severe, untreated heart disease or airway obstruction Venous hypoplasia and difficult veins
Hematological	Prone to myeloproliferative disorders (Acute Myeloid leukemia) Immunosuppression
GIT	Hirschsprung's disease, duodenal atresia

Table 13.3 Signs and symptoms that suggest a craniocervical abnormality with cord compression in children with Trisomy 21

Cord compression signs and symptoms	
History	Refusal to participate in usual activities, refusal to turn the head due to pain or stiffness, increasing fatigability Dizziness or syncope (vertebral artery kinking or stretching) Deterioration of gait Loss of fine motor skills (clumsiness) Bladder or bowel dysfunction Altered sensation in hands or feet
Examination	Altered head & neck movement (flexion, extension, rotation), torticollis Abnormal gait Long tract neurological signs in legs

injury associated with upper respiratory tract infections either spontaneously or during the perioperative period.

The signs and symptoms that suggest a craniocervical abnormality with cord compression are listed in Table 13.3. The parents of these children are generally very knowledgeable about Trisomy 21 and will know if there are any concerns about their child's neck. Nevertheless, if any of these indicators are present, elective surgery should be deferred until the cervical spine has been evaluated. Otherwise, consideration should be given to whether the patient is likely to be a difficult intubation or if surgical positioning will require an abnormal neck position.

In practice, x-rays are infrequently ordered in the asymptomatic child before anesthesia, and instead the head and neck are kept in a neutral position. The

American Academy of Pediatrics states routine radiographs are not recommended in asymptomatic children at any age. Cervical radiographs are inaccurate before age of 3 years due to lack of vertebral mineralisation as well as having a low predictive value for risk of developing atlanto-axial instability. Furthermore, the interpretation of plain films is not straightforward. The problems include lack of patient co-operation for successful imaging, lack of ossification, and debate about the upper limit of normal for the anterior atlanto-dental interval (often quoted as 4.5 mm). Plain films only assess passive and not active flexion of the cervical spine. If the films are abnormal, either CT with sagittal reconstructions or MRI is performed to show the abnormalities. If previous films were abnormal, repeat radiography is justified, particularly if ossification was incomplete at the time of the original films.

The greatest subluxation occurs during neck flexion. However, both laryngoscopy (which involves extension & lifting of the skull on C1) and rotary subluxation during surgical positioning have been implicated in adverse outcomes. The LMA secures the airway with reduced head & neck movement compared to intubation. Videolaryngoscopy also reduces movement compared to direct laryngoscopy. Changes to surgical positioning such as rotating the table instead of the patient, or avoiding use of a shoulder roll during tonsillectomy reduce head and neck movement. Wake-up tests for patients requiring prolonged sedation in ICU have been suggested.

13.3.3 Obstructive Sleep Disorder

Many children with Trisomy 21 undergo tonsillectomy to treat OSD. They are considered at risk of postoperative airway obstruction, particularly when young and small.

13.3.4 Cardiac Defects

About 50% of children with Trisomy 21 have congenital heart disease. They are usually screened at birth and correctional surgery performed if required. Detection of a previously undiagnosed murmur would be an indication for postponement of anesthesia and referral to a cardiologist.

Keypoint
Consider imaging and neurological referral if the patient has neurological symptoms, previous abnormal radiology without follow-up, or surgery requiring unusual positioning of the neck.

13.3.5 Summary

Although children with Trisomy 21 have many changes to the various organ systems including the airway, they are usually reasonably straightforward to manage.

Apart from taking care with their neck, intubation is usually not difficult. From a practical point of view however, they often have difficult veins and are anxious at induction. As they grow older, managing their behavior at induction in a stress-free manner can become a major challenge.

Review Questions

1. Robin Sequence is associated with mandibular hypoplasia. Why does this cause airway obstruction and difficulty with intubation?
2. A 7 year old child with Trisomy 21 presents for tonsillectomy. He has no neck symptoms.
   (a) Why is he at risk of neurological problems with anesthesia and surgery?
   (b) Would you request cervical spine X-rays before anesthesia?
   (c) What precautions would you take to minimize the risk of neurological sequelae?

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Neonatal Anesthesia

14

Chris Johnson and Dan Durack

This chapter outlines differences between the neonate and older patients, some common neonatal conditions, and some aspects to consider in the care of the preterm neonate so that trainees will have some background knowledge if they are involved with these patients.

14.1 The Neonate

A neonate is a baby in the first 4 weeks of life. Preterm neonates are those born at less than 37 weeks gestation. Several terms are used to describe the age of former preterm infants (Table 14.1). The neonatal period is when physiological and pharmacological changes are greatest and technical and equipment needs most specialized. Great changes and differences occur even within the neonatal period, particularly in the first few days of life when the changes from birth are stabilizing.

14.2 The Neonatal Cardiovascular System

When based on weight, the neonate has twice the metabolic rate of an adult. As a result, neonates have twice the oxygen consumption, twice the minute ventilation and twice the cardiac output of an adult (Table 14.2). As the cardiac output in a neonate is already high, there is less ability to increase it in response to illness. Other differences of the cardiovascular system of neonates are listed in Table 14.3.

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Table 14.1 Various terms used to describe the age of preterm neonates

Term	Description
Gestational age	Time between the first day of the last menstrual period and delivery. A term baby is 37–40 weeks gestation
Chronological age (Post-natal age)	Time since birth. A baby celebrates its first birthday 52 weeks after birth
Postmenstrual age (PMA) or Post-conceptual age (PCA)	Gestational age + chronological age. A 6 week old baby born at 35 weeks gestation has a PMA of 41 weeks
Corrected age	Chronological age minus the number of weeks born before 40 weeks of gestation. A 6 week old baby born at 35 weeks has a corrected age of 1 week

Postconceptual age is no longer used

Table 14.2 Respiratory and cardiovascular differences between neonate and adult

Parameter	Neonate	Adult
Oxygen consumption	7 mL/kg/min	3 mL/kg/min
RR (breaths/min)	30–60	15–20
MV	220 mL/kg/min	100 mL/kg/min
Tidal volume	6 mL/kg	7 mL/kg
FRC	30 mL/kg	34 mL/kg
Anatomical dead space	2.2 mL/kg	2.2 mL/kg
Cardiac output	200 mL/kg/min	70 mL/kg/min

Note increased oxygen consumption, cardiac output and increased minute ventilation achieved by increased respiratory rate

Table 14.3 Characteristics of the cardiovascular system in neonates

Cardiovascular system characteristics	Reason
Contractility dependent on extracellular calcium concentration	Poorly developed sarcoplasmic reticulum
Rate dependent cardiac output	Relatively fixed stroke volume from non- compliant ventricle
Poorly developed sympathetic nervous system	Unable to increase systemic vascular resistance
Parasympathetic nervous system predominance	Prone to bradycardia

Term neonates have a heart rate of 100–160 bpm and normal systolic blood pressure of approximately 60–70 mmHg. Preterm neonates have a lower blood pressure.

14.2.1 Patent Ductus Arteriosus (PDA)

The ductus arteriosus is a vascular communication between the pulmonary artery and descending aorta, and is an essential component of fetal life. It generally closes soon after birth but in some types of congenital heart disease, ongoing patency may be essential for survival. A small PDA is usually benign and NSAIDs may be used to promote closure. Left-to-right shunting through a large PDA risks pulmonary overload and congestive heart failure. This is managed with fluid restriction and diuretics. Surgical closure may be required, either by cardiac catheter or by thoracotomy.

Table 14.4 Summary of airway differences

Neonatal airway features
Occiput relatively large—more difficult to position for optimal intubating conditions
Obligate nasal breathing, most resistance in nose, don't cope with nasal obstruction. 40% of term babies can convert to oral breathing if nasal obstruction
Underdeveloped mandible with little space in mouth for tongue
Larynx higher in neck with fewer vertebral joints above larynx that can flex
Long, floppy, U-shaped epiglottis
Larynx appears to be more anterior at laryngoscopy
Vocal cords angled forward (more likely to catch ETT on anterior commissure)
Short trachea makes right endobronchial intubation more likely

14.3 The Neonatal Airway

Differences in the airway (Table 14.4) (see also Chap. 4) make the larynx appear anterior at laryngoscopy and have the potential to make intubation more difficult. However, intubation is readily achieved in most neonates with a straight Miller blade laryngoscope and laryngeal pressure. The routine use of a videolaryngoscope for intubation of neonates is also a reasonable approach nowadays.

Note
Positioning for intubation is different in neonates compared to adults: A head ring to stabilize the relatively large head; a small roll under the shoulders if the head is particularly large; mild head extension (too much and the epiglottis may be pushed against the tongue base); no neck flexion needed because of their high larynx.

14.4 The Neonatal Respiratory System

Neonates have several differences that place them at risk of respiratory and ventilatory failure.

14.4.1 Lung Development

The lung is underdeveloped at birth—alveoli develop late in gestation and lung development continues after birth. A preterm baby has only terminal sacs with underdeveloped alveolar ducts. Term babies have 20–50 million alveoli and the number increases to the adult number of 300 million by 8 years. Surfactant production begins around 23 weeks gestation and sufficient levels are present from early in the third trimester through to birth. Surfactant deficiency is a problem in preterm neonates, resulting in reduced compliance, atelectasis and respiratory distress

syndrome (RDS). Surfactant is so important for lung function in neonates that antenatal steroids are given to mothers to stimulate surfactant production if delivering at 34 weeks or less. Preterm neonates born at less than 30 weeks gestation are given surfactant via an ETT. Bronchopulmonary dysplasia (BPD) refers to lung damage caused by mechanical ventilation and subsequent inflammatory reaction.

14.4.2 Airway and Respiratory Mechanics

Respiration is less efficient and the work of breathing higher because of the characteristics of the chest wall, diaphragm and tracheobronchial tree (Table 14.5). The neonatal larynx is high in the neck and the posterior oral airway is potentially obstructed by the high and long epiglottis in proximity to the soft palate and tongue. This allows simultaneous feeding and breathing, but in combination with immature coordination between respiratory and pharyngeal muscles, neonates and young infants preferentially breathe through their nose. Only about 40% of term babies can convert to oral breathing if the nose is obstructed, but nearly all can convert by the age of 5 months.

Note
Neonates and infants younger than 3 months are termed 'obligate nasal breathers' because less than half can quickly convert to breathing through their mouth if their nose is obstructed.

14.4.3 Control of Respiration

The respiratory center in the brain stem of the neonate is immature, and respiratory control is not fully developed. Neonates have periodic breathing- the respiratory rate varies and includes periods of self-correcting apnea lasting 5 or 10 s. Neonates also have a biphasic response to hypoxia—they increase ventilation initially, but then become apneic. After about 3 weeks of age the response to hypoxia is sustained hyperventilation as in children and adults. Neonates also have a reduced response to

Table 14.5 List of the major differences in respiratory physiology in neonates compared to children and adults

Respiratory physiology in neonate
Horizontal ribs rather than 'bucket handle'
Piston-like, diaphragmatic breathing which is compromised by gastric or abdominal distension
Diaphragm has less type I muscle fibers (25% vs adult 60%; adult levels by 9 months) and copes with increased work of breathing poorly. Diaphragm is flatter and develops less pressure for any given muscle tension
Compliant rib cage which in-draws if upper airway obstruction
Small diameter, poorly supported airways
Immature respiratory control

hypercarbia compared with children and adults. Finally, neonates have increased sensitivity to stimulation in the superior laryngeal nerve territory and respond with hypoventilation, apnea or bradycardia.

14.4.4 Apnea and Anesthesia in Neonates

As a further indication of their immature respiratory control, neonates, and especially preterm neonates, are prone to apnea after anesthesia. An apnea is considered significant if it lasts longer than 15 s, or is associated with oxygen desaturation <90% or bradycardia (<100 bpm). They usually occur in the first 2 h after anesthesia, but may occur anytime during the first 12 h. The incidence of apnea after anesthesia increases with increasing prematurity—7% of neonates born at 34–35 weeks will have apneas, but 80% born at less than 30 weeks will have apneas. Anesthesia or sedation may cause apnea even if the infant wasn't having them before. These apneas are not self-correcting and are a life-threatening risk of anesthesia in preterm infants. It is the reason for overnight admission even after minor surgery (Table 14.6). Apneas are often seen in these infants immediately after anesthesia while still in the OR (sometimes while still intubated and awaiting extubation). They sometimes respond to stimulation, and sometimes need IPPV briefly. Apnea in the PACU indicates a higher risk of apnea later on the ward. Overall, 6–10% of preterm neonates aged 44 weeks PMA or less will have apnea after anesthesia.

14.4.4.1 Risk Factors for Apnea After Anesthesia

Preterm infants aged less than 52 weeks PMA are at risk of apnea after anesthesia or sedation. The risk declines with age, is very low after 46 weeks PMA and is

Table 14.6 Summary of apnea in infants after anesthesia and sedation

Key features	Notes
'Apnea'	Longer then 15 s, or 10 s if associated desaturation or bradycardia Usually within first few hours after anesthesia Risk period extends to 12 h post op Usually responds to stimulation; some require IPPV
Risk groups	Other preterm baby (less than 35 weeks) until 52 weeks PMA Mildly preterm baby (35–37 weeks) until 48 weeks PMA Term baby until 44 weeks PMA
Other risk factors in preterm infants	Co-morbidities (especially neurological, respiratory) Intraoperative opioids or sedatives Anesthesia technique and agents Anemia?
Prevention	Analgesia without opioids Light GA with low-solubility volatile and regional analgesia Caffeine base 10 mg/kg Spinal anesthesia

PMA post menstrual age

negligible after 52 weeks PMA. Preterm infants under 44 weeks PMA are most at risk. The degree of prematurity at birth also affects the risk—infants born mildly preterm at 35–37 weeks have a lower risk of apnea than neonates born before 35 weeks. Term neonates (born at 37 weeks gestation or more) are at a lower risk of apnea than preterm neonates, but a risk exists until 44 weeks PMA. Co-morbidities including anemia (Hb <100 g/L), lung disease, neurological problems and pre-existing apnea increase the risk of postop apnea.

Keypoint
Term neonates require admission and monitoring for postoperative apnea until a postmenstrual age of 44 weeks, and preterm infants until 52 weeks (some centers still use 60 weeks).

14.4.4.2 Prevention Strategies to Reduce Apnea

The risk of postoperative apnea can be reduced by postponing elective surgery until the infant is older. Term infants should not have day-stay surgery until they are 44 weeks PMA (that is, 4 weeks old if born at 40 weeks gestation, 7 weeks old if born at 37 weeks). Preterm infants should not have day-stay surgery until they are 52 weeks PMA (some centers use 60 weeks). The risk in infants born mildly preterm (35–37 weeks) is lower and some centers allow day-stay surgery after 48 weeks PMA in these infants if there are no other risk factors. This last group still needs to be monitored for 6–8 apnea-free hours before discharge. Although anemia increases apnea risk, many centers accept mild anemia unless there are other reasons for transfusion.

General anesthesia can be modified to reduce the risk. Regional or local anesthesia should be used in place of opioids, allowing a light plane of anesthesia with relatively insoluble agents such as sevoflurane. Longer acting drugs of all classes should be avoided.

Spinal anesthesia was thought to greatly reduce the risk of postop apnea. More recent work suggests spinal anesthesia does not reduce the overall incidence of apnea compared to general anesthesia. However, it does reduce the number of infants needing any intervention greater than stimulation to resolve their apnea, and the number of apneas in the PACU. Spinal anesthesia is discussed in Chap. 10, Sect. 10.5.4. In summary, its disadvantages are technical difficulties with lumbar puncture in small infants, and the short duration of spinal anesthesia in infants.

IV caffeine during anesthesia reduces the incidence of postop apnea. Preterm infants at high risk (44 weeks PMA or less) are given caffeine base 10 mg/kg IV (equivalent to caffeine citrate 20 mg/kg) during anesthesia to prevent apnea. Caffeine is also used in the neonatal nursery to prevent apnea in premature neonates, so it is important to check the baby has not already been given caffeine. Aminophylline can be used if IV caffeine is not available, although it has more cardiovascular side effects.

Keypoint
Spinal anesthesia was thought to greatly reduce the risk of postop apnea. It is now realized it does not affect the overall incidence of postop apnea, but does reduce the severity of apneas and incidence of early apneas.

14.4.4.3 Monitoring for Apnea

Detection of apnea prevents hypoxia or hypoxic cardiac arrest. An 'apnea monitor' is used, usually in combination with pulse oximetry. The monitor uses ECG leads on the chest and detects respiratory movement via the impedance between the leads and measures heart rate via the ECG. It will not detect obstructive apnea (chest moving but no air flow) until bradycardia develops. Most apnea begins in the first few of hours after anesthesia. The risk diminishes with time and monitoring is ceased when there has been no apnea for 12 h.

Apneas nearly always respond to stimulation alone and rarely require bag-mask ventilation. Groups of infants that require monitoring are those in the 'risk group' of Table 14.6.

14.5 Fluid and Glucose Requirements

Neonates have a greater proportion of their bodies as water, a larger blood volume and higher fluid, glucose and sodium requirements than older children and adults (Table 14.7). Body water makes up 80% of weight at birth, falling to 60% at age 1 year. The extracellular fluid volume is larger than the intracellular fluid volume (the opposite of children) until about 3 months of age. Fluid requirements are low for the first few days after birth while lung water is reabsorbed, and then high in keeping with the neonate's high metabolic rate.

Table 14.7 Differences in body fluid compartments and fluid requirements between neonate and adult

Fluid compartment	Neonate	Adult
Total body water	70–75%	65%
Extracellular fluid volume	50%	25%
Blood volume	90 mL/kg	70 mL/kg
Sodium requirement	3 mmol/kg/day	
Glucose requirement	6–8 mg/kg/min	
Fluid requirements		
Day 1	60 mL/kg/24/h	
Day 2	75	
Day 3	90	
Day 4	105	
Day 5	120	
Day 7 onwards	150	

Fluid requirements are low initially because fluid is being absorbed from the lungs after birth. Based on data from Newborn clinical guidelines, Starship Children's

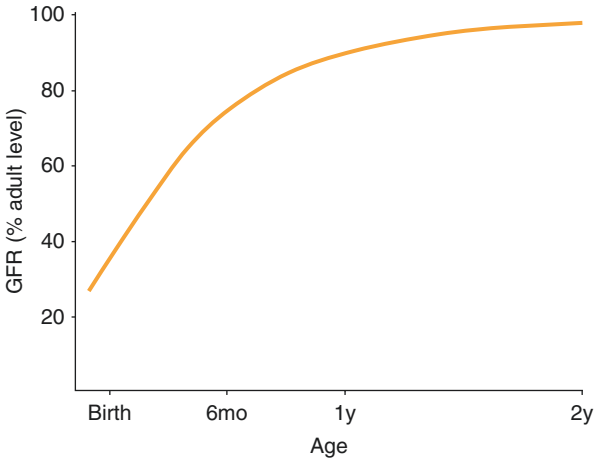

Fig. 14.1 Glomerular filtration rate (GFR) at birth is roughly one quarter of the adult, but reaches the adult level at 2 years of age. Modified from Anderson BJ, Holford NHG. Negligible impact of birth on renal function and drug metabolism. Pediatr Anesth 2018;28: 1015–21

Glucose requirements are high in neonates to match their metabolic rate and limited gluconeogenesis. A commonly used maintenance fluid is 10% glucose with 0.2% saline. Hypoglycemia is defined as <2.6 mmol/L in neonates (4.0 mmol/L in children). In the neonatal unit, hypoglycemia is corrected gradually by increasing feeds or the rate of glucose administration. Boluses of glucose are avoided and very rarely used. Renal function is immature at birth with reduced glomerular filtration rate (GFR) and poor concentrating ability. GFR reaches 50% of the adult level by 48 weeks PMA, 90% of the adult rate by 1 year, and reaches the adult rate by 2 years (Fig. 14.1).

14.5.1 Neonatal Blood

The neonate has predominantly fetal hemoglobin (HbF) which has an oxygen dissociation curve shifted to the left—oxygen extraction at the tissue level is impaired due to the higher venous oxygen levels after birth. The hemoglobin level at birth is variable, but commonly about 16 g/dL. Adult hemoglobin (HbA) is produced from birth, but red cell production is inadequate and the hemoglobin falls, reaching a low point of 8–11 g/dL at 2–3 months (called the 'physiological anemia'). Nearly all of the hemoglobin at this stage is HbA, and so tissue oxygen delivery is actually improved compared to earlier with HbF.

Note
The presence of HbF in neonates is a key reason for a higher transfusion-trigger hemoglobin in neonates than children.

The coagulation system of the neonate is immature and does not reach adult levels until about 6 months of age. The coagulation changes are due to reduced levels of the vitamin K dependent factors and reduced levels of coagulation inhibitors

(Antithrombin III, Protein C and S). Vitamin K is often given to neonates because of this coagulopathy. Platelet numbers are normal, but they do not reach adult activity until the neonate is 2 weeks old. Neonates do not have blood group antibodies in their plasma apart from some transferred through the placenta from the mother. Cross match of blood is performed on maternal serum.

14.6 Temperature

Neonates can only control body temperature over narrow range of environmental temperatures compared to children and adults. Their thermoneutral temperature depends on the age and weight of the baby, but for a naked term baby it is 32–35 °C. Methods to maintain body temperature are during surgery are described in Sect. 14.9.2.

14.6.1 Heat Loss and Production

Neonates have large heat losses and a decreased ability to generate heat, so are at great risk of hypothermia during transport and while in theatre. Losses are through the skin, particularly by convection and radiation. Evaporation is also an important source of heat loss in preterm infants because of their thin skin. Heat losses are high because of the neonate's large surface area to weight ratio and poor insulation from subcutaneous fat. The head (20% of surface area) is a significant site of heat loss and should be kept covered.

Heat production is limited—neonates do not shiver, or at least not enough to generate any heat. They do however have brown fat that is rich in mitochondria located around the great vessels in the neck and thorax, and also in the axilla and between the scapulae. This fat is used for non-shivering thermogenesis, which can double heat production in neonates and infants until 2 years of age. Non-shivering thermogenesis is inhibited by anesthesia, as is shivering in older children and adults.

Tip

Think of heat loss when you uncover an infant to insert an IV.

Consider underbody or overhead warming, covering patient with a clear plastic sheet, insulating cap for the head.

14.7 Pharmacology of Anesthetic Agents in Neonates

In general, neonates have an increased volume of distribution but reduced metabolism and clearance. Initial doses however, are still often lower than in older children because of pharmacodynamic differences arising from immature end organs (Table 14.8). Immaturity of the blood brain barrier was thought to be responsible for apparent

Table 14.8 Factors affecting drug action in neonates

Factors affecting drug action in neonates	Example
Increased volume of distribution due to increased body water	Prolonged action of vecuronium; less respiratory depression from bolus dose of fentanyl
Microsomal enzyme activity reduced by about 50%	Reduced infusion doses
Reduced glomerular filtration and tubular secretion	Reduced excretion of morphine and metabolites
Reduced protein binding	Reduced dose of thiopentone
Increased cardiac output and distribution to VRG	Fast onset of NMBD's
Low proportion of fat and muscle	Less redistribution of induction agents, slow to wake
Immaturity of end organ function	Reduced MAC, sensitivity to NMBD's

Table 14.9 Drug doses in neonates

Agent	Effect/dose	Comment
Propofol	2–3 mg/kg	May cause significant hypotension for up to 1 h after bolus
Volatile agents	Reduced MAC compared to infants; high rate of uptake/washout	Immature CNS; high cardiac output & minute ventilation
Muscle relaxants	Fast onset; first dose same as children, second dose will have longer duration	High cardiac output; increased volume of distribution offset by reduced acetylcholine release
Suxamethonium	2 mg/kg	High dose to overcome very short duration of action in neonate
Vecuronium	0.1 mg/kg—Long duration of action in neonates	Large volume of distribution
Rocuronium	0.3–0.45 mg/kg to allow for sensitivity and long duration of action	Prolonged duration of action
Atracurium	0.5 mg/kg	Very fast onset, shorter duration
Morphine	Reduced dose needed	Reduced clearance morphine and metabolites; caution with infusions
Fentanyl	Similar/reduced dose	Reduced clearance
Remifentanil	No dose change required	Increased volume of distribution offset by increased clearance
Local anesthetics	Reduced initial dose; avoid infusions	Markedly reduced metabolism of bupivacaine, reduced protein binding, high risk of toxicity

sensitivity of the neonate to some drugs such as morphine, but it is now realized that pharmacokinetic differences are responsible. Doses have a fast onset due to the high cardiac output in neonates that predominantly goes to the vessel rich group of tissues. Non-depolarizing relaxants for example, work very quickly in neonates. Neonates are slow to wake after propofol—they have low fat and muscle content, and as a result the induction agents have less mass to redistribute into and the brain concentration remains higher for longer. Also, propofol causes prolonged hypotension in a proportion of neonates. Table 14.9 lists some common agents and differences in their use in neonates.

Note
Remifentanil is unique among the opioids for neonates. The enzyme which metabolizes remifentanil is fully active at birth. The dose of remifentanil is unchanged or slightly higher in neonates than children because of a larger relative volume of distribution, offset by increased clearance.

Practice Point
Five anesthetic drugs different in neonates compared to children:

- Sevoflurane—reduced MAC
- Propofol—reduced dose, may cause prolonged hypotension after single bolus dose
- Vecuronium—long acting in neonates
- Remifentanil—fully active enzyme system, increased dose
- Local anesthetics—reduced metabolism, reduced dose

14.8 The Effects of Prematurity

A preterm infant is defined as being born at less than 37 weeks gestation. Extreme preterm neonates are born before 28 weeks gestation. All of the organ systems are immature in the preterm infant and the problems they face depend on both the gestational age and weight of the baby (Table 14.10). A short overview of these problems is listed in Table 14.11.

14.8.1 Respiratory Distress Syndrome (RDS)

RDS or hyaline membrane disease (HMD) is a common lung disease in preterm infants. It is caused by surfactant deficiency in alveoli that are not completely developed. There is an influx of inflammatory cells and edema of airways, and a proteinaceous exudate forms a hyaline membrane in the distal alveolar sacs. RDS begins within 4 h of birth and causes the signs of respiratory distress listed in Table 14.12. Lung compliance is reduced and there is atelectasis and ventilation-perfusion

Table 14.10 50th percentile birth weight of babies born at different gestational ages

Gestational age (weeks)	50th centile birth weight (g)
40	3500
34	2300
30	1450
28	1140
26	890

Table 14.11 Some of the changes in different organ systems associated with prematurity

System	Changes associated with prematurity
CVS	Increased incidence of PDA Increased blood volume (100 mL/kg) More pronounced physiological anemia later
Respiratory	Only terminal sacs rather than alveoli Reduced surfactant Increased risk of RDS Increased risk of apnea with or without anesthesia More likely to need respiratory support after birth or anesthesia
Gastrointestinal	Increased risk of hypoglycemia Unable to suck-feed if less than 34 weeks (need NGT) Increased risk of necrotizing enterocolitis
CNS	Increased risk of intraventricular hemorrhage and neurodevelopmental defects Risk of retinopathy of prematurity

Table 14.12 Signs of neonatal respiratory distress

Signs of neonatal respiratory distress
Tachypnea (respiratory rate more than 60)
Nasal flaring
Expiratory grunting
Chest retractions
Desaturation

mismatch. The CXR classically shows a diffuse, 'ground glass' appearance in both lung fields with air bronchograms and loss of the heart borders. Treatment includes respiratory support, oxygen and surfactant. There is a trend towards CPAP rather than intubation and ventilation.

14.8.2 Retinopathy of Prematurity (ROP)

ROP is an eye disease of prematurity, particularly infants less than 32 weeks gestation or of extreme low birth weight (<1500 g). Excessively high arterial oxygen concentration is a major cause, but other factors are involved as it can occur in very small preterm infants despite maintaining normal oxygen levels. ROP is a two phase disease, the first phase being a hyperoxic state after exposure to high oxygen concentrations. Hyperoxia causes retinal vasoconstriction, resulting in vaso-obliteration of some existing peripheral retinal vessels. In the second phase, increased metabolism in the developing eye results in the non-perfused peripheral retina becoming hypoxic, which then triggers the release of vascular endothelial growth factor. This leads to retinal neovascularization. In some cases, the neovascularization eventually results in the development of retinal detachment and visual loss. The inspired oxygen concentration should be reduced during anesthesia and transport to keep the oxygen saturation in the low to mid 90s in neonates younger than 32 weeks or weighing less than 2.5 kg.

14.9 An Overview of Anesthesia for Neonates

Neonatal anesthesia is a specialized area and is generally performed by fellowship-trained pediatric anesthetists in tertiary centers. This section gives a brief overview of neonatal anesthesia techniques for trainees involved in neonatal cases (Table 14.13).

Most neonatal surgery is performed under general anesthesia. Awake spinal anesthesia can be used for abdominal and lower limb procedures, and some centers have extensive experience in this technique. Spinal anesthesia (see Chap. 10, Sect. 10.5.4) reduces the risk of airway and respiratory problems and avoids the concern of potential neurotoxicity from volatile agents. The lumbar puncture however can be difficult, and the block only lasts 45 min.

14.9.1 Assessment

Pre-anesthetic evaluation determines the consequences of the surgical condition and any coexisting conditions. The parents may still be at the birthing place and away from their baby, which may make preop discussions more difficult. Weight and postmenstrual age are important as these determine the degree of physiological changes present, including apnea risk. Current management of the baby's airway, breathing and circulation are noted. Fluid and glucose management in NICU

Table 14.13 List of main considerations in neonatal anesthesia

Aspect of anesthesia	Important considerations in neonate
Temperature	Vulnerable to hypothermia
BSL	Ensure glucose supply and monitor BSL
Airway	Use a 3 mm ID cuffed or uncuffed ETT (3.5 uncuffed if term infant), straight blade laryngoscope or videoscope Rapid desaturation and hypercarbia with apnea
Ventilation	Fast rates, short inspiratory time Small tidal volumes, care with equipment dead space Apnea after anesthesia Adverse effects of high FiO_2 for lungs and retina
CVS	Sick neonates vulnerable to hypotension from propofol and volatile agents Fentanyl-based anesthesia Careful use of volatile agents (reduced MAC) Fluid load—consider 4% Albumin Small blood volume—consider group & hold or cross match Ensure vitamin K has been given Umbilical catheters may need to be removed for some abdominal operations 2Fr long lines are not suitable for large or rapid fluid boluses
Drugs	Metabolism and elimination of most drugs reduced. At risk of prolonged effect

forms a basis for ongoing treatment in theatre. Investigations vary according to the baby's condition, but most surgical cases have had the hemoglobin and electrolytes measured. A newborn's hemoglobin is often higher than other pediatric patients at 160 g/L, but the value depends on the time of cord clamping and how much blood was left in the placenta. Several conditions requiring surgery are associated with a higher incidence of cardiovascular abnormalities, and a pre-operative echocardiogram may be required. These conditions include tracheo-esophageal fistula, congenital diaphragmatic hernia, VACTERL & CHARGE associations, and exomphalos.

14.9.2 Temperature

The body temperature of neonates and infants is maintained during anesthesia by warming the operating room, using a forced air warmer, warming IV fluid boluses and using passive humidification of anesthetic gases. Although a theater temperature of over 25 °C for neonatal cases is traditional, it is a very uncomfortable temperature for staff (who may already be stressed caring for a sick neonate). A contemporary approach is to keep the OR cooler and create a microclimate around the baby with a forced air warmer.

Note
Some neonates have a fine, 2FG PICC line in situ. This line is very thin and even anesthetic drugs need to be given slowly and gently. The PICC line is not suitable for fluid bolus or blood. Another IV line needs to be established for surgery.

14.9.3 Induction

Some anesthetists give IV atropine before induction in view of the parasympathetic predominance in neonates, but its routine use is probably not necessary with current agents and techniques. Inhalational induction has the advantage of more gradual loss of consciousness with more time to assess airway and take over breathing. IV induction is rapid, but preoxygenation is difficult and usually inadequate, so reliance is placed on the rapid establishment of mask ventilation after induction. Rapid sequence induction in neonates is modified from the adult technique. The majority of anesthetists do not use cricoid pressure because it compresses the trachea (preventing mask ventilation before intubation) and distorts the airway for laryngoscopy. Instead, reliance is placed on the fast onset of induction agents and relaxants in neonates. Mask ventilation after induction and before intubation is crucial to avoid hypoxia.

Tip
During intubation of the neonate, insert miller blade into mouth and laryngopharynx under direct vision—don't blindly insert the blade.

Keep the tongue swept to left side of blade (not bulging over right side of blade) and keep blade out of corner of mouth

Lift the epiglottis directly or indirectly and use laryngeal pressure to improve view if needed

14.9.4 Intubation

Neonates are intubated and ventilated for most procedures for several reasons: their airway may be technically difficult to manage and difficult to access after surgery starts, and hypoxia occurs very quickly if airway obstruction develops. Furthermore, they are susceptible to respiratory depression from anesthetic drugs and do not tolerate increases in the work of breathing. Assisted ventilation via an LMA may be a suitable technique for simple cases when access to the airway during the case is possible.

Note
If intubation of the neonate is not successful at the first attempt, it is vital to concentrate on bag mask ventilation to restore lung volume before the next intubation attempt. Apneic periods during intubation cause loss of lung volume and relatively high pressures are usually required to recruit lung volume. Hypoxia is inevitable by the second or third attempt at intubation if recruitment is not performed. Following intubation, the requirement for high pressures diminishes as further recruitment occurs. NB: Empty gas from stomach. Gentle cricoid pressure may be handy during recruitment to prevent stomach distension.

In practice, neonates are usually easy to intubate despite all their airway differences. A small head ring stabilizes the head during intubation and the head is tilted back slightly as during an adult intubation. Sometimes, the large head flexes the neck when they are supine, and either removing the head ring or placing a small pad under the shoulders overcomes this. The larynx is not actually located anteriorly, but appears anterior at laryngoscopy. A straight blade laryngoscope and external pressure to bring the larynx into view are key points. A videoscope is an alternative. A size 1 Miller blade and 3.0 mmID cuffed ETT can be used in babies from 3 kg or if there is a large leak using an uncuffed ETT. For smaller babies a 3.0 uncuffed ETT is first choice. The largest uncuffed ETT that still has a leak at 20 cm H_2O is best to

facilitate suctioning & reduce risk of occlusion postop. Very small preterm neonates weighing less than about 1 kg are best intubated using the size 0 Miller blade and a 2.5 mm ID uncuffed ETT. Small curved Macintosh blades are anatomically unsuitable for neonates and it is illogical to use a scaled-down adult blade for neonatal intubation.

Tip
A term neonate weighing more than 3 kg will most likely accept a 3.5 mm uncuffed or 3.0 mm cuffed ETT. Intubation of smaller neonates should initially be with a 3.0 uncuffed ETT.

14.9.5 Maintenance

Maintenance techniques vary according to the medical condition of the baby. Healthy, term neonates will tolerate volatile agents if doses are adjusted (allowing for reduced MAC) and fluid boluses given if required. Most neonatal surgery is abdominal, and nitrous oxide is avoided to minimize bowel distension. Sick neonates undergoing emergency procedures may only tolerate low doses of volatile agents without hypotension. As this group is usually ventilated postop, a common technique is to rely on remifentanil or fentanyl, relaxant, fluid boluses, and then add a volatile agent as required and tolerated. Depth is assessed on the basis of hemodynamic changes in response to surgical stimulation. A dose of fentanyl in the order of 10–50 μg/kg would be considered an adequate anesthetic in a sick, preterm neonate.

Tip
A starting point for anesthesia for major neonatal surgery when postop ventilation is planned:

- Inhalational induction with Sevoflurane and oxygen/air
- Muscle relaxation, pressure controlled ventilation with air/oxygen, minimize FiO_2 if preterm
- Fluid load with 10 mL/kg warm saline or 4% Albumin
- Fentanyl incrementally to 10 μg/kg
- Additional fentanyl or low dose volatile as tolerated.

14.9.5.1 Ventilation

Initial ventilator settings for neonates with normal lungs are rate 25–30 breaths/min, inspiratory pressure 15–20 cmH_2O, inspiratory time < 1 s and PEEP 5 cmH_2O. Neonates have short alveolar time constants and do not need long inspiratory times. Neonatal intensive care units ventilate at rates of 50–60 breaths/min and inspiratory times of only 0.3–0.5 s to facilitate synchronization with the

ventilator when awake, and to reduce volutrauma. A large proportion of carbon dioxide production is from the work of breathing in the neonate and this work is eliminated with muscle paralysis. Distal sampling of $ETCO_2$ is important (see Chap. 6 Sect. 6.5.2).

14.9.5.2 Blood Pressure

Blood pressure and fluid management aim to maintain adequate cerebral perfusion pressure. It is not really known what the blood pressure of a neonate should be during anesthesia, nor is there and a well-defined lower limit for blood pressure. Cerebral oximetry studies suggest blood pressure under anesthesia does not need to be as high as in the awake state to maintain cerebral perfusion.

Observational studies have documented the values in Table 14.14. These values were recorded during anesthesia, but there is no information on outcomes to help decide if they are safe and acceptable as limits. These are often lower than blood pressures suggested in pediatric life support documents. Another rule used for guidance is that the mean blood pressure (in mmHg) should be no lower than the neonate's gestational age. This rule is not evidence-based. NIBP devices also vary in the accuracy of diastolic measurement in small babies and the resulting calculated mean pressure.

There is a great deal of interest in blood pressure during neonatal anesthesia, because of concerns that hypotension may contribute to neurodevelopmental changes. However, a causative relation between low BP and outcome has not been established. There are concerns also that excessive fluid administration may cause pulmonary or peripheral edema. In general, neonates usually need a fluid bolus initially to prevent hypotension, and then to replace losses. The balance between continuing fluid or giving vasopressors or inotropes varies between centers based on experience and preference. Vasopressors must be used carefully, as they carry a risk of causing intraventricular hemorrhage (IVH) in neonates.

14.9.5.3 Fluid Management

Maintenance fluids containing glucose are continued during anesthesia and surgery, usually via a volumetric pump. Blood glucose levels are measured during all but the shortest procedures, aiming to keep BSL above 3.0 mmol/L. Fluid losses are treated with boluses of crystalloid or albumin. As these fluid volumes are small (10 mL/kg

Table 14.14 Observed mean BP values in infants during anesthesia

Weight (kg)	Mean BP values one standard deviation below average under anesthesia (mmHg)
2	29
3	31
4	34
5	36

Values given are 1 SD below the average BP observed. They give an indication of lower blood pressures commonly present during neonatal anesthesia, but it is not known if they are safe or desirable blood pressures. Adapted from de Graaff et al. Anesthesiology 2016; 125:904–13

is 30 mL in a neonate!), syringes of fluid are often used. The fluid is warmed either by placing the syringe under a warming blanket or by drawing fluid from a reservoir via a blood warmer. Blood transfusion is uncommon during neonatal surgery. The transfusion trigger is around 120 g/L—higher than children because of the neonate's high level of HbF and limited cardiovascular reserve. Transfusion blood is drawn into a syringe via a macrofilter and warmed before administration.

14.9.5.4 Postoperative Care

Extubation is possible only if the baby is warm, well perfused, has no significant pulmonary problems, and is medically stable. Local policies also play a role, as some NICU prefer to ventilate neonates after a laparotomy while receiving morphine, whereas other units are comfortable managing such a patient awake and breathing spontaneously. All neonates, including term babies, are considered at risk of postoperative apnea.

Note
A blood transfusion cannot be given in the same line as 10% Dextrose. They are not compatible, and the blood will clot and block the IV line and cannula.

14.10 Some Neonatal Surgical Conditions

14.10.1 Malrotation and Subsequent Volvulus

Intestinal malrotation occurs when the embryological midgut does not rotate normally in the fetus. As a result, the small intestine is mostly on the right side and has a narrow mesenteric attachment making it prone to volvulus (Fig. 14.2). Neonatal

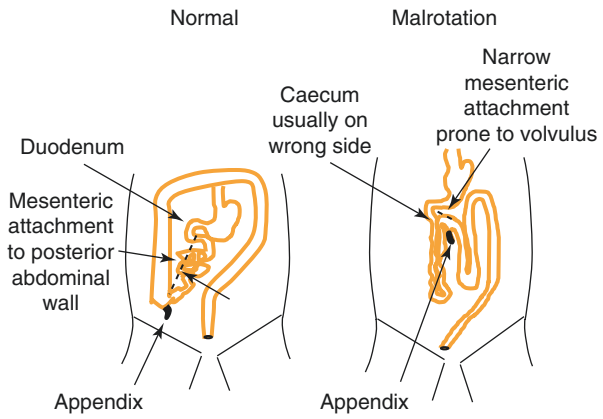

Fig. 14.2 Schematic representation of anatomical changes in malrotation of intestine

volvulus causes intestinal obstruction and intestinal ischemia, and is a 'true' surgical emergency. Some of these infants have hypovolemia and sepsis. A pragmatic approach is required, balancing the need for volume resuscitation against the desirability of immediate surgery. Anesthesia should only be delayed until reasonable hemodynamic stability is achieved. The Ladd procedure surgically corrects the malrotation. Anesthesia usually consists of low-dose opioid, volatile anesthesia and muscle relaxation. Invasive monitoring is not always required, and extubation at the end of procedure is often possible, followed by low-dose opioid infusion for analgesia.

14.10.2 Necrotizing Enterocolitis (NEC)

NEC is a condition of preterm neonates in which there is inflammation of the bowel wall causing intramural gas, wall necrosis, perforation and shock.

14.10.2.1 Background

NEC is mostly a condition of preterm neonates, and the more preterm, the more likely it becomes. It most commonly begins within the first 2 weeks of age. It presents with abdominal distension, bilious NGT aspirates, bloody stools and intramural and intrahepatic gas on abdominal X-ray. The neonate becomes septic and unwell with the systemic consequences listed in Table 14.15. Mortality in the acute phase is up to 40% in infants <1 kg. Conservative management includes antibiotics, ventilation and cardiovascular support, ceasing oral intake and starting TPN. Babies with NEC requiring surgery are usually very small—less than 1–1.5 kg. Surgical management is either by insertion of a peritoneal drain (often performed in NICU), or laparotomy with bowel resection and ostomy formation.

14.10.2.2 Assessment

The baby's general condition is assessed, paying particular attention to circulating volume status, level of cardio-respiratory support, and presence of changes in Table 14.15. Blood should be cross matched.

14.10.2.3 Management

Anesthetic issues are listed in Table 14.16. These babies are often very small, very sick, and very challenging for the anesthetist. The neonate will already be intubated and ventilated in NICU and have IV access with or without inotropic support. Alternative IV access is useful if it can be obtained, because bleeding can

Table 14.15 Systemic effects in neonate of necrotizing enterocolitis (NEC)

Changes during NEC
Thrombocytopenia
Anaemia
Metabolic acidosis
Electrolyte changes
Coagulation changes

Table 14.16 Concerns and problems for anesthesia of neonate with necrotizing enterocolitis for laparotomy

Anesthesia issues in NEC
Usually very small, preterm neonate weighing less than 1.5 kg
Septic shock, thrombocytopenia, coagulopathy
Large fluid requirement
Potential for significant blood loss from inflamed, friable tissue
Blood not compatible with maintenance IV 10% glucose

occur during surgery from the inflamed, friable tissues. If blood is transfused through the same IV line as maintenance 10% glucose or TPN, the blood will clot and block the IV cannula and line. Even if there is minimal blood loss, fluid requirements are high and several boluses of 10 mL/kg of saline or albumin are usually required. An opioid-based anesthetic technique is used and volatile agents added only if hemodynamically tolerated. The baby is returned to NICU ventilated postop. Long-term problems include loss of intestinal length from bowel resection.

14.10.3 Gastroschisis and Exomphalos

These are abdominal wall defects in which the intestines and sometimes other organs protrude from the abdominal cavity and expose the newborn to the risks of infection, fluid loss and gut ischemia.

14.10.3.1 Background

Both conditions are often associated with prematurity. Gastroschisis is more common and is possibly due to an early vascular incident. The defect is located to the right of the umbilicus and the herniated intestines are not within any type of membranous sac. The intestines are exposed to the amniotic fluid in utero and are inflamed and thick-walled. Associated anomalies are present in 10–15%, but they usually involve the GI tract and are of little consequence to anesthesia. Exomphalos is rarer, and consists of a large central herniation into a membranous sac that was part of the umbilical cord. Associated anomalies are present in 70%, with cardiac and chromosomal defects most common. Lung development and function are also affected. It is associated with Beckwith-Wiedemann syndrome (macroglossia, visceromegaly and hypoglycemia). The blood sugar level is checked in case the baby has this syndrome and is hypoglycemic.

Immediately after delivery, babies with abdominal wall defects have a plastic sheet or bowel bag placed over the herniated intestines or over the entire lower body. The bag reduces infection and also fluid and heat loss. The bowel is observed for vascular compromise, as kinking of the mesentery can occur. Surgery aims to return the protruding organs into the abdominal cavity and close the abdominal wall. It is usually done within several hours of birth, or urgently if there is bowel ischemia. Non-operative management is often used: the herniated intestines are placed within a tubular plastic silo while the baby is in neonatal intensive care. The silo is reduced in size over several days to return the intestines to the abdominal cavity. Anesthesia may be required for final closure of the abdominal wound.

14.10.3.2 Assessment

Preoperative assessment determines the baby's size and gestational age, assesses the lungs, and detects any associated anomalies. Fluid status is also assessed. An echocardiogram is performed in all neonates with exomphalos, but usually only in gastroschisis if there is cyanosis or a heart murmur that might indicate a cardiac defect.

14.10.3.3 Induction and Maintenance

These neonates might be considered at risk of regurgitation and aspiration, but a classic rapid sequence induction is not usually performed because of the reasons discussed previously. Maintenance of anesthesia usually includes muscle relaxation and controlled ventilation. There are two major intraoperative issues apart from the usual neonatal anesthesia concerns. The first is fluid loss and the second is intra-abdominal pressure after the herniated organs are returned to the abdominal cavity.

Fluid is lost by evaporation from the bowel surface and into the lumen of the intestine. Intravascular depletion follows and large amounts of fluid are often required during surgery. This fluid can be either salt-rich crystalloid or a colloid such as albumin. Volumes up to 70–100 mL/kg may be needed according to the hemodynamic state of the child and length of surgery. This fluid is in addition to the maintenance glucose/saline that is continuously infused during surgery. Replacement fluid is given as 10 mL/kg boluses, usually warmed in syringes. Concerns about postoperative pulmonary problems from excessive fluid administration have resulted in a reappraisal of fluid management of these babies and there is an argument to use smaller volumes and add inotropic support early.

Intra-abdominal pressure rises after the herniated organs are returned to the abdominal cavity. This pressure may compromise ventilation as well as the vascular supply to the mesentery, kidneys and lower limbs. The ability to safely close the abdominal cavity is often a matter of surgical judgement. An assessment of lung compliance and ease of ventilation is often requested. Closure is too tight if airway pressures over 30 cmH_2O are needed to maintain adequate ventilation. Intra-abdominal pressure can be measured if closure has been completed. An alternative to closure is to construct a tubular 'silo' with plastic to hold and protect the intestines outside of the abdomen, with gradual reduction of bowel into the peritoneal cavity over several days.

14.10.3.4 Postop Management

If the abdominal wall hernia was very small and there are no concerns about raised Intra-abdominal pressure or coexisting anomalies, extubation at the end of surgery can be considered after planning for post op analgesia. Usually, the neonate is sedated and ventilated postop while the adequacy of ventilation and analgesia are assessed. If a silo was created, it is gradually made smaller over several days while the neonate is sedated and ventilated.

14.10.4 Congenital Diaphragmatic Hernia

Neonates with congenital diaphragmatic hernia (CDH) have a defect in the diaphragm with abdominal viscera in the chest and abnormally developed lungs. The

primary defect in CDH is probably pulmonary hypoplasia, which in turn causes a defect in the diaphragm during development. The pulmonary hypoplasia is also the main problem for the baby rather than the hernia itself.

14.10.4.1 Background

The pathological features of pulmonary hypoplasia affect both lungs, although the lung on the opposite side to the hernia is well formed and expanded. The lung is hypoplastic with abnormal airways, alveoli, and vasculature. There is reduced bronchial budding and inhibited development of alveolar sacs, & pulmonary arterioles have increased muscularity. These changes cause pulmonary hypertension and persistent fetal circulation with right-to-left shunting through the ductus arteriosus. The degree of pulmonary hypoplasia affects outcome. Fetal surgery and other interventions have been tried to improve lung development, but are not beneficial. Cardiac and other anomalies are commonly present.

Eighty-five percent of the hernias are on the left side through the foramen of Bochdalek. The liver usually herniates in a right-sided defect, perhaps limiting intestinal herniation and lung compression (however, there is no difference in outcome between right and left hernias). Diaphragm eventration is where the diaphragm is still intact but thin and ineffective.

After birth, mechanical ventilation is begun with the aims to oxygenate and reverse pulmonary hypertension while avoiding barotrauma to the hypoplastic lung. This 'gentle ventilation' strategy includes keeping airway pressure below 25 cmH_2O, keeping preductal saturation >85% and allowing permissive hypercapnia. High frequency oscillatory ventilation (HFOV) can be used either as a rescue mode or primary mode of ventilation, but its exact role in management is not clear. Inhaled nitric oxide and ECMO are also occasionally used when pulmonary hypertension and right heart failure are problematic. However, their effectiveness is controversial and their role in treatment is not clear. ECMO improves short but not long-term outcome.

Surgery may be performed several days after birth when the degree of pulmonary hypoplasia and its effect on the circulation have been assessed and the baby's condition stabilized. The sickest babies who are difficult to ventilate and have poorly controlled pulmonary hypertension do not usually go to theatre. Some babies require HFOV, nitric oxide and sildenafil therapy to maintain oxygenation. If they have been stable for a couple of days and there is some reserve to deal with any post-op deterioration, then surgery may go ahead while still on HFOV. These babies are often operated on in NICU to reduce the risks of transfer to theatre.

Surgery is via an abdominal incision; the abdominal viscera are removed from the thorax and the diaphragm closed. A patch is used if needed to close either the diaphragm or abdomen. Thoracoscopic repair is being increasingly used. One-lung ventilation is not required as intraoperative inflation of the hypoplastic lung is not a problem. After the diaphragm is repaired, the hypoplastic lung only partly fills the thoracic cavity, leaving a pneumothorax. This is not drained, but the cavity fills with fluid and the lung expands over several weeks. Surgical repair of the hernia does not improve ventilation.

14.10.4.2 Anesthetic Management

The neonate is transferred from NICU intubated, ventilated and with invasive monitoring in situ. Anesthesia is usually reasonably straightforward, as only those babies with stable ventilation and pulmonary pressures go to surgery. The major concerns are to avoid pulmonary hypertension and barotrauma. A high-dose opioid technique is frequently used to blunt changes in pulmonary vascular resistance in response to surgical stress. Inhaled nitric oxide can be used if pulmonary hypertension occurs, but is not commonly required. Ventilation is usually straightforward during anesthesia. The baby is returned to NICU ventilated postop.

Keypoint
The main problem in congenital diaphragmatic hernia is pulmonary rather than diaphragmatic.

14.10.4.3 Postop Management

A 'honeymoon period' after surgery lasts for hours to days, but the neonate can then deteriorate with worsening thoracic compliance, ventilation and pulmonary hypertension. There is a significant post op mortality. Long term problems are common, including reduced pulmonary function, gastro-esophageal reflux and neurodevelopmental delay.

14.10.5 Tracheo-esophageal Fistula

Tracheo-esophageal fistula is an uncommon neonatal surgical condition that presents several unique challenges for anesthesia. It refers to several combinations of esophageal atresia and fistula formation between the esophagus and trachea (Fig. 14.3).

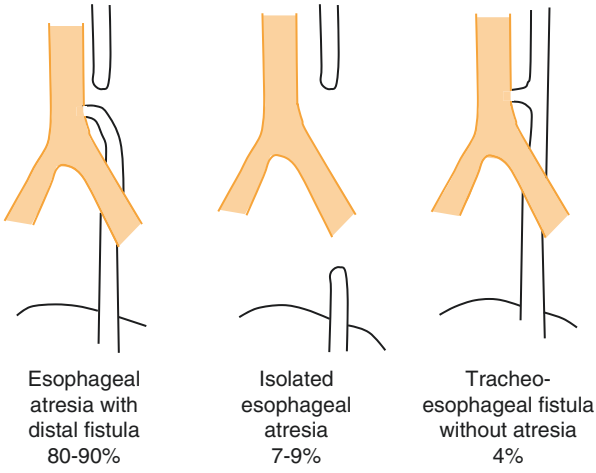

Fig. 14.3 The three most common variants of tracheo-esophageal fistula. Only the first, most common variant is associated with the problem of gastric inflation that is difficult to reverse. The third variant, tracheo-esophageal fistula without esophageal atresia, is also called 'H-type'

14.10.5.1 Background

In most variants, a fistula between the trachea and esophagus allows gas to enter the stomach which inflates and pushes the diaphragm upwards, restricting ventilation. In the most common variant, there is no access to the stomach other than through the fistula, and no simple way to decompress the stomach if it inflates. The second most common variant has no fistula but only esophageal atresia, making anesthetic management much more straightforward. The 'H-type' variant has a patent esophagus which allows passage of a NGT to decompress the stomach if it inflates. However, connecting the stomach to the atmosphere with a NGT or gastrostomy may create a passage between the trachea and stomach of such low resistance that gases follow this path rather than ventilating the lungs. Decompression of the stomach is a temporizing measure allowing some time for the surgeon to clamp the fistula, but it is not a complete solution.

Inadvertent inflation of the stomach during ventilation of the lungs is a serious problem, but it is often overstated. In practice, the stomach does not often significantly inflate with gentle ventilation of normal lungs. Neonates with abnormal, poorly compliant lungs are more at risk, although often they are ventilated in NICU before surgery.

The commonest variant has a blind upper esophageal pouch with the lower esophagus joining the posterior wall of the trachea just above the carina. Neonates with this variant of TOF have trouble clearing saliva and may cough, choke or have desaturation episodes from saliva or attempted feeds irritating the larynx. Diagnosis is confirmed by trying to pass a NGT that then curls in the esophageal pouch on X-ray. The H-type variant usually presents later—at a few weeks of age with coughing during feeds. The fistula is often in the neck, and a neck approach used for surgery.

About 50% of neonates with tracheo-esophageal fistula have with other congenital anomalies. These anomalies include cardiac defects (27%), VACTERL (19%) and urogenital defects (18%). Prematurity and cardiac problems both increase the mortality from TOF—the mortality is very high in preterm neonates <1500 g with cardiac problems.

A Repogle tube (Fig. 14.4) is inserted orally into the upper esophageal pouch to remove saliva, and the baby may be nursed head up to reduce lung soiling. Surgery is usually performed within 24 h of birth to prevent lung damage from either saliva through the larynx, or stomach acid through the fistula. Some small, preterm babies have surgery sooner (even in the middle of the night) if there is concern that their lung function will worsen and require ventilation—surgery is brought forward to close the fistula while lung function is good. Surgery is usually via a right

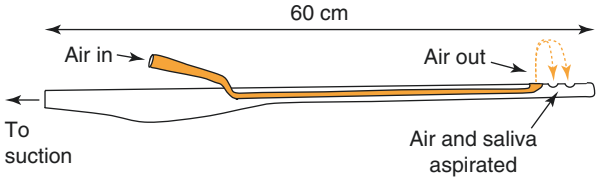

Fig. 14.4 A Repogle tube

thoracotomy, but if the aortic arch is abnormally located on the right, a left thoracotomy may be used. An extrapleural approach is most commonly used, providing some protection if an anastomotic leak occurs, and avoiding the need for an intercostal drain postop. Very preterm babies or those with a large gap may undergo a staged procedure in which initial surgery closes the fistula and a later procedure anastomoses or replaces the esophagus.

14.10.5.2 Anesthetic Management

There are several specific concerns during anesthesia and surgery for tracheoesophageal fistula (Table 14.17). Although a thoracotomy is performed, one-lung ventilation is not used and instead the lung is retracted out of the way. TOF repair can also be carried out thoracoscopically, during which one-lung ventilation helps greatly with surgical access but is technically difficult to provide. Blood loss is not usually a problem and transfusion is not required unless there is a major surgical complication.

Many strategies have been described to reduce the risk of gastric inflation via the fistula. However, this is most likely to be a problem if the lungs are poorly compliant and require high airway pressures for ventilation.

14.10.5.3 Induction

The Repogle tube is removed just before induction as it prevents mask seal and takes up room in the mouth during laryngoscopy. Some centers routinely perform a rigid bronchoscopy before thoracotomy to determine the location of the fistula. This generally requires a spontaneous ventilation technique during bronchoscopy. A balloon catheter can be passed during bronchoscopy to occlude the fistula, but this is technically difficult, uses equipment not specifically designed for the purpose and adds the risk of the balloon shifting and occluding the tracheal lumen.

A rapid sequence induction is used in some centers because of concern about aspiration of saliva. However, the Repogle tube (removed immediately before induction) reduces the volume of saliva present, and aspiration of saliva into the lungs is not as dangerous as acid aspiration. Inhalational induction is more controlled than a rapid sequence induction, and allows time to assess the airway and ability to gently assist ventilation.

Table 14.17 Summary of anesthesia concerns and problems (in addition to the usual neonatal anesthesia concerns) in neonates with trachea-esophageal fistula

Anesthesia concerns in TOF repair
Coexisting anomalies, particularly cardiac
Potential for lung problems and difficult ventilation
Rigid bronchoscopy commonly performed to determine fistula location
Inflation of stomach, compression of diaphragm, difficult ventilation
Compression of trachea and great vessels during surgery
Blood in trachea with possible occlusion of ETT
Tension on anastomosis between the two ends of esophagus postop

14.10.5.4 Intubation

Some intubation strategies have been described to reduce the risk of gastric inflation via the fistula. The first is to position the ETT below the level of the fistula by deliberately performing an endobronchial intubation and then withdrawing the ETT to just above the carina. This is a reasonable approach in theory, but in practice the neonatal trachea is so short that nearly all intubations end up quite distal in the trachea anyway. In addition, the fistula is often very close to the carina. The second is to turn the ETT bevel away from the fistula hoping that this will increase resistance for gas entering the fistula. However, there is a gap around the ETT within the tracheal lumen, and gas will flow in the gap to enter the fistula no matter which way the bevel faces. In practice, keeping airway pressure low seems to be the most important strategy rather than any tweaking of ETT position. If gastric insufflation occurs and ventilation is inadequate, deliberate endobronchial intubation can be used to temporize the situation. Deliberate left sided intubation is best, as the right lung will be retracted during thoracotomy to ligate the fistula. Deliberate left endobronchial intubation can be achieved by turning the baby's head to the right, and facing the ETT bevel to left while advancing the ETT.

14.10.5.5 Maintenance

Maintenance of anesthesia usually includes muscle relaxation and controlled ventilation, avoiding high PEEP and accepting hypercapnia until the fistula is ligated. This technique maintains oxygenation and allows an opioid based anesthetic technique to be used.

A spontaneous ventilation technique aims to avoid positive pressure within the trachea and fistula. However, it is difficult to achieve satisfactory operating conditions and adequate oxygenation during spontaneous ventilation because of cardiovascular and respiratory depression. This is especially true once the chest has been opened. The upper lung is then at atmospheric pressure and makes no contribution to ventilation and ventilation of the lower lung is impaired by mediastinal flap. It is a difficult technique to make work in practice.

An arterial line is commonly inserted and occasionally also a CVC, although neither is mandatory. Their insertion may significantly lengthen the duration of anesthesia before the fistula is occluded. The major problem during surgery is rapid changes to ventilation because of compression of the trachea and bronchi. Vascular compression with changes in cardiac output is also a problem, but less common. Close attention needs to be paid to compliance and tidal volume, which can be done by either hand ventilation, (especially with the T-piece), or measurement of respiratory parameters on modern ventilators. The anesthetist needs to liaise with the surgeon about issues such as tracheal compression or occlusion, and work with the surgeon to facilitate surgery. There may be brief periods when ventilation needs to be stopped while the trachea is occluded to enable a surgical manoeuver. Almost all of these infants have some degree of tracheomalacia, but this does not usually cause any troubles during repair.

Tip

In practice, the major problem during TOF surgery is intermittent compression of the trachea and its effect on ventilation and oxygenation.

It is a difficult situation if the stomach inflates and compromises ventilation during surgery. One approach is to quickly tie off the fistula, although in practice this takes considerable time. Another is to perform a gastrostomy, either percutaneously with a needle or by a mini-laparotomy. However, a gastrostomy creates a tracheocutaneous fistula and ventilation will go out through this path if it offers the least resistance. A needle gastrostomy offers a higher resistance to ventilation and may be better. If ventilation is compromised, the quickest and simplest option is to push the ETT in for a deliberate left-sided endobronchial intubation. Any of these techniques should be seen only as a way to temporize until surgery occludes the fistula.

After the fistula is controlled, the two ends of the esophagus are anastomosed. This usually involves passing a NGT through the proximal esophagus and into the surgical field for the surgeon to thread though the distal esophagus before completing the anastomosis. The NGT is left in for several days post op while it is used for feeds and then removed and oral feeds begun.

Postop Management

Sedation and ventilation are usually continued after surgery because of concerns about tension on the anastomosis. The duration varies from 1or 2 days to several days, depending on the degree of tension and institutional preferences. Longer term problems in these babies include tracheomalacia which leads to a weak cough ('TOF-cough") and esophageal strictures that require dilatation.

Review Questions

1. Why are neonates usually intubated and ventilated during anesthesia?
2. What are the problems that occur as a result of pulmonary hypoplasia in a neonate with congenital diaphragmatic hernia?
3. What are the anesthetic issues surrounding prematurity and the very young? (organize your answer by systems, and apply the physiological changes to anesthetic management)

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Anesthesia for Pediatric General Surgery

15

Claudia Rebmann

Children having general surgery present an enormous diversity of ages, conditions and procedures. The majority of procedures involve simple, superficial surgery and are performed on healthy children managed as day cases who require little or no pre-operative investigations. Local anesthetic techniques are useful for these surgeries, and some suitable techniques are summarized in Table 15.1. Children also undergo major surgery that may require special considerations, and these are discussed later.

15.1 Herniotomy

Inguinal hernias are common in children. They occur in three percent of term infants and are more common in preterm infants, who are also more likely to have bilateral hernias. In adults, hernias are due to a defect in the abdominal wall, but in children they are due to a patent processus vaginalis. This leaves a peritoneal diverticulum

Table 15.1 Summary of local anesthetic techniques common to several general surgical procedures

Procedure	Local anesthetic technique
Herniotomy	Caudal or ilioinguinal/iliohypogastric
Orchidopexy	Caudal or ilioinguinal/iliohypogastric
Umbilical hernia repair	Rectus sheath block or local infiltration
Circumcision	Caudal or dorsal nerve block or ring block
Exploration scrotal contents	Local infiltration
Laparoscopic appendicectomy	Infiltration of port sites

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that intestine can herniate into, or for fluid to accumulate and cause a scrotal hydrocele. An inguinal hernia usually presents as a groin lump that can be reduced. An irreducible or obstructed hernia is more common in infants and causes bowel obstruction and compression of the testicular or ovarian vessels. Infants and children with an obstructed hernia undergoing emergency surgery are at risk of regurgitation and aspiration and are intubated after a modified rapid sequence induction. Preterm neonates are more prone to obstructed hernias and their hernias are electively repaired at an early age, often before they are discharged home from the neonatal nursery.

Note
Hernia repair in children—herniotomy, during which the patent processus vaginalis is tied off. Hernia repair in adults—herniorrhaphy during which the abdominal wall defect is repaired. Different cause and different procedure.

15.1.1 Anesthesia for Herniotomy in Children

Beyond infancy, general anesthesia is given using a laryngeal mask airway (LMA), and either an ilioinguinal/iliohypogastric block or local infiltration is used to supplement postoperative analgesia. Surgery takes 30–60 min.

15.1.2 Anesthesia for Herniotomy in Neonates and Infants

There are four issues related to anesthesia in this age group: general or regional anesthesia, management of the airway, analgesia and the risk of apnea after anesthesia. Although neurotoxicity from general anesthesia has been raised as a concern in these infants, the surgery cannot be delayed until an older age because of the risk of the hernia causing obstruction, and there is no evidence of a neurotoxic effect in humans from a single brief anesthetic.

15.1.2.1 General or Regional Anesthesia

General anesthesia is most commonly used for herniotomy. Awake spinal anesthesia can be used for neonates if surgery is shorter than 30–40 min. It doesn't reliably give adequate surgical conditions in older infants. Regional anesthesia avoids the risk of airway management in the neonate, avoids respiratory problems in some very small preterm neonates with chronic lung disease, and avoids the possibility of neurotoxicity from anesthesia. It also reduces early apnea after anesthesia (see below). The disadvantages are the high technical failure rate performing the spinal block (more than 10%), and its short duration (see Chap. 10, Sect. 10.5.4). Awake caudal anesthesia can be used, but the block is slower in onset and not as dense, and leg movement during surgery can be a problem. If a spinal block is used for surgery, wound infiltration or an iliohypogastric block is done for analgesia after surgery.

15.1.2.2 Airway Management

Most neonates and young infants are intubated for herniotomy. There are advantages and disadvantages of intubation compared to the LMA in this age group (Table 15.2). Intubation is common because access to the airway is limited due to its proximity to the surgical site, and hypoxia develops rapidly if the airway is lost. Beyond about 3 months of age, the LMA may be associated with less adverse respiratory events than intubation.

15.1.2.3 Analgesia

There are three options for analgesia.

1. Caudal analgesia is safe and reliable, and is a good choice for neonates and infants, particularly for bilateral repair. Caudal analgesia has the advantage of providing good quality analgesia during surgery, allowing a light plane of anesthesia to potentially reduce the risk of postoperative apnea in former preterm neonates. A block to T10 is required, achieved by a dose of 1 mL/kg of ropivacaine 2 mg/mL.
2. The second option is an ilioinguinal-iliohypogastric nerve block (see Chap. 10, Sect. 10.7.1). This is a good choice in older children who may be upset by leg weakness and numbness resulting from caudal epidural analgesia. A suitable volume is about 0.2 mL/kg of ropivacaine 2 mg/mL per side as required.
3. The final option is wound infiltration with local anesthesia by the surgeon. This option does not provide intraoperative analgesia, and supplementation with opioids is needed.

Preschool-aged children may still benefit from a small dose of fentanyl during surgery, even if a regional block has been given. Emergence delirium is common in this group, and fentanyl reduces its incidence (see Chap. 1, Sect. 1.8.1). After discharge, pain is not severe and is managed with paracetamol, and ibuprofen if the patient is older than 3 months.

Table 15.2 Options for managing the airway of neonates and infants during general anesthesia

Technique	Comments
LMA	
Pros	May reduce respiratory events associated with extubation
	Laryngospasm and obstruction possible during surgery
Cons	Necessitates deeper plane of anesthesia
	Low leak pressure may prevent IPPV
	Size 1 classic LMA unreliable
Intubation	
Pros	Secures airway
	Avoids airway obstruction during anesthesia
	Facilitates IPPV and PEEP
	Facilitates light plane of anesthesia without risk of laryngospasm
Cons	Awake extubation may be associated with coughing and desaturation

15.1.2.4 Postoperative Apnea

Neonates, and especially former preterm neonates, are at risk of apnea after anesthesia. This occurs in 6–10% of former preterm infants age 44 weeks postmenstrual age (PMA) or younger. Awake spinal anesthesia does not reduce the overall incidence but reduces the number of early apneas in PACU and the level of intervention needed to treat apnea. Intravenous caffeine base 10 mg/kg (equivalent to 20 mg/kg caffeine citrate) reduces the incidence of post-operative apnea after general anesthesia and is given to former preterm infants with a postmenstrual age of less than 44 weeks at the time of surgery. Former preterm infants who are younger than 52 weeks PMA (60 weeks in some centers) and term neonates younger than 44 weeks PMA must be admitted overnight for apnea monitoring (see Chap. 14, Sect. 14.4.4).

Keypoints

Children with obstructed hernia are at risk of aspiration.

Former preterm infants are at risk of apnea after anesthesia.

15.2 Undescended Testis and Orchidopexy

About 3% of term boys are born with an undescended testis. Most undescended testes can be palpated in the inguinal canal and the majority will descend into the scrotum during the first year. They are associated with infertility, testicular tumors and psychological problems. They are also more susceptible to testicular torsion and infarction and are often associated with inguinal hernias. If the testis has not descended by 6–9 months of age it is unlikely to ever descend and is surgically brought into the scrotum (orchidopexy).

Orchidopexy surgery uses the same groin incision as herniotomy, as well as a scrotal incision. An ilioinguinal/iliohypogastric nerve block provides good analgesia but does not cover the scrotum. Subcutaneous infiltration over the symphysis pubis blocks the genitofemoral nerve, or the surgeon can infiltrate the scrotal incision during surgery. Opioid analgesia is usually required. A caudal block with of 1 mL/kg of local anesthetic to block to about T10 is a good choice for young children. Antiemetics are routinely given to children older than 2–3 years. Orchidopexy pain tends to be more severe and longer lasting than the pain after herniotomy and many other day stay procedures in children. Despite this, analgesia on discharge is usually successfully managed with paracetamol and ibuprofen. Older boys (preteens) may need oral opioids for the first 24 h after surgery.

If the testis is not even palpable in the inguinal canal, the 2-stage Fowler Stevens procedure is performed. Firstly, laparoscopy is performed and if the testis is present, the testicular vessels are clipped. In the second stage several months later, laparoscopy is performed again, and the testis is pushed into the scrotum and fixed there through a scrotal incision.

15.3 Torsion of the Testis and Surgery to Explore Scrotal Contents

Acute scrotal pain may be due to torsion of the testis or the appendix of the testis (Hydatid of Morgagni). The majority of cases occur around puberty and are due to torsion of the appendix of the testis. Surgery to explore the scrotal contents is performed urgently because of concern of testicular ischemia. Pain is not usually severe enough to delay gastric emptying, and face mask or LMA anesthesia is reasonable unless the child is not fasted or is vomiting beforehand. The procedure is not particularly painful afterwards. These children are usually too old for caudal analgesia, and instead wound infiltration is used with opioid analgesia and antiemetics.

15.4 Circumcision

Male circumcision is commonly performed for recurrent balanitis or balanitis xerotica obliterans (BXO) that results in phimosis (inability to retract the foreskin). Some children undergo circumcision during infancy for social or religious reasons. On the one hand, during infancy the risk of anesthesia is higher and there is the possibility of neurotoxicity from anesthesia. On the other hand, the risk of anesthesia is reduced if the anesthetist cares for large numbers of children each year, and a single, short anesthetic does not affect neurodevelopment in humans.

15.4.1 Analgesia for Circumcision

The procedure is very stimulating, and laryngospasm is a concern early in surgery when anesthetic depth might not have been optimized. Caudal analgesia, dorsal nerve block and ring block are suitable alternatives for analgesia after circumcision (Table 15.3). A caudal block to the level of only S2–4 is needed for circumcision.

Table 15.3 Comparison of local analgesia techniques for circumcision in children

Block	Duration	Comments
Caudal	2–4 h	More reliable block in younger children Major central block May delay walking
Penile	4–6 h	May be technically difficult (ultrasound may improve success rate) Rare penile ischemia May not cover ventral surface of penis
Ring block	2–4 h	May cause local swelling and interfere with surgery May cause local hematoma Less reliable in younger children
Antiseptic/local anesthetic creams	Can be reapplied	Variably effective, good supplement after discharge No intraoperative analgesic effect

This requires a dose of 0.5 mL/kg ropivacaine 2 mg/mL or L-bupivacaine 0.25%, maximum of 10–15 mL. An alternative caudal technique is to aim for a saddle block using a small volume of more concentrated solution (L-bupivacaine 0.5% 0.2–0.3 mL/kg), but in practice motor block is difficult to avoid. Caudal block is probably best used for children younger than 6–8 years. It often causes paresthesia of the legs in older children, which is annoying to them. A ring block of the penile shaft is simple to perform, but local swelling or hematoma from the local anesthetic may affect surgery, and its duration is shorter than other techniques. A Cochrane review of the three alternatives for analgesia found no difference in the need for rescue or other analgesia between the three. In day-case surgery, penile block may be preferable to caudal block in children old enough to walk due to the possibility of temporary leg weakness after caudal block. After discharge, analgesia is provided with a local anesthetic cream and simple oral analgesics.

15.5 Hypospadias Repair

Hypospadias is a condition in which the urethral opening is not at the tip of the penis, located instead at some point further down the ventral side of the glans penis or shaft of the penis. More proximal urethral defects are more likely to have an associated ventral shortening and curvature, called a chordee. Several surgical repairs are used (Magpi, Wackmans), but all involve laying open the upper urethra and then closing it over a catheter to create a new, distal urinary opening. The initial repairs are usually carried out in infancy, although some mild cases are not detected until later in childhood when the boy begins to stand to urinate. Caudal analgesia is ideal for this procedure as it reliably blocks the sacral segments. Major hypospadias repairs require strong analgesia for 24–48 h. Either a caudal catheter and local anesthetic infusion can be used, or if a single-shot caudal was used, an intravenous morphine infusion is started in recovery in preparation for the caudal wearing off. Ring blocks of the penis cause local swelling and may interfere with surgery, and penile blocks may be used, but they do not cover the ventral surface well. Retrospective studies comparing penile block and caudal block for hypospadias surgery have found an association between caudal block and the occurrence of urethral fistula after surgery. However, the overall incidence of this complication is low and it is unclear if caudal analgesia causes the complication, or if it occurs because a caudal block is more likely to be performed in more difficult, proximal hypospadias cases.

15.6 Division of Tongue Tie

Although a short and simple surgical procedure, anesthesia for division of tongue tie is challenging. The frenulum tethers the tongue (tongue tie) and affects feeding in infants and speech in children. A scalpel or diathermy is used to divide the frenulum, usually with minimal bleeding. A shoulder roll helps to open the infant's mouth

and improves access for the surgeon. Anesthesia is challenging for several reasons. The procedure is commonly performed in infants and their small airway is shared with the surgeon. The procedure is brief, but very stimulating and may trigger laryngospasm. An LMA is commonly used to manage the airway. The risk is loss of the airway, either due to displacement of the LMA or laryngospasm. A key point is to ensure adequate depth of anesthesia before incision—a bolus of propofol 1–3 mg/kg is wise if there is any doubt. Fentanyl is given so the baby is not in pain after awakening, and paracetamol is adequate for analgesia after surgery.

15.7 Umbilical Hernia Repair

Umbilical hernia repair is performed under general anesthesia, most often with an LMA. There are three points of note about this procedure. Firstly, the peritoneal cavity is entered, and omentum or bowel can protrude into the wound during surgery. Although this could be prevented with muscle relaxation, acceptable operating conditions are provided by maintaining a deep plane of anesthesia with apnea and positive pressure ventilation—if the child breathes spontaneously, the tone in the abdominal wall may push the omentum into the wound. Secondly, the procedure is more painful than inguinal hernias, and a multimodal approach is needed, including a rectus sheath block or wound infiltration. Simple oral analgesics are adequate after discharge. Finally, it is associated with a high incidence of nausea and vomiting, and dual antiemetic therapy is indicated.

15.8 Laparoscopic Surgery

Laparoscopic surgery is performed for a widening range of procedures in children of all ages, including neonates. It is considered to improve outcome by minimizing tissue trauma and pain, speeding recovery and shortening hospital stay.

15.8.1 Physiological Effects of Laparoscopy

Young children absorb proportionally more carbon dioxide through the peritoneum than older children and adults. This is due to a proportionally large peritoneal surface area and a lack of intraperitoneal fat that reduces the distance between capillaries and peritoneum and would otherwise buffer carbon dioxide. Children appear to handle this increased carbon dioxide load without significant acidosis.

As in adults, carbon dioxide insufflation in children increases intra-abdominal pressure, decreases total lung compliance and functional residual capacity (FRC), and causes atelectasis and ventilation-perfusion mismatch. Infants and neonates are particularly at risk of respiratory compromise—their closing lung capacity is already close to FRC and their oxygen consumption is high. The severity of these pulmonary effects depends on the abdominal pressure, and for these reasons a lower

pressure is used in neonates and infants than in children and adults. Fortunately, the infant abdominal wall is very pliable and the abdominal contents can be visualized at lower pressures.

The cardiovascular effects of the pneumoperitoneum depend on the intra-abdominal pressure and age. They are the result of four factors—mechanical compression of splanchnic vessels, postural changes, increased sympathetic tone and the release of vasoconstrictors including renin and vasopressin. At low abdominal pressures, venous return and cardiac output increase, and the systemic and pulmonary vascular resistance increases. Blood pressure and heart rate commonly increase. Cardiac output falls at pressures above 15–20 mmHg. Neonates and infants are more sensitive to the cardiovascular effects from pneumoperitoneum. Bradycardia may occur with peritoneal stretching from rapid carbon dioxide insufflation, although tachycardia more commonly occurs. Children with cyanotic heart disease are at risk of paradoxical gas embolism and may not be suitable for laparoscopic surgery.

Note
Typical pneumoperitoneum pressure to reduce respiratory and cardiovascular effects during laparoscopy
- Neonates and infants younger than 4 months: 5–6 mmHg
- Small children: 8–10 mmHg
- Older children and adults: 10–15 mmHg

15.8.2 Anesthesia Management

Intubation and ventilation is usual practice. Endobronchial intubation may occur in infants because of cephalad displacement of the diaphragm and shift of the carina during the pneumoperitoneum and reverse Trendelenburg position. Venous access ideally should be in the upper limbs to avoid problems from inferior vena cava (IVC) compression, although in practice the pneumoperitoneum should be stopped if there are any problems. Invasive monitoring may be warranted in some neonates or unwell children having prolonged procedures. The pneumoperitoneum reduces lung compliance, and the inspiratory pressure must be increased if pressure-controlled ventilation is used.

Nitrous oxide is probably best avoided, although 50% inspired nitrous oxide is used by many anesthetists without problems. Carbon dioxide is insufflated in children using an open cut-down technique rather than a Verres needle or trocar to reduce the risk of intravascular injection of gas. The flow rate is limited to 0.5–1 L/min in neonates and small infants, and only increased to adult values of 4 L/min in larger, healthy children. The gas is warmed to prevent hypothermia. Neuromuscular blockade usually facilitates lower intra-abdominal pressures. Observation of the flow rate and pressure helps predict and prevent physiological changes and potential crisis situations. If carbon dioxide is inadvertently given subcutaneously, it is rapidly absorbed and the $ETCO_2$ may abruptly rise to high levels.

After surgery, non-parenteral analgesia is often adequate for many procedures. However many children benefit from either an opioid infusion or oral opioids for the first 24 h. Children may also develop referred shoulder-tip pain from sub-diaphragmatic gas.

15.9 Appendicectomy

Appendicitis presents late in young children, nearly always after the appendix has perforated. Anesthetic management is broadly similar to adults—a modified rapid sequence induction after fluid replacement with Ringer's lactate or saline. Morphine 0.15–0.2 mg/kg, paracetamol and NSAIDs are often given during surgery. Children recovery quickly after straightforward appendicectomy. If the appendix was not perforated, they are able to begin oral fluids immediately after surgery and given oral analgesia with oxycodone or morphine, paracetamol and ibuprofen. Children who have a perforated appendix recover slowly after surgery and usually need IV opioids for analgesia. This group of children are often old enough to use patient-controlled analgesia (PCA). Some children with perforated appendicitis require total parenteral nutrition until gut function returns.

15.10 Infantile Hypertrophic Pyloric Stenosis

Hypertrophy of the muscular layers of the pyloric causes gastric outlet obstruction, leading to projectile vomiting. Pyloric stenosis is a common reason for intra-abdominal surgery during the first 12 weeks of life. Although surgery is required to relieve the obstruction, pyloric stenosis is a medical rather than a surgical emergency. Early rehydration and correction of electrolyte and acid base abnormalities contribute to a perioperative mortality of less than 0.3%.

Pyloric stenosis usually occurs in term infant boys aged between 2 and 8 weeks. Infants of this age weigh roughly 4 kg. Most babies are usually otherwise well. There is a short history of non-bilious projectile vomiting after feeds, and the hypertrophied pyloric muscle may be felt in the upper abdomen during a test feed. Clinical examination will show varying degrees of dehydration and possible muscle wasting. An abdominal ultrasound may assist in the diagnosis. Blood tests classically reveal a hypochloremic, hypokalemic metabolic alkalosis. Early recognition and treatment is important to avoid severe dehydration, metabolic derangements and eventual hypovolemic shock.

15.10.1 Pathophysiology

There are three stages in the pathophysiology of pyloric stenosis:

1. Hypochloremic, hypokalemic metabolic alkalosis with dehydration and alkaline urine
2. Potassium depletion with paradoxical acidic urine
3. Shock, lactic acidosis and starvation ketosis.

Gastric outlet obstruction from pyloric stenosis causes the loss of hydrogen chloride, water and small amounts of sodium and potassium. Bicarbonate formed during the production of hydrogen chloride enters the plasma, causing metabolic alkalosis (Fig. 15.1). This causes the characteristic hypochloremic, hypokalemic metabolic alkalosis, with varying degrees of dehydration. (In contrast, vomiting without gastric outlet obstruction causes loss of hydrogen from the stomach and bicarbonate from the duodenum, with a neutral effect on acid-base balance).

In the kidney, bicarbonate, chloride and sodium are filtered in the renal glomerulus. Sodium is reabsorbed in the tubule to maintain the extracellular fluid (ECF) volume. Some sodium also accompanies the bicarbonate in the urine, and so the urine contains small amounts of sodium, which is different to other clinical situations with low ECF volumes. Reabsorption of chloride in the renal tubule is maximal because of hypochloremia, but there is insufficient chloride to reabsorb alongside sodium (to maintain electroneutrality), and some bicarbonate is also reabsorbed. While there is insufficient chloride ion, the kidney cannot excrete all the bicarbonate needed to correct the metabolic alkalosis. This is the reason resuscitation fluid must contain chloride.

Dehydration and reduced ECF volume stimulate aldosterone secretion, and sodium reabsorption in the tubule in exchange for potassium (Fig. 15.2). This causes kaliuresis and depletion of total body potassium—most potassium loss in infants with pyloric stenosis occurs in the urine. The plasma potassium concentration is a poor guide of this depletion and is often normal because potassium is an intracellular ion.

If untreated, pyloric stenosis causes severe dehydration, forcing the kidney to maintain the ECF volume rather than the pH, and sodium reabsorption in the renal

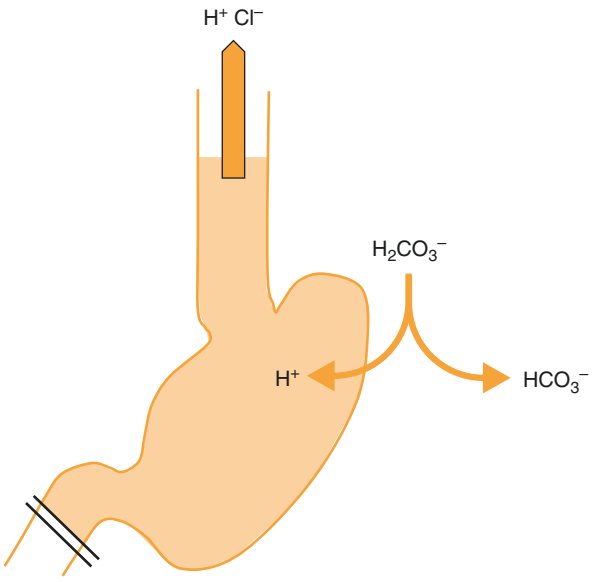

Fig. 15.1 Pathophysiology of pyloric stenosis. Gastric outlet obstruction causes vomiting and loss of hydrogen and chloride ions. Bicarbonate produced during formation of gastric acid enters blood stream ('alkaline tide'), raising plasma-bicarbonate concentration

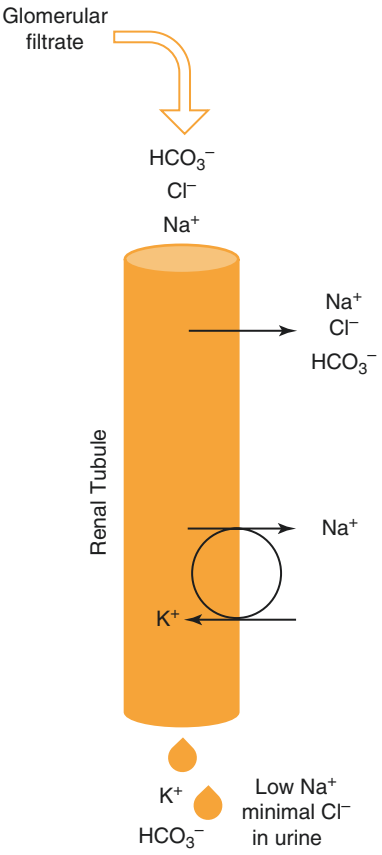

Fig. 15.2 In the kidney, sodium and chloride are reabsorbed in the renal tubule and excess bicarbonate excreted. Potassium is lost in exchange for sodium reabsorption

tubule is maximized by exchanging for H^+ ions. Hydrogen ions are then secreted in the urine, causing paradoxical aciduria that makes the metabolic alkalosis even worse (Fig. 15.3). Later, hypovolemic shock and lactic acidosis develop and are superimposed on the metabolic alkalosis.

Note
Pyloric stenosis causes a hypochloremic, hypokalemic metabolic alkalosis. The key to reversing the metabolic alkalosis is chloride and volume. Only when chloride is given (usually as sodium chloride) can the kidney excrete enough bicarbonate to correct the alkalosis.

15.10.2 Assessment and Preparation for Surgery

Hypovolemia and electrolyte and acid/base abnormalities must be corrected before surgery. Most cases now are mild, and the metabolic disturbance can be corrected in

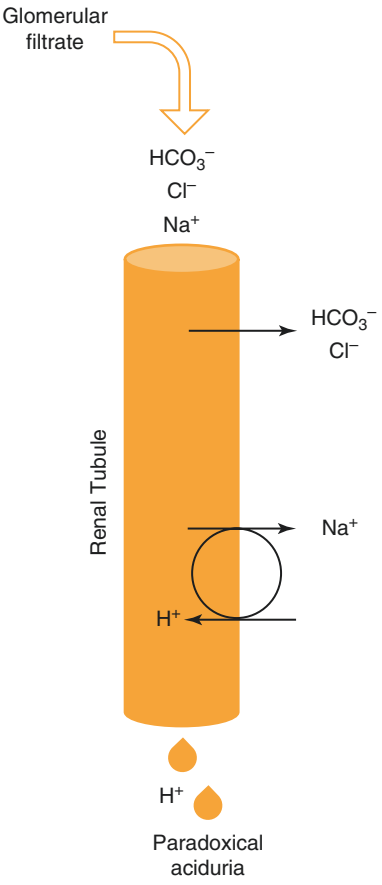

Fig. 15.3 Severe dehydration causes the kidney to maintain ECF volume rather than maintain correct pH. Sodium is absorbed in exchange for hydrogen, causing a paradoxical aciduria

Table 15.4 Classification of severity of electrolyte disturbance in pyloric stenosis before resuscitation

Severity	Serum chloride concentration	Serum bicarbonate concentration
Mild	90 mmol/L or more	35 mmol/L or less
Severe	85 mmol/L or less	42 mmol/L or more

12–24 h. Infants with more severe disturbance have a chloride level of 85 mmol/L or less, are more likely to be very dehydrated or shocked, and may take 36–72 h to correct (Table 15.4).

Preparation before surgery includes fasting, inserting a 8–10F nasogastric tube, and rehydrating with IV fluids. Fluid therapy for the commonest, mild cases is typically a bolus of normal saline 20 mL/kg followed by 5% dextrose in normal saline with added potassium (KCl 20 mmol/L) at 1–1.5 times maintenance rate. Nasogastric losses are replaced with additional normal saline. More severe cases may need extra boluses of saline for initial resuscitation.

Table 15.5 Electrolyte and acid/base targets for resuscitation

Measured parameter	Target level
Serum Cl^-	100 mmol/L or higher
Serum Na^+	132 mmol/L or higher
Serum K^+	3.2 mmol/L or higher
Serum HCO_3^-	Below 30 mmol/L
pH	7.35–7.45
Urine Cl^-	20 mmol/L or higher (if measured)

Surgery can proceed when the baby is rehydrated, the plasma chloride is more than 100 mmol/L, and bicarbonate levels less than 30 mmol/L (Table 15.5). Urine output should also be adequate, usually judged on the number of wet nappies (because these babies don't usually have a urinary catheter inserted). The urinary chloride concentration is also a good marker of assessing metabolic resuscitation, but is seldom measured. Correction of the metabolic disturbance is important—uncorrected alkalosis may delay recovery from anesthesia and will increase the risk of postoperative apnea.

15.10.3 Surgery

The Ramstedt pyloromyotomy splits the serosa and underlying muscular layers of the pylorus through to the mucosal layer. The procedure is usually performed laparoscopically, although it is not certain if this has benefits compared to an open approach through a right upper quadrant or umbilical incision. Surgery is associated with minimal blood or extravascular space losses.

15.10.4 Anesthesia

Infants with pyloric stenosis usually arrive in theatre with an IV cannula in situ. It is vital that the stomach is emptied before induction as these infants often still have milk in their stomach. The fine-bore nasogastric tube used in the baby's medical management does not reliably empty the stomach, and is best replaced with a larger orogastric tube (10F or 12F). Aspiration of the stomach is done with the baby supine and then in the lateral (both sides) and prone positions. The nasogastric or orogastric tube is then often removed before induction because it may affect the mask-seal for ventilation or obscure the view at laryngoscopy. It does, however, usually need to be reinserted during surgery to deflate the stomach. Some surgeons will ask for air to be injected into the stomach so they can push it into the duodenum to test for mucosal perforation and the adequacy of the myotomy.

An intravenous, modified rapid sequence induction or an inhalational induction can be used. Both have advantages and disadvantages.

15.10.4.1 Modified Rapid Sequence Induction

This technique is particularly popular in North America. It includes IV induction, with or without cricoid pressure and either suxamethonium or a non-depolarizing

muscle relaxant. Gentle ventilation after induction and before intubation is vital, as preoxygenation is difficult to perform and an apneic baby will desaturate very quickly. Many anesthetists do not use cricoid pressure in infants because it may compress the trachea and distort the larynx at laryngoscopy. This technique prioritizes the risk of regurgitation and aspiration above other risks. The disadvantage of this technique is its rapidity—mask ventilation must be established within seconds of induction. There is little time to adjust hand or mask position, or to correct a mask leak affecting ventilation. It is a technique that relies on excellent airway skills to avoid hypoxia or a hurried, traumatic intubation.

15.10.4.2 Inhalational Induction

Many anesthetists favor inhalational induction because of concerns of loss of airway control after an IV induction. The safety of the inhalational induction relies on emptying the stomach as above before induction. Induction is slower, and allows more time to assess the airway and potential issues as the baby loses consciousness. Cricoid pressure can be applied if desired after loss of consciousness, and a small dose of non-depolarizing relaxant is given to facilitate intubation.

15.10.4.3 Maintenance

These babies are usually intubated with a size 3.0 cuffed or 3.5 uncuffed ETT. Surgery is stimulating, and tachycardia usual. Nitrous oxide is useful for intraoperative analgesia. Opioids are avoided to minimize postoperative apnea, which is a risk in these infants due to persisting CSF alkalosis, even after plasma electrolytes have returned to normal. Some suggest a small dose of alfentanil or remifentanil to reduce intraoperative tachycardia. Hypocarbia should be avoided during lung ventilation as it increases the risk of postoperative respiratory depression. Analgesia is provided by intravenous paracetamol and infiltration of wound and port sites with local anesthesia.

Intraoperative fluids are reduced to maintenance rate as there are minimal blood or extravascular fluid losses. After completion of surgery, neuromuscular blockade is reversed, the orogastric tube aspirated and removed, and the infant is extubated awake in the lateral position.

15.10.4.4 Postoperative Care

Infants must be monitored for apnea in the post-operative period. Opioids may potentiate the risk and are not usually needed after surgery. Analgesia is with oral or IV paracetamol (these infants are usually too young for ibuprofen). Postoperative vomiting is common (15–35%) after pyloromyotomy, although usually self-limiting. Persistent vomiting suggests incomplete myotomy or mucosal perforation.

Intravenous fluids are continued at maintenance rate until oral feeding is established. The speed at which feeds are restarted may be slow, fast or on-demand, depending on institutional preferences. Most feeding regimens have babies on full feeds by 16–24 h. Otherwise healthy infants may be discharged once they have tolerated two to three full feeds. Infants with significant pre-operative vomiting, severe electrolyte imbalance or malnutrition may need a longer period of recovery. The key points of anesthesia for a baby with pyloric stenosis are listed in Table 15.6.

Table 15.6 Anesthesia considerations for pyloromyotomy

Key points about pyloric stenosis
Pyloric stenosis is a medical but not a surgical emergency
Correction of volume deficit, electrolyte and acid-base abnormalities with chloride-containing IV fluid. Endpoint: adequate urine output and normal Cl^- and HCO_3^- levels
Functional gastric outlet obstruction with an increased risk of pulmonary aspiration. Careful suctioning of large bore gastric tube with infant supine, lateral and prone
Neonatal anesthesia with consideration of respiratory and cardiovascular physiology and temperature control. Intubation with 3.0 mmID cuffed ETT
Avoid opioids if possible
Postoperative analgesia with paracetamol. Monitor for apnea and hypoglycemia

Table 15.7 Important considerations for anesthesia for laparotomy for intussusception. General principles of anesthesia for an infant are also relevant

Intussusception keypoints
Hypovolemia from vomiting, bowel losses and rectal bleeding
May have sepsis from ischemic bowel
High risk of pulmonary aspiration of stomach contents
May require large volumes of fluid

15.11 Intussusception

Intussusception is the telescoping of a length of bowel into the lumen of more distal bowel. In classical infant intussusception (ileocolic intussusception) the ileum invaginates through the ileo-cecal junction into distal bowel. Occasionally the lead point is a polyp or Meckel's diverticulum, but more commonly there is no apparent cause. It usually occurs in infants between 4 and 10 months of age. Intussusception often follows a viral gastroenteritis or upper respiratory tract infection and presents with abdominal pain, vomiting and blood-stained mucous stools. If not treated promptly, the trapped bowel becomes ischemic and may perforate. The infant can be hypovolemic, and initial therapy may involve stomach decompression with a gastric tube and fluid resuscitation. Initial diagnosis is made with ultrasound. This is followed by a barium or air enema, which will confirm the diagnosis and reduce the intussusception in 80% of cases. If reduction is unsuccessful or if there are signs of peritonitis, urgent laparotomy is performed. If the intussusception cannot be reduced at laparotomy, bowel resection is performed.

Infants with intussusception vary in the severity of illness, but are often hypovolemic, look unwell and at risk of vomiting and aspiration (Table 15.7). Resuscitation with isotonic crystalloid or colloid must be aggressive and may need to take place whilst initiating and maintaining anesthesia. Large volumes of fluid may be needed, and hypotension and shock may worsen with reperfusion of the ischemic bowel. The aim is to make sure the baby has received at least 20–30 mL/kg of fluid before induction and then more depending on the infant's condition and test results. Induction aims to minimize cardiovascular depression. Depending on how unwell and shocked the infant is, doses may be as low as fentanyl 1–2 μg/kg followed by

propofol 2 mg/kg or ketamine 1–2 mg/kg followed by a relaxant. These infants may need a period of stabilization postoperatively before extubation.

Postoperative analgesia includes intravenous paracetamol, wound infiltration, and morphine infusion. Although a lower abdominal incision is used for surgery, caudal analgesia is not usually used because of concerns about sepsis.

15.12 Abdominal Tumors

The commonest solid abdominal tumors in childhood are Wilms tumor (nephroblastoma) and neuroblastoma. Both present similar anesthetic problems (Table 15.8). Children have anesthesia for tumor removal and for procedures connected with chemotherapy including bone marrow biopsy (to exclude metastases), IV access and imaging procedures.

15.12.1 Wilms Tumor

Wilms tumor (nephroblastoma) is a malignant tumor of the kidney. It is bilateral in 5–10% of cases, and mostly occurs in young children aged 6 months to 5 years. It presents late, usually as an asymptomatic abdominal mass, or sometimes causing fever, hematuria, malaise, anemia or weight loss. Abdominal pain usually indicates an acute complication such as hemorrhage into the tumor. About 10% of children are hypertensive due to increased renin secretion that can be managed with ACE-inhibitors. The tumors can become very large, predisposing the child to regurgitation and aspiration under anesthesia. Some invade the inferior vena cava, and can even extend into the atrium, placing the child at risk of the tumor embolizing into the pulmonary circulation before or during surgery.

Treatment is with nephrectomy or with chemotherapy before and after surgery for advanced tumors. The timing of chemotherapy may vary with different oncologists. Surgery involves a large transverse transperitoneal incision and may range from nephrectomy with lymph node sampling to a very extensive dissection of intra- and retroperitoneal structures. Overall cure rates exceed 85% with modern multimodal treatment strategies.

Table 15.8 Anesthetic considerations for surgical resection of Wilms tumor and neuroblastoma

Wilms tumor and neuroblastoma keypoints
Lengthy, major abdominal surgery in infants or small children with high postop analgesia requirements
Often large tumor with significant mass effect
Significant fluid shifts and the potential for rapid and major hemorrhage
Intermittent IVC compression during tumor resection
Thermoregulation
Consequences of paraneoplastic phenomena, such as hypertension and acquired von Willebrand's disease
Vascular tumor thrombus extension into the proximal IVC or right atrium
Preoperative or previous treatment with chemotherapeutic drugs

15.12.2 Neuroblastoma

Neuroblastoma is a tumor of ganglion cells, the same stem cell of the neural crest causing pheochromocytoma. It makes up about 7% of all childhood cancers. Most are located in the abdomen (40% of all neuroblastomas are in the adrenal glands, 25% parasympathetic chain), but can also be within the thorax, pelvis and elsewhere. It is a cancer of young children—40% of children are less than 1 year old, and it is rare after 10 years of age. Metastases are present in more than 50% of children at presentation, more in infants. Survival, however, is higher in infants than older children. Urinary catecholamines (HMMA and HVA) are present in the urine of most children with neuroblastoma. Only about a fifth of children, however, have hypertension. The proportion is lower than in pheochromocytoma because neuroblastoma tissue has fewer norepinephrine storage vesicles. The release of catecholamines may also produce fever, sweating, flushing and diarrhea. Paroxysmal or sustained preoperative hypertension requires perioperative anti-hypertensive therapy. Even with adequate preparation, significant hemodynamic changes may occur during surgery. The related tumor, ganglioneuroma, is benign and does not secrete catecholamines.

Treatment of localized tumors is by resection, and children with advanced tumors are given chemotherapy before and after surgery. Hypertension only occurs during tumor removal, and especially if the tumor has not been shrunk with chemotherapy preoperatively. Hypertension and tachycardia during tumor manipulation is generally controlled by increasing the depth of anesthesia.

15.13 Ureteric Reimplantation

Ureteric reflux, or vesicoureteric reflux, is retrograde flow of urine from the bladder into the ureters. It can cause recurrent urinary tract infections, ureteric dilatation, hydronephrosis, and eventually scarred, poorly functioning kidneys. It is a common childhood urological anomaly, affecting 0.5–1% of children. Treatment for reflux includes either an injection of bulking agents such as Deflux® or Vantris® at the insertion point of the ureter into the bladder to create a valve, or surgically re-implanting the ureters into the bladder. Ureteric reimplantation is performed through a lower abdominal incision and the main concern for anesthesia is postoperative analgesia. Wound pain is moderate but bladder spasm related to the surgery and ureteric/suprapubic catheters can be difficult to manage. Strategies include caudal or lumbar epidural analgesia, and antispasmodics such as oxybutinin, NSAIDs and intravesical pethidine. Infants and babies tend to tolerate bladder spasms better than older children and have lower analgesic requirements.

15.14 Pyeloplasty

Pyeloplasty is a surgical reconstruction of the renal pelvis to relieve pelvi-ureteric junction (PUJ) obstruction. It is performed in infants and children as an open or laparoscopic procedure. Infants are sometimes diagnosed by ultrasound in utero.

The incision for open pyeloplasty is painful, though less so in infants. A caudal block can be performed for analgesia, but a large volume of dilute local anesthetic is needed to raise the block high enough to cover the wound. The high point of the block is also the first part not covered when the block recedes. Paracetamol and ibuprofen are routinely used, and an opioid infusion is usually required in children. An alternative is a local anesthetic wound infusion combined with opioid infusion. After laparoscopic pyeloplasty, local anesthetic infiltration of the port sites and simple analgesics are usually adequate, though some children will benefit from an opioid infusion for 24 h after surgery.

Review Questions

1. An 8 week old baby has pyloric stenosis. Fluid resuscitation has been performed and the baby is fit for anesthesia.
   (a) What induction technique will you use and why?
   (b) What size ETT would you use for intubation?
   (c) What postop analgesia would you use, and what is the rationale for your treatment?
2. A 7 month old has a short history of vomiting and blood stained stools. You suspect intussusception. The infants pulse is 140 bpm, the peripheries are cool and blood pressure is 78/50 mmHg.
   (a) Describe your immediate management
   (b) What are the possible options if you are unable to insert a peripheral IV?
3. A 6 week old infant (born at 36 weeks gestation) presents for herniotomy. Can the infant be discharged home on the day of surgery? Justify your answer.
4. An otherwise well 7 year old boy who weighs 25 kg requires laparoscopic appendicectomy. List the drugs and doses you would use for induction. Discuss the steps during your induction up to intubation of the trachea.
5. Describe the anesthesia and analgesia considerations in an 18 month old boy for elective day case orchidopexy.

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Anesthesia for Ear, Nose and Throat Surgery in Children

16

Ian Forsyth and Rohan Mahendran

Ear, nose and throat (ENT) surgery is the most common reason for anesthesia in children—1.5% of all children in Western Australia have an anesthetic for an ENT procedure each year. It involves the challenges of managing a shared and potentially soiled airway as well as the possibility of airway obstruction in the postoperative period. Safe anesthesia requires vigilance, good communication with the surgical team and flexibility of anesthetic technique. This chapter outlines the principles of anesthesia for common ENT procedures in children. Bronchoscopy of the airway is discussed in the next chapter.

16.1 Anesthesia for Ear Surgery

16.1.1 Myringotomy and Tubes (M&T)

Abnormal function of the eustachian tubes is common in children and may lead to otitis media with effusion (OME), or 'glue-ear'. Small ventilation tubes, or grommets, are placed through the tympanic membrane to ventilate the middle ear and prevent hearing loss and speech delay. It is uncomplicated surgery lasting 10–15 min, with anesthesia using a LMA or facemask. Nitrous oxide is safe to use. The ears may be sore for a short time after surgery, and analgesia is required or the child may wake up distressed. Paracetamol with or without a small dose of opioid is usually sufficient for analgesia. Some anesthetists do not obtain intravenous (IV) access during anesthesia for M&T insertion. Proponents argue this saves time and avoids 'handing over' the airway while the IV is inserted. Analgesia is either omitted, given

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orally preoperatively, or with intranasal fentanyl intraoperatively. The obvious risk of this approach is the inability to administer IV drugs in an emergency, and prevention of emergence delirium is limited to fentanyl. It seems difficult to justify this risk when IV insertion only takes a matter of seconds in skilled hands.

16.1.2 Myringoplasty and Tympanoplasty

Myringoplasty is the repair of a chronic perforation of the tympanic membrane. Tympanoplasty is a more extensive repair that may include surgery to the middle ear bones. The surgical approach for both procedures is either transcanal or via an incision behind the ear. Anesthetic considerations include minimizing bleeding that may obscure the operative field and prevention of nausea and vomiting. Nitrous oxide may lift the graft off the tympanic membrane and should be discussed with the surgeon.

16.1.3 Cochlear Implant

Cochlear implant surgery can be life changing for children with severe sensorineural deafness by restoring hearing, speech development and communication. Electrodes run from a receiver under the soft tissue behind the ear through the mastoid and into the cochlea. These patients may have an underlying syndrome associated with their sensorineural deafness (such as Treacher Collins syndrome and Klippel-Feil anomaly), which may be associated with airway difficulties. Facial nerve monitoring is used during surgery, and the child is either intubated without a muscle relaxant or using a short-acting relaxant. TIVA is commonly used to help maintain tight blood pressure control and to reduce bleeding, and nausea and vomiting (PONV). Small doses of opioid and local infiltration by the surgeon achieve analgesia.

16.2 Tonsillectomy and Adenoidectomy

Tonsillectomy is a common procedure usually performed for obstructive sleep apnea (OSA) in preschool-aged children, and for recurrent tonsillitis in older children. Three percent of all children undergo tonsillectomy, and 80% of tonsillectomies are performed for OSA. Pre-operatively, children require assessment of co-existing conditions that affect upper airway size, such as Trisomy 21 or craniofacial abnormalities, and for bleeding disorders such as Von Willebrands disease. Most tonsillectomies are extracapsular, and the tonsil is removed by dissecting between the capsule and muscular wall. For intracapsular tonsillectomy, the capsule is left intact making the procedure less painful, but the tonsil may regrow later.

16.2.1 Obstructive Sleep Apnea

OSA is characterized by severely reduced or obstructed airflow during sleep caused by abnormal upper airway anatomy. The symptoms of OSA in children are different to adults. OSA is discussed further in Chap. 11, Sect. 11.8. In summary however, there are three broad causes of OSA in children. The first is soft tissue occupying the limited space in the upper airway, most commonly adenotonsillar hypertrophy, but also a large tongue in Trisomy 21. Secondly it is caused by hypotonia or discoordination of the pharyngeal muscles, and finally by bony abnormalities in craniofacial syndromes. The cause is frequently a combination of these three factors, for example a child with Robin sequence has a reduced airway size from micrognathia, but also has tonsillar hypertrophy of a degree that might not be a problem in a normal-sized airway.

OSA is common in preschool-aged children because their tonsils and adenoids are large relative to the size of their airway. Adenotonsillectomy is the initial treatment for OSA in children, and improves sleep study parameters, behavior and quality of life in both obese and non-obese children. Non-surgical treatment for OSA includes noninvasive ventilation during sleep, and nasal steroid sprays to reduce inflammation of the adenoids. The ENT surgeon usually diagnoses OSA clinically, and not all children require a sleep study to confirm the diagnosis before tonsillectomy. There is no consensus however, on which sub-group of children need a preoperative sleep study. Typical criteria include suspicion of severe OSA, presence of a craniofacial syndrome, morbid obesity, neuromuscular disorders and young age. In addition, children who are a high anesthetic risk (such as those with cardiac or pulmonary disease) should have a pre-operative sleep study, as a normal result might avoid surgery.

Very rarely, children with severe OSA and co-morbidities (such as morbid obesity or a craniofacial syndrome) may have chronic hypoxia and hypercarbia with a reduced ventilatory response to both. This is rare in modern practice, and screening with ECG or CXR is not warranted unless there are clinical signs of cardiac dysfunction or unusually long-standing and untreated severe OSA. These children may be polycythemic with pulmonary hypertension and right ventricular hypertrophy. The presence of polycythemia and a right ventricular strain pattern on ECG (increased P wave lead 2 and large R wave V1) would suggest a sleep study and echocardiogram should be performed. In very severely affected children with pulmonary hypertension secondary to OSA, a brief period of non-invasive ventilation (BIPAP) may optimize them preoperatively.

Keypoint
OSA significantly increases anesthetic risk for tonsillectomy, particularly in children younger than 3 years.

Table 16.1 Factors that increase the risk of airway obstruction after tonsillectomy in children with OSA

Risk factors for postoperative problems in children with OSA
Young age, especially less than 3 years
Obesity
Craniofacial abnormality with reduced oropharyngeal size (e.g. Trisomy 21)
Severe OSA on polysomnography (10 or more obstruction/h, or SaO_2 below 80%; RDI > 20)
Co-morbidities such as cardiac disease

Postoperative monitoring in HDU or ICU might be required in these children
RDI respiratory disturbance index

Children with OSA have an increased risk of respiratory depression from opioids and anesthetic agents, and of upper airway obstruction and apnea after tonsillectomy. The first few hours and first night after surgery are the times of maximal risk due to airway edema, bleeding, splinting of pharyngeal muscles and effects of opioids. Methods to reduce this risk include the cautious use of opioids during anesthesia, and continuous pulse oximetry and observation after surgery. Some children with OSA are at particularly high risk of upper airway obstruction and are best monitored in HDU or ICU (Table 16.1).

16.2.2 Anesthesia Technique

Experienced anesthetists successfully use many different techniques to ensure safe and smooth anesthesia for tonsillectomy. Tonsillectomy is a short, highly stimulating procedure involving a shared and potentially bloody airway. Respiratory incidents occur in between 1 and 20% of children after adenotonsillectomy (depending on the population studied), and are twice as common in children younger than 3 years. Children are at risk of laryngospasm and postoperative airway obstruction, and it can be challenging to achieve adequate analgesia while avoiding over-sedation and airway obstruction. To maximize safety, the anesthetic technique may need to vary depending on the indication for surgery, local procedures and the postoperative monitoring available. Airway obstruction can occur in PACU, and a person with adequate skills must be readily available. It is important the anesthetic technique ensures airway issues are avoided in recovery, particularly if the anesthetist is alone and possibly has started the next case when problems in PACU occur. One approach is listed in Table 16.2, but is likely to vary depending in different centers. Sedative premedication may cause airway obstruction in young children with severe OSA. Small doses of clonidine and midazolam may be used if required and the child is monitored after the premed is given.

Table 16.2 There are many different techniques for anesthesia for tonsillectomy

Anesthetic component	Reason
IV or inhalational induction	
Flexible LMA, oral RAE ETT in young children	More secure airway than LMA in young children
Pressure support ventilation or IPPV	Control CO_2, maintain lung volume & reduce atelectasis
Paracetamol 15 mg preop or IV intraop	Multimodal analgesia
Fentanyl 1–2 μg/kg plus morphine 0.05 mg/kg IV	Comfortable once awake, but not obstructed
Parecoxib 0.6–0.9 mg/kg (max 40 mg)	Multimodal analgesia
Dexamethasone 0.15 mg/kg (max 8 mg)	Antiemetic, improves analgesia
Ondansetron 0.15 mg/kg (max 4 mg)	Antiemetic
Hartmanns 10–20 mL/kg, continue maintenance rate postoperatively	Maintain hydration despite reduced oral intake postop
Extubate awake	Safe airway for recovery
Opioid boluses once awake in recovery if required	Use small dose opioid intraoperatively, titrate further doses once child awake
Paracetamol 15 mg/kg, 6 hourly postop oral or IV Oxycodone 0.05–0.1 mg/kg, 6 hourly prn	Analgesia required after discharge. Conservative paracetamol dose as likely to require for 7 days or more
Monitor oxygen saturation, observe for upper airway obstruction, excessive sedation, respiratory depression	Risk of OSA persists or may even be higher immediately postop

Above is one technique, given as a suggestion to form a backbone or starting point for an individual's own technique and depending on the surgical preferences, child's age and medical conditions

16.2.2.1 Airway Management

In many centers, endotracheal intubation is the routine airway of choice, but elsewhere the LMA is routinely used with endotracheal intubation reserved for small children and others at higher risk of airway obstruction during surgery.

Endotracheal Intubation

A south-facing oral RAE tube is used for intubation in tonsillectomy. In small children, intubation can be achieved without the use of muscle relaxants (using a bolus of propofol after inhalational induction instead), although in larger children a small dose of relaxant (such as 0.25 mg/kg of atracurium) may be required to optimize intubating conditions. The ETT sits in the midline between the blade of the mouth gag and the tongue and gives a secure airway unlikely to be displaced and does not impede the operative field. Throat packs are not used as they obscure the surgical view, although the surgeon may place a gauze swab above the vocal cords to limit air leak if an uncuffed ETT is used. One must consider if the advantages of intubation (better surgical access in a shared airway, more definitive airway securement) outweigh some of the disadvantages (risks

of intubation, time taken for airway instrumentation for an often high-turnover list). Occasionally a malpositioned or incorrectly sized surgical gag can obstruct the ETT after insertion, and it is best to test ventilate following the gag insertion and before commencing surgery.

Laryngeal Mask Airway

Flexible, reinforced LMAs are often used instead of ETTs. Their advantages and disadvantages are listed in Table 16.3. Their main advantage is they are fast to insert and can be left *in situ* for awake removal in recovery. Their biggest disadvantage is they may dislodge or kink and become obstructed when the gag is inserted or opened. As a general rule, children less than 15 kg are more difficult to manage using an LMA, as tightening of the surgical gag tends to obstruct or dislodge the LMA. LMAs also reduce the ability for recruitment maneuvers, which may be particularly important in small children who are more at risk of atelectasis due to their small airways and often baseline chronic respiratory tract infections.

Keypoint

The ETT and LMA are both suitable for anesthesia in larger children. The ETT is better for small children as it improves surgical access, secures the airway with less likelihood of obstruction, and assists in maintaining end-expiratory lung volume. Whichever technique is used, airway patency must be checked when the surgical gag is inserted and opened.

Tip

To improve the likelihood of obtaining an adequate airway with a LMA during tonsillectomy, choose a size that errs on the small size for the child's weight, do not tape the LMA shaft until the gag is inserted, and use lubricant on the gag so it does not grip the LMA and push it inwards.

Table 16.3 Advantages and disadvantages of airway management using the LMA during tonsillectomy in children

Advantages of LMA	Disadvantages of LMA
Simple insertion	Does not prevent laryngospasm during surgery
Maintain airway until child awake	Airway may obstruct when gag inserted, particularly in young children
Protect lower airway from soiling with blood	May obstruct surgical field
	Not all surgeons comfortable with their use
	Not as easy to give positive pressure recruitment maneuvers

16.2.2.2 Anesthesia Maintenance

Positive pressure ventilation has some advantages over spontaneous ventilation during tonsillectomy, particularly in smaller children (Table 16.4). The choice between spontaneous and controlled ventilation is also made based on experience and familiarity with the technique. Spontaneous ventilation is commonly used if the airway is managed with a LMA, but gentle positive pressure ventilation is also a reasonable approach.

IV fluids are routinely given to tonsillectomy patients to compensate for fasting, bleeding and reluctance of the child to drink post operatively. A volume 10–20 mL/kg of an isotonic fluid such as normal saline or Hartmann's with is usually given, and the IV is left in place postoperatively in case of bleeding within the first 24 h (primary bleeding).

16.2.2.3 Airway Obstruction and Desaturation During Tonsillectomy

Ventilation can become difficult at any stage during tonsillectomy. The gag may cause airway obstruction and this is usually detected soon after the gag is inserted. Nevertheless, if there is obstruction without apparent cause, the gag should be released as soon as possible. Desaturation during tonsillectomy has several common causes (Table 16.5). One cause is the child coughing and straining, with chest

Table 16.4 Advantages of spontaneous and controlled ventilation during tonsillectomy in children

Spontaneous ventilation with LMA	IPPV with ETT
May allow titration of opioid against respiratory rate	Permits lighter GA with lower inhalational agent dose
May simplify conclusion of anesthesia and extubation	May facilitate awake extubation
	Avoids hypoventilation and atelectasis by maintaining end-expiratory lung volume

Table 16.5 A list of common reasons for airway obstruction or desaturation during tonsillectomy

Common problems during tonsillectomy
Obstructed mask ventilation at induction due to large tonsils (CPAP or oral airway may help)
Obstruction or kinking of ETT or LMA due to the mouth gag
Circuit disconnections
Endobronchial intubation
Occlusion of ETT or breathing filter with blood or mucus
Coughing or straining
Atelectasis due to hypoventilation, presence of URTI, aspiration of blood
Bronchospasm
Laryngospasm

wall rigidity preventing ventilation except between coughing 'spasms'. This is common as anesthesia is lightened in preparation for extubation, and in children with reactive airways from recent URTIs. Treatment is to synchronize manual ventilation with gaps between the child's coughing and to consider deepening anesthesia with propofol 1–2 mg/kg. If anesthesia is maintained with an LMA, malposition or laryngospasm are other common causes to consider (see Chap. 8, Sect. 8.3).

16.2.2.4 Extubation

At the end of surgery, the posterior pharynx is inspected for clots and bleeding points. Clots may form in the posterior pharyngeal space behind the uvula and need to be looked for carefully—'the coroners clot'. There is debate about awake or deep extubation or removal of the LMA. There is no correct answer as it depends on a number of factors including the presence of OSA, experience of the recovery staff and immediate availability of an anesthetist if another case is being started. Experienced and competent anesthetists do both. The safest method is probably to have the patient extubated in the left lateral position when fully awake. This is particularly important in children with OSA. The 'tonsil position' (left lateral, slightly head-down to minimize bleeding onto the vocal cords) is commonly used.

Note
Choosing to extubate a deeply anesthetized child comes with a responsibility to ensure someone is available to manage the child's airway in recovery if laryngospasm or other problems develop.

16.2.3 Analgesia

Tonsillectomy is painful, and children will wake very unhappily if analgesia is inadequate. Furthermore, crying and screaming causes venous congestion and may contribute to bleeding early after surgery. There are many successful intraoperative analgesic regimens used. The principles are to minimize sedation and respiratory obstruction. Most analgesic regimens for tonsillectomies will involve the use of an opioid and paracetamol. It is important to remember that all children with OSA, and particularly younger children, have an increased sensitivity to respiratory depression and obstruction and require judicious dosing of opioids. There are no conclusive studies comparing different opioids for tonsillectomy, and how opioids are used is probably more important than the choice of opioid. In spontaneous ventilation, titration against respiratory rate is an option used by some, although the intense stimulation during surgery likely counteracts the respiratory effects of opioids at that time. Children with severe OSA (as determined by lowest saturation level during sleep study of <85%) require half the morphine dose to achieve the same analgesia as children with milder or no OSA (Fig. 16.1). Tramadol causes less sedation and respiratory depression, which is useful in the

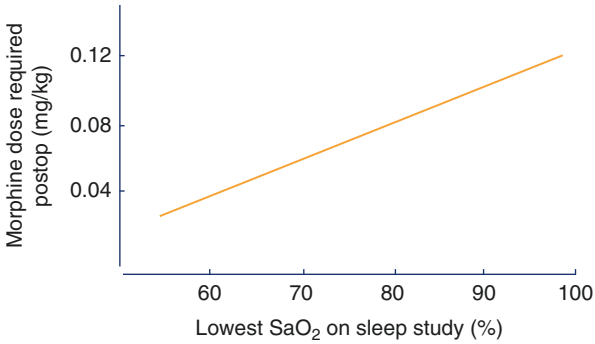

Fig. 16.1 Severe OSA (low SaO_2 during sleep study) is associated with less opioid to achieve adequate analgesia. Adapted from Brown KA. Anesthesiol 2004; 100: 806

setting of OSA. Teenagers and older children experience more pain after tonsillectomy than younger children, because the tonsil is more integrated into surrounding tissue and more difficult to dissect.

Keypoint
Children with OSA are sensitive to opioids and require smaller doses for analgesia and are at higher risk of respiratory depression or obstruction.

Non-steroidal anti-inflammatory drugs (NSAIDs) reduce pain, opioid requirement and nausea and vomiting after tonsillectomy. There is controversy about the safety of non-steroidal anti-inflammatory drugs (NSAIDs) after tonsillectomy, and some surgeons avoid their use.

The Cochrane review found there is insufficient evidence to exclude an increased risk of bleeding when NSAIDs are used in pediatric tonsillectomy. Ketorolac increases bleeding after tonsillectomy and should not be used. Diclofenac is widely used with a safe history. Of the non-selective NSAIDs, diclofenac affects platelet function the least, but is not available commercially in a liquid form for oral use. Ibuprofen is also widely used. There is limited data on its safety, and some studies show an increased incidence of bleeding in older children or increased severity of bleeding. Although ibuprofen was included in the Cochrane Review, it did not constitute a large proportion of the sample size studied. A small study showed the off-label use of parecoxib during surgery reduced pain, although previous pharmacokinetic work has suggested a dose of parecoxib lower than that studied. There are no liquid preparations of COX-2 selective NSAIDs available for oral use in children, although some centers prepare their own.

Local anesthesia of the tonsil bed for post op analgesia has been well studied in recent years and provides a modest reduction in pain relief in recovery, but may extend into the longer-term postoperative period. Topical application and injection of local anesthetics appear to provide the same benefit. There have also been small studies using adjuvants to local anesthetic including dexamethasone, magnesium,

pethidine, ketamine and tramadol with some suggestion of reduced postoperative pain and vomiting. Infiltration of the tonsillar bed with local anesthesia has risks—the carotid arteries run superior to the tonsil bed and there are case reports of death from intra-arterial injection. Drug-spread in the lateral pharyngeal space can also rarely block the vagus nerve causing recurrent laryngeal nerve and vocal cord paralysis. It is also theoretically possible to disrupt the nerve supply to the carotid body, affecting the ventilatory response to hypoxia.

16.2.4 Antiemetics and Dexamethasone

About 40% of children will vomit after tonsillectomy if an antiemetic is not given, and although avoided in the past, multi-agent antiemetic prophylaxis is now standard. Ondansetron (0.15 mg/kg, max 4 mg) is given both during and after tonsillectomy if required. Dexamethasone (0.15 mg/kg maximum 8 mg) is also given as an anti-emetic and to reduce post-operative swelling and morbidity. It shortens the time to eating post-tonsillectomy and reduces pain by 1 on a scale of 0–10. The minimum effective dose required is not known, although one study suggests a dose of 0.0625 mg/kg is effective as an antiemetic. Some studies show an association between dexamethasone and bleeding after tonsillectomy, but the evidence is not strong and dexamethasone is still routinely given.

Tip
Ondansetron 0.15 mg/kg plus dexamethasone 0.15 mg/kg IV is commonly given during anesthesia for tonsillectomy as PONV prophylaxis.

16.2.5 Postoperative Care After Tonsillectomy

Tonsillectomy is a big operation for a child. They mount a stress response, and are weak and washed out for a week or 2 after. Nearly half visit a general practitioner, most often because of pain. It takes 7 days until they return to a normal sleep pattern. The predominant post-operative issue is adequate analgesia balanced against the risk of airway obstruction or apnea. Fatal respiratory complications after tonsillectomy are two times more likely in children than adults. This risk is greatest on the first operative night. Vigilance and well-trained recovery staff are essential, as is the availability of an anesthetist to immediately deal with any airway obstruction. Removal of tonsils may not improve obstruction immediately. There is the potential for edema, bleeding, and residual anesthetic agents or opioids may make these children even more prone to obstruction during the first night after surgery. Pre-existing syndromes or craniofacial abnormalities further increase the risk of obstruction, and are likely to need HDU or ICU monitoring after surgery.

Overnight monitoring and observation in an appropriate environment is important. All patients with OSA should be monitored with pulse oximetry overnight,

and those with severe OSA may require admission to HDU or ICU. Some centers allow older children who do not have OSA to be discharged home several hours after tonsillectomy ('day-stay tonsillectomy'). This is becoming more common and relies on an anesthetic technique that ensures the child is comfortable, not vomiting and not at risk of sedation or airway obstruction. It is also important that the child has responsible parents who have ready access to transport to return to the hospital if necessary. Children with OSA and all young children need overnight hospital admission after tonsillectomy for monitoring.

Post-operative pain varies significantly, but is often difficult for the parents to manage after discharge. While some children are seemingly comfortable on paracetamol alone, others have significant pain and become reluctant to swallow and take fluids or medicines. The temporary use of 2% viscous lidocaine gargle, rectal paracetamol and NSAIDs, such as diclofenac, can be useful in this situation to get pain under control and initiate eating, drinking and taking oral medicines. Care needs to be taken, however, that the child is adequately hydrated before administering NSAIDs. The pain after tonsillectomy is more severe than many other types of surgery, and often worsens again between days 4 and 7 after surgery, when the tonsillar bed scab sloughs away. By day 10 most children are recovering well (Fig. 16.2). Although most children have their sleep disordered breathing improved by tonsillectomy, this may take several weeks to occur, and there is no improvement in one third.

A multimodal approach to analgesia after tonsillectomy is individually tailored to the child depending on their age, co-morbidities and severity of OSA. Parents are given clear instruction and education of the expected pain requirements to optimize analgesia and anticipate the pain requirements with pre-emptive dosing. As discussed earlier, children with OSA are sensitive to opioids and are at risk of respiratory depression and obstruction after tonsillectomy. It would be ideal to avoid opioids in these children, and some surgical groups have reported success with paracetamol and NSAIDs alone. More commonly however the pain at rest and with swallowing will require stronger analgesia.

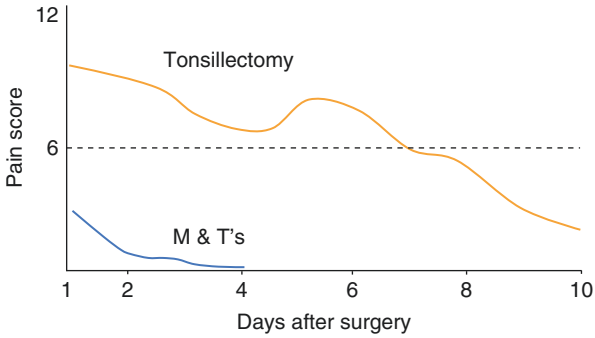

Fig. 16.2 Average pain scores assessed by parents at home after surgery. Pain after tonsillectomy remains significant (score > 6) for 1 week, including a period of increased pain towards the end of the first week. In comparison, pain after myringotomy and tubes is minor. Based on Stewart DW. Pediatr Anesth 2012;22: 136–43 and Wilson CA. Pediatr Anesth 2016;26: 992–1001

Table 16.6 Problems with the different oral opioids used for analgesia after tonsillectomy

Agent	Problems other than respiratory depression
Morphine elixir	Low and variable bioavailability (30–40%) Perhaps more sedating than oxycodone Limited evidence of safety in OSA
Oxycodone elixir	Not licensed for children No studies in children with OSA Few studies of efficacy of oral administration in children
Tramadol drops	Some children are ultra-rapid metabolizers and at risk of respiratory depression (although lower risk than codeine) Not licensed for young children Concentrated oral formulation with risk of overdose

All opioids cause respiratory depression in children with OSA

Table 16.7 Doses of oral opioids for analgesia after tonsillectomy

Agent	Oral dose
Morphine	0.1–0.2 mg/kg 4–6 hourly as required
Oxycodone	0.05–0.1 mg/kg 6 hourly as required
Tramadol	1–2 mg/kg 6 hourly as required

All opioids cause respiratory depression in children with OSA, and the dose should be at the lower end of the range for young children with OSA

Oxycodone and morphine are commonly used as strong analgesics after tonsillectomy because they are available in liquid preparations. A series of deaths in children with OSA after tonsillectomy were thought to be due to the ultra-rapid metabolism of codeine to morphine, causing respiratory depression. Codeine is now contraindicated after tonsillectomy in children in most countries. Tramadol may cause less respiratory depression, but is not available in a suitable preparation for children (liquid drops marketed for palliative care of adults are extremely concentrated and risk accidental overdose in children). Some children are also ultra-rapid metabolizers of tramadol placing them at risk of respiratory depression. The FDA in the United States has issued a warning against the use of tramadol in children, but this has been rejected by professional bodies in Europe and Australasia, and tramadol is still used in many centers. Nevertheless, all of the opioids have the risk of causing life-threatening respiratory depression. The risk is highest in small, young children with severe OSA. Doses should always be conservative. The risks and problems of opioids are listed in Table 16.6, and their typical doses in Table 16.7. Opioid side effects such as constipation, nausea and dysphoria are common.

16.3 Adenoidectomy Without Tonsillectomy

Adenoidectomy is performed to correct nasal obstruction and dysfunction of the eustachian tube affecting hearing. The airway can often be managed with an LMA, as it does not obscure the surgical field. Children younger than 12–18 months are better intubated to give a more secure airway that is less prone to obstruction. Small

children having an adenoidectomy alone often still have large tonsils and are vulnerable to obstruction in PACU. Postoperative analgesia requirements are far less than tonsillectomy, and paracetamol and ibuprofen alone or in combination with a small dose of opioid is usually adequate. Most children are discharged home on the same day of surgery.

16.4 Lingual Tonsillectomy

The vast majority of tonsillectomies are palatine. A lingual tonsillectomy is an uncommon procedure to remove tonsillar tissue from the posterior tongue. Nasal intubation may be required. There is a small risk of post-operative bleeding and swelling of the tongue, and careful postoperative monitoring is required.

16.5 Bleeding After Tonsillectomy

About 1% of children bleed from the tonsillar bed after tonsillectomy. Adenoidal bleeding is rare. Primary hemorrhage occurs in the first 24 h after surgery, whereas secondary hemorrhage may be related to infection and occurs up to 14 days after surgery. It occurs after discharge from hospital. The hemorrhage varies from mild ooze to arterial bleeding with anemia and hemodynamic instability or even death. The child may swallow large amounts of blood before presentation, making assessment of the amount of bleeding difficult. Before anesthesia, information about the duration of bleeding, previous anesthetic (including intubation grade), and any predisposing reasons for the bleeding (infection, NSAIDs, or family history of bleeding disorder) is collected. The child is carefully examined to assess blood loss, paying attention to pallor, pulse rate, and capillary refill. Beware of the pale, listless and somnolent child who may be shocked. Resuscitation with isotonic crystalloid or colloid is begun, and a group and hold or cross match are often appropriate. The hemoglobin and clotting screen should be checked but should not delay surgery to stop the bleeding.

Ultimately the anesthetic technique used will depend on the airway and hemodynamic status of the child as well as the experience of the anesthetist. A bleeding tonsil is an emergency with the potential problems of a difficult, soiled and shared airway in a child with a full stomach and hypovolemia. Most cases have only minor bleeding that needs brief cauterization to control and are straightforward to manage. Others, however, have arterial bleeding with edematous vocal cords that are completely obscured by blood that rapidly fills the mouth during intubation and may block the sucker during removal. If intubation proves to be very difficult, inserting an LMA may retrieve the airway and permit control of the bleeding.

The commonest approach to induction is a rapid sequence induction in the supine position taking care with drug doses in a child who is hypovolemic. An alternative is induction with the child in the lateral, head down position to reduce aspiration of

Table 16.8 List of important details of anesthesia for bleeding after tonsillectomy

Bleeding tonsil checklist
Adequate fluid resuscitation
Low threshold for cross match and coagulation screen
Check previous intubation grade
Two anesthetic suction units
Difficult intubation trolley immediately available
Two bright laryngoscopes
Surgeon and assistant scrubbed in theatre
Orogastic tube to empty stomach after intubation
Extubate awake

blood and using an inhalational technique to avoid paralysis in the presence of a difficult airway. Although this approach has some advantages, it tends to be used less as this position for intubation is unfamiliar and may contribute to difficulty. An ETT that is 0.5 mm smaller than the size used for the original surgery is often selected to allow for upper airway edema.

In addition to the standard anesthetic equipment, it is important to ensure that there are two anesthetic suction units at induction in case one blocks with blood clots (Table 16.8). The difficult-intubation trolley should be in theatre and the brightest available laryngoscope should be available as blood readily absorbs light and a dim laryngoscope can give a surprisingly poor view. A videolaryngoscope is likely to have its image obscured by blood. The surgeon and assistant should be scrubbed and ready in theatre. An orogastric tube should be inserted to empty the stomach at the end of the surgery and the patient should be extubated in the left lateral position, wide-awake. See also Chap. 8, Sect. 8.2.

Tip

Most children with bleeding tonsils have a small bleeding point and the main anesthetic issue is blood in their stomach. Others have a serious bleeding point, and their mouth fills with blood between induction and laryngoscopy. The severity of bleeding is usually apparent before anesthesia.

16.6 Neck Abscesses

Neck abscesses are fairly common in children. Most are superficial abscesses caused by infected lymph nodes in the parapharyngeal region. The infection is superficial to the deep fascia of the neck and the airway is not affected. An LMA is most often used for their brief, surgical drainage.

Deeper neck abscesses are rare. Peritonsillar abscess, or quinsy tonsillitis, is an abscess in the connective tissues between the tonsillar capsule and pharyngeal muscles. It usually occurs in one tonsil of older children and adolescents and is treated with antibiotics if small, or surgical drainage if large. In co-operative, older children, the abscess can be at least partly drained using a syringe and needle while awake. A neck ultrasound or CT may be useful to quantify the severity and extent

of large abscesses. Mouth opening is limited by pain (trismus) but will usually relax after induction. The vocal cords can usually be seen easily, but the airway must be instrumented without rupturing the abscess. Rarely, the abscess extends to cause supralaryngeal edema, indicated by signs of airway obstruction. Airway edema is still a risk after drainage and children are monitored in an area where signs of obstruction can be immediately recognized and acted on. If the airway is very edematous at intubation, consider ventilation and extubation in ICU after the infection and swelling have resolved.

Abscesses of the submandibular space (Ludwig's angina) originate from an abscess of the molar teeth. They occur in teenagers or adults, and are uncommon in children because their deciduous teeth are rooted high in the mandible (see Chap. 18, Sect. 18.2). Submandibular abscesses cause airway obstruction and make intubation difficult—a tense floor of the mouth and inability to protrude the tongue indicate significant swelling and risk.

Retropharyngeal abscesses originate from infected lymph nodes and usually occur in young children. Pus may track along deep fascial planes to the upper mediastinum. These deeper abscesses are more concerning for airway management. Signs of airway obstruction, including stridor, drooling, muffled voice or hoarse cry indicate significant swelling and airway involvement.

Review Questions

1. A 3 year old child has been intubated and ventilated for tonsillectomy. Part-way through surgery, the $ETCO_2$ trace becomes irregular and the oxygen saturation falls. What will you do?
2. A 6-year-old boy with Trisomy 21 syndrome presents with a day 6 post tonsillectomy bleed pale and lethargic. He was previously a grade 3 intubation. What is your anesthetic plan?
3. You have just induced a child for ear grommet insertion. Just before you are about to place the LMA you get an urgent call from recovery telling you that the previous tonsillectomy patient is blue and not breathing. You are the sole anesthetist in the hospital at this time. What is your approach?
4. A child with Von Willebrand's disease presents for elective tonsillectomy. Describe your management
5. You are asked to see a 16-year-old boy with a large tonsillar abscess.
   (a) What are the treatment options?
   (b) What clinical signs and symptoms would particularly concern you?
   (c) How would you anesthetize this patient?
6. A 10 year old girl with Trisomy 21 presents for adenotonsillectomy. She has recurrent respiratory infections and tires easily when playing. On examination SaO_2 is 93% in air, temperature 37.2 °C and she has a non-radiating grade 3/6 systolic murmur.
7. Why might it be best not to proceed with anesthesia

Further Reading

OSA

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Bronchoscopy and Removal of Foreign Bodies from the Trachea

17

Marlene Johnson and Craig Sims

Bronchoscopy is performed to assess the airway in a child who has suspected laryngeal or tracheal anomalies, for investigation of stridor and obstruction, and for the removal of foreign bodies. Anesthesia is challenging as the airway is shared with the surgeon and unprotected.

17.1 Types of Bronchoscopes

There are many types of bronchoscopes used for assessment and management of airway conditions. Commonly used scopes include:

- Ventilating bronchoscope (rigid)
- Rod telescope (rigid)
- Optical grasper (rigid)
- Fiberoptic bronchoscope (flexible)

Each scope has distinct advantages and uses in specific scenarios, which are outlined below.

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17.1.1 Storz Ventilating Bronchoscope

The most commonly used rigid bronchoscope is the Storz ventilating bronchoscope (Fig. 17.1). This is a hollow tube with a removable flat glass eyepiece at the proximal end. Next to the eyepiece are connectors for the fiberoptic light source and anesthetic gases, and a rarely-used port for suction or biopsy. The distal end is open and has fenestrations that allow for gases to pass if the distal scope is partly occluded.

An anesthetic circuit can be connected to the side arm of the bronchoscope. A T-piece circuit is often preferred as it is lightweight and in close reach of the anesthetist. The circle circuit can be used, but there is uncertainty about how much gas passes through the filter into the patient rather than back down the expiratory limb of the circle. In addition, the APL valve is located at a distance on the anesthetic machine and needs to be frequently adjusted during ventilation because of the variable leak around the bronchoscope. When the eyepiece and instrument ports are occluded, manual ventilation through the side arm of the bronchoscope is possible.

The bronchoscope is available in a range of sizes. Careful attention must be paid to the size of the bronchoscope selected. Too large, and it will cause damage to the tracheal mucosa and mucosal edema; too small, and manual ventilation will be difficult. The correct size is one in which there is an air leak at 20 cmH_2O. Instruments, such as a rod telescope (see below), graspers or suction may be passed through the lumen of the Storz scope.

This scope is particularly useful for removing airway foreign bodies in the trachea and proximal bronchial tree. To retrieve a foreign body, the glass eyepiece is removed and a long forceps is passed down the lumen of the scope to grasp the foreign body. The view of the foreign body down the scope can be poor, as it is

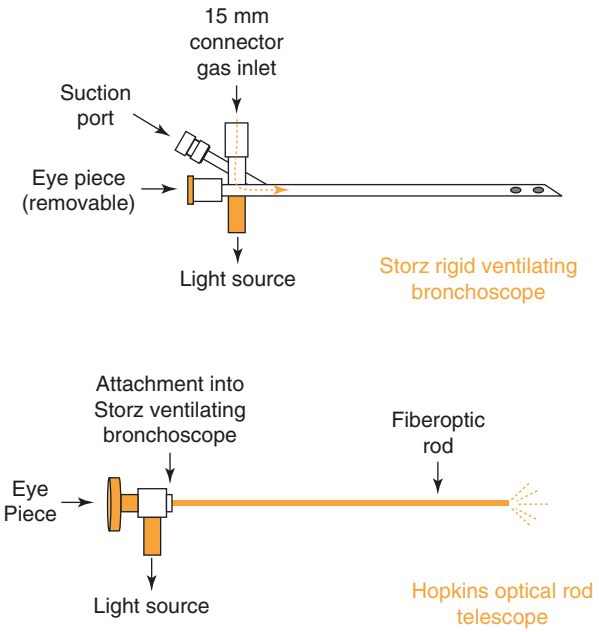

Fig. 17.1 The Storz ventilating bronchoscope and accompanying rod telescope

viewed down the length of the bore of the scope and the view is partly obscured when the forceps are inserted. The optical grasper (see below) gives a much better view and is growing in popularity among surgeons.

17.1.2 Hopkins Rod Telescope

The Hopkins rod telescope may be used alone or passed through the lumen of the ventilating bronchoscope to examine the larynx and trachea. The rod telescope is rigid, has its own light source and magnifies the view for the surgeon. It is much narrower than the Storz ventilating bronchoscope. Subsequently, it is likely to cause less damage to the mucosa and may be inserted further down the bronchial tree.

There is no gas channel on the rod telescope, so alternative methods to provide oxygen or anesthetic gases are required. Supplemental oxygen may be provided using nasal prongs. Alternatively, anesthetic gases and oxygen may be delivered through an ETT in the oropharynx or the nasopharynx.

When used in conjunction with the ventilating bronchoscope, it greatly narrows the lumen of the bronchoscope and increases the resistance to breathing. This is particularly a problem with the small bronchoscopes that are used in infants.

17.1.3 The Optical Grasper

The optical grasper is a rod telescope with distally placed forceps operated by a lever near the eyepiece (Fig. 17.2). Surgeons are using the optical grasper more frequently because it gives a clear, magnified view of the foreign body. However, it has no channel for anesthetic gases and ventilation through it is not possible. If the surgeon uses these forceps, a spontaneous ventilation technique must be used. This technique is described later in the section 'Assessment of stridor'.

Keypoint
Foreign body removal with a ventilating bronchoscope—spontaneous or controlled ventilation are possible. Foreign body removal with optical grasping forceps—spontaneous ventilation is the only option.

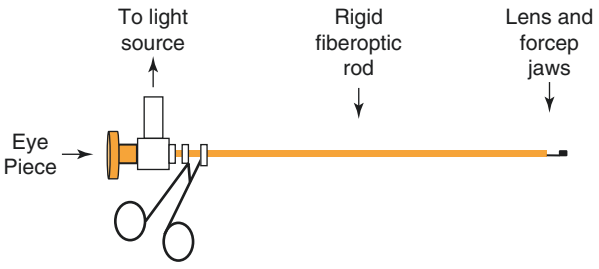

Fig. 17.2 Optical grasper, which is similar to a rod telescope with grasping forceps attached. It is not possible to ventilate or insufflate gas with this instrument

17.1.4 Fiberoptic Bronchoscope

A flexible fiberoptic bronchoscope is often used by respiratory physicians to perform diagnostic procedures. This is discussed further at the end of this chapter.

17.2 Inhaled Foreign Bodies

Inhalation of a foreign body is a potentially life-threatening event. A small reduction in airway radius will result in a large increase in resistance to airflow. Organic foreign bodies may result in airway hyper-reactivity as well as mucosal edema, which will cause further airway narrowing. These factors coupled with the high oxygen consumption of infants and small children cause hypoxia to occur rapidly. Inhaled peanuts are one of the most challenging foreign bodies to manage, as they cause local granulation and generalized tracheobronchitis within hours of aspiration. They may also fragment and be extremely difficult to remove.

The typical patient is a toddler or preschool-aged child. Children of this age are at higher risk because they display oral exploration behavior and lack molars for grinding food. The onset of symptoms is usually sudden. Following aspiration, there is great variation in the severity of airway obstruction ranging from asymptomatic to severe distress or asphyxia. Specific symptoms and signs will depend on the site, size and type of foreign body:

- Signs of laryngeal or tracheal obstruction: coughing, choking, respiratory distress, cyanosis, stridor, tachypnea
- Signs of obstruction of a main bronchus: respiratory distress, tachypnea, wheeze or absent breath sounds on the affected side

The larger the foreign body, the higher up in the airway it will have lodged and the more severe or life threatening the symptoms. However, there may also be no symptoms or signs if the item is small or not significantly occluding the airway. In these cases, it can be challenging to differentiate from other common pediatric respiratory conditions, such as croup, asthma and pneumonia. A thorough history from the caregiver is key.

Inspiratory and expiratory chest X-rays (CXR) and a lateral X-ray of the neck are performed as part of the diagnostic work up. However their diagnostic value is low. The CXR is often normal, and most foreign bodies aspirated by children are radiolucent. Air trapping with hyperinflation might be seen on the expiratory film due to a ‘ball valve effect’, but while this is the classical X-ray finding, it is not common and usually the chest X-ray is normal. The presentation may also be more chronic with a cough or chest infection, or with atelectasis or consolidation on the CXR. CT can also be considered, but may require sedation, and there are concerns about radiation exposure. Diagnosis from history and radiology can be challenging, and bronchoscopy is often required for both diagnosis and management (Fig. 17.3).

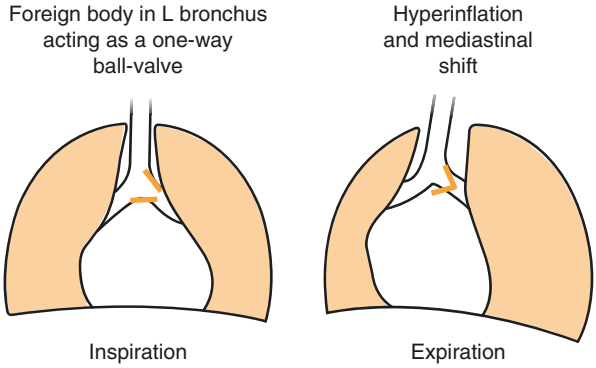

Fig. 17.3 Classical CXR of an inhaled foreign body (FB) in the left main bronchus. The inspiratory film is normal, but on expiration there is obstructive emphysema with diaphragmatic, tracheal and mediastinal shift. The FB itself is usually radiolucent. It is more common however to find a normal CXR

Table 17.1 Anesthetic technique for rigid bronchoscopy and removal of foreign body—differences between adult and pediatric patients

Child	Adult
Gas induction fast, simple, safe (though slowed if tracheal or main bronchus obstruction)	Gas induction slow
Usually able to ventilate via bronchoscope	Large leak around bronchoscope may mandate spontaneous or jet ventilation techniques
Usually able to obtain satisfactory operating conditions with local anesthetic spray & volatile agents	Usually require muscle relaxants or remifentanil to obtain satisfactory operating conditions

It is preferable that the child is fasted before anesthesia as the airway cannot be fully protected during the procedure. Clearly however, the risk of waiting needs to be balanced against the fasting duration. Anesthesia of a small child for bronchoscopy and removal of a foreign body is difficult. It is preferable to have two anesthetists, one of whom should be well trained in pediatric anesthesia.

17.3 Anesthetic Techniques for the Removal of Foreign Bodies in Children

Although children are at greater risk of developing laryngospasm or hypoxia during bronchoscopy compared to adults, they are easier to keep motionless under anesthesia without muscle relaxants and there is usually an adequate seal to allow ventilation with a ventilating bronchoscope (Table 17.1). Sedative premedication should only be used if the benefits outweigh the risk of its effects on respiratory function. This depends on the degree of respiratory distress and the anxiety of the child. Anticholinergic agents can be used to dry the airway but are not routinely necessary with current agents and techniques. The anesthetic issues specific to bronchoscopy

Table 17.2 Anesthetic issues for removal of foreign body from trachea or bronchus

Anesthetic issues
Short, stimulating procedure, the duration of which is difficult to predict
Massive air leak when eyepiece removed
Often co-existing diseases or airway problems

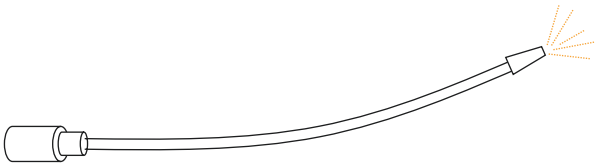

Fig. 17.4 The flexible, plastic MAD device to spray local anesthetic onto the vocal cords and trachea

are listed in Table 17.2. One hundred percent oxygen is used throughout the procedure to avoid hypoxia caused by obstruction, hypoventilation and one lung ventilation during endobronchial scope placement.

Either intravenous or inhalational induction is a reasonable approach. Inhalational induction is usually fast in children, but will be slowed if there is total occlusion of a main stem bronchus causing ventilation-perfusion mismatch. Inhalational induction is often preferred, as there is a more gradual loss of airway tone and more time for the anesthetist to assess the child's airway and respiratory efforts during induction. If an IV line is in situ, many would give a small dose of propofol, maintaining spontaneous ventilation, and then deepen anesthesia with volatile agents.

After induction, the vocal cords and trachea are sprayed with local anesthetic, which reduces coughing and laryngospasm during bronchoscopy. To spray the larynx, the child is preoxygenated, deepened and the cords and trachea sprayed with lidocaine (lignocaine) 3–4 mg/kg under direct laryngoscopy. Use the 2% IV preparation to give a suitable volume to spray through a MAD (mucosal atomizer device) sprayer (Fig. 17.4). Laryngospasm may occur from the stimulation of the local anesthetic spray but will usually settle rapidly as the local anesthetic takes effect. Intubation is not usually performed at this stage as it may cause trauma to the larynx and cause diagnostic confusion, or it may push any foreign body distally. Topical lignocaine has a duration of effect of 20–25 min. Repeat administration of lignocaine may be required for prolonged procedures, but the total dose should not exceed 4 mg/kg.

After induction of anesthesia, there are two options for anesthesia maintenance—controlled or spontaneous ventilation (Table 17.3). There is debate over the superior method of ventilation, and technique differs between pediatric centers. Current evidence suggests there is little difference in complications, operative time and recovery time between the two techniques.

Note

A foreign body that shifts proximally or is dropped within the trachea during removal causing total obstruction of the trachea can be pushed distally to allow at least one lung to ventilate.

Table 17.3 Advantages and disadvantages of spontaneous and controlled ventilation during bronchoscopy

Controlled ventilation	Spontaneous ventilation
Always- Spray vocal cords and trachea with lidocaine 3–4 mg/kg	
Better oxygenation and depth control	Unlikely to dislodge a foreign body
Better surgical conditions (less coughing, laryngospasm) Limited time for surgical instrumentation	Allows prolonged instrumentation down scope
May need to use IV anesthesia or supplement volatile technique with IV agents Risk of ball valve hyperinflation and pneumothorax	May be difficult to keep motionless and avoid hypoventilation and hypoxemia

17.3.1 Controlled Ventilation

While the eyepiece of the bronchoscope is in place, the Storz bronchoscope gives a closed circuit that makes ventilation possible. When the eyepiece is removed for instrumentation, there is a huge leak and ventilation is not possible. Gentle, positive-pressure ventilation while the eyepiece is in place avoids hypoxemia and atelectasis. There is a concern that a foreign body might be 'blown' distally during inspiration, but this does not seem to be a problem in practice. Indeed, the peak inspiratory flow rates in the trachea would be higher when the child is awake and crying! However, controlled ventilation does mean that the child is left apneic when the eyepiece is removed, limiting the time the surgeon has to pass instruments through the bronchoscope before desaturation occurs and the eyepiece must be replaced and ventilation restarted. In most cases, quite a lengthy time of apnea is possible as ventilation permits the child to be well oxygenated beforehand.

17.3.2 Spontaneous Ventilation

For removal of a foreign body, spontaneous ventilation has the advantage of not dislodging the foreign body distally into the bronchial tree, which might make it harder to retrieve or create a 'ball-valve' obstruction. The other advantage is the lack of a disruption of ventilation when there is a massive leak in the circuit while the surgeon is retrieving the foreign body with the bronchoscope's eye-piece removed. However, it can be difficult to maintain the correct depth of anesthesia—adequate to prevent movement and coughing, which in turn may result in desaturation that is difficult to resolve, but also avoiding a depth that results in hypoventilation and desaturation. A bolus of propofol helps resolve the first problem, while intermittently assisting with respiration with the eyepiece in place may resolve the latter problem.

Keypoint
Spontaneous ventilation must be used if the bronchoscopy is to look for airway collapse or obstruction, as in the investigation of stridor.

17.3.3 Maintenance of Anesthesia

Anesthesia during rigid bronchoscopy can be maintained with volatile or intravenous agents. The simplest approach is to use sevoflurane supplemented with 1–2 mg/kg boluses of propofol to quickly deepen anesthesia if required. Sevoflurane anesthesia is simple to perform and maintain spontaneous ventilation, but air entrainment diluting the sevoflurane and pollution are problems.

An intravenous technique removes the link between ventilation and depth of anesthesia, and avoids pollution. Propofol with remifentanil is a common technique. Preschool children and infants tolerate higher doses of remifentanil than adults while still maintaining spontaneous ventilation, and require roughly twice the maintenance dose of propofol compared to adults. This IV technique requires experience to achieve an adequate depth with maintenance of spontaneous ventilation, making a volatile-based technique simpler for many anesthetists.

Propofol and dexmedetomidine is becoming a popular technique for rigid bronchoscopy. Compared to propofol and remifentanil, it causes less respiratory depression and is more hemodynamically stable. A loading dose followed by an infusion of dexmedetomidine is usually required to gain satisfactory surgical conditions. Dexmedetomidine should be used cautiously in neonates as they have reduced drug clearance.

Tip
Often the most straightforward anesthetic technique for rigid bronchoscopy is to gently control ventilation with volatile agents through a T-piece circuit on the side arm of the bronchoscope, supplemented with small boluses of propofol as required.

During bronchoscopy, a gentle hand on the upper abdomen provides useful information on respiratory rate, adequacy of ventilation and depth of anesthesia, whilst simultaneously permitting the anesthetist to watch the procedure. Watching the bronchoscopy allows the anesthetist to know whether the scope is in the trachea ventilating both lungs, or endobronchial with consequently reduced compliance, reduced leak around the scope, and reduced oxygenation. About one third of children cough and desaturate during bronchoscopy, with little difference between IV and inhalational techniques. Dexamethasone is often given IV to reduce edema at the level of the cricoid ring. The dose is 0.5–0.6 mg/kg (up to 12 mg).

After the bronchoscopy is finished and the scope removed, the child can either be intubated and allowed to wake up, or more commonly an anesthetic facemask is used to administer oxygen and monitor respiration before transfer to recovery. Children who have had occlusion of a bronchus and lung collapse from the foreign body, or a prolonged procedure, may benefit from intubation and a brief period of ventilation with PEEP to re-expand the lung after the foreign body is removed. Postoperatively, the child should be monitored for signs of stridor and airway obstruction due to edema. Stridor is not common, but children who have had

multiple insertions of the bronchoscope during foreign body removal are at high risk. If worsening stridor occurs, nebulized adrenaline (epinephrine) 1:1000 may be useful (0.5 mL/kg, maximum 5 mL) (See Chap. 1, Sect. 1.9.2).

Note
A child with lung or lobar collapse will benefit from a short period of ventilation to restore lung volume after the foreign body is removed.

17.4 Anesthetic Techniques for Assessment of Stridor in Children

Inspiratory stridor is caused by extrathoracic airway obstruction, and laryngomalacia is the commonest cause in infants (Table 17.4). In laryngomalacia the supraglottic structures collapse during inspiration, resulting in stridor and impedance to the flow of air. It is thought to be due to the immature development of neuromuscular pathways required to maintain airway patency. Most children will have resolution of symptoms by 24 months of age and can be managed conservatively. Children with severe or persisting symptoms may require surgical intervention, most commonly in the form of a supraglottoplasty.

Expiratory stridor is caused by intrathoracic obstruction, most commonly tracheomalacia. In tracheomalacia, there is increased compliance of the central airways, so when there is positive intrathoracic pressure relative to the tracheal lumen, the airway has a tendency to collapse. Congenital causes may present in isolation, or with conditions such as tracheo-esophageal fistula, craniofacial anomalies and chromosomal defects. Acquired cases may occur after trauma, positive pressure ventilation (especially in premature neonates), infection or compression by external structures. Resolution of symptoms often depends on the underlying cause.

Biphasic stridor is caused by obstruction at the glottis or subglottis, most commonly subglottic stenosis.

Children with stridor have their larynx and trachea examined for dynamic airway collapse and anatomical anomalies while under anesthesia. A flexible bronchoscope via an LMA (see below) or a rigid Hopkins rod telescope is used for the procedure. To use the rod telescope, the surgeon performs a laryngoscopy with either the suspension laryngoscope attached onto the operating table, or a hand-held

Table 17.4 List of common causes of stridor in children

Cause of stridor
Laryngomalacia
Vocal cord dysfunction
Tracheomalacia, tracheal stenosis
Croup (viral laryngotracheitis)
Foreign body

The list is not exhaustive, and many other diagnoses are possible depending on the age of the child, duration of symptoms and clinical features

anesthetic laryngoscope. With one of these laryngoscopes in place, the vocal cords and trachea are examined with the telescope. Spontaneous ventilation is always required so that dynamic collapse of the airway during respiration can be assessed.

17.4.1 Anesthetic Technique

The same spontaneous ventilation technique for removal of foreign body with the Storz bronchoscope and optical grasper may be used for assessment of stridor. After induction, the vocal cords and trachea are sprayed with local anesthetic to reduce coughing and laryngospasm (Table 17.5). There are concerns that local anesthetic may worsen laryngomalacia because of its sensorimotor effects on the laryngeal muscles. However, topicalization of the airway is still usually performed, as it is very difficult to perform bronchoscopy without this.

Before the bronchoscope is inserted by the surgeon, the vocal cords must be brought into view. The surgeon either holds an anesthetic laryngoscope in one hand, or inserts a suspension laryngoscope. As the telescope has no gas channel, oxygen and anesthetic gases must be given into the mouth and laryngopharynx. Two methods are commonly used. The first is to connect gases onto the side port of the suspension laryngoscope. The second is to insufflate gas into the mouth either through a nasopharyngeal airway, nasal prongs or by having the surgeon hold an ETT along the blade of the laryngoscope. The method and exact details depend on the technique being used by the surgeon to perform the laryngoscopy and bronchoscopy, and discussion with the surgeon beforehand is vital to decide on a plan to manage the airway. With either of these methods, gas is being insufflated into the mouth, to be inhaled by the child. There is also entrainment of room air diluting the anesthetic gases and oxygen concentration and pollution from excess gas. Both of these factors are considered when choosing between volatile or intravenous anesthesia techniques. Most importantly however, the airway is not sealed and there is no way of

Table 17.5 Steps in anesthesia for diagnostic bronchoscopy

Step	Reason
Spontaneous ventilation	Assess dynamic airway compliance
Spray cords with lidocaine (lignocaine)	Reduce coughing and laryngospasm
Surgeon inserts laryngoscope	Holds upper airway open, lines up mouth and trachea for rigid bronchoscope
Gasses insufflated into oral/laryngopharynx	Maintains anesthesia and inspired oxygen; entrainment of room air and pollution though
If ventilation needed, remove laryngoscope and bag-mask ventilate, or surgeon temporarily intubates via laryngoscope	Airway is open, with no seal that would permit positive pressure ventilation

ventilating or assisting ventilation if apnea or hypoventilation occurs. There is also growing interest in a possible role for high flow nasal oxygen during this procedure.

Although spontaneous ventilation is required and aimed for, apnea or hypoventilation can occur. Positive pressure ventilation is then given either by intubating the trachea, or by removing the bronchoscope and laryngoscope and using a facemask or LMA. At the end of the procedure, the laryngoscope is removed and the child placed in the lateral position and allowed to wake. Some surgeons ask for the child to wake up with the laryngoscope is in place so that the respiratory effort will be greater, inspiratory and expiratory flow rates greater, and any airway collapse maximal.

Note
By paying attention to the chest movement and position of the vocal cords during the bronchoscopy, it can be immediately determined if apnea is from respiratory depression or from breath holding or laryngospasm as a result of light anesthesia. Immediately starting correct management avoids desaturation episodes.

17.5 Flexible Fiberoptic Bronchoscopy

Fiberoptic bronchoscopy is usually performed in children as a diagnostic procedure by respiratory physicians. Spontaneous ventilation is required to allow dynamic assessment of the airway. After induction, the cords and trachea are often sprayed with local anesthetic followed by insertion of an LMA. The fiberscope is passed through a Bodai connector (Fig. 17.5), into the LMA and trachea. The connector maintains an airtight seal around the scope. The scope narrows the lumen of the LMA shaft and increases resistance to breathing, depending on the relative sizes of the scope and LMA. Broncho-alveolar lavage is performed during bronchoscopy in children with cystic fibrosis or other respiratory diseases. Saline is injected through the bronchoscope into the lung and then suctioned into a collecting chamber to be examined for cells and inflammatory markers. Only a small proportion of the injected fluid is retrieved, and although the procedure is usually fairly well tolerated, oxygen therapy is often needed for a few hours after anesthesia.

Rather than passing the bronchoscope through an LMA, it can be passed through a bronchoscopy mask. This mask has an extra opening that the bronchoscope is passed through. Its advantage over the LMA is that the bronchoscope can be passed through the nostril rather than mouth and there is no distortion of the laryngopharynx from the LMA.

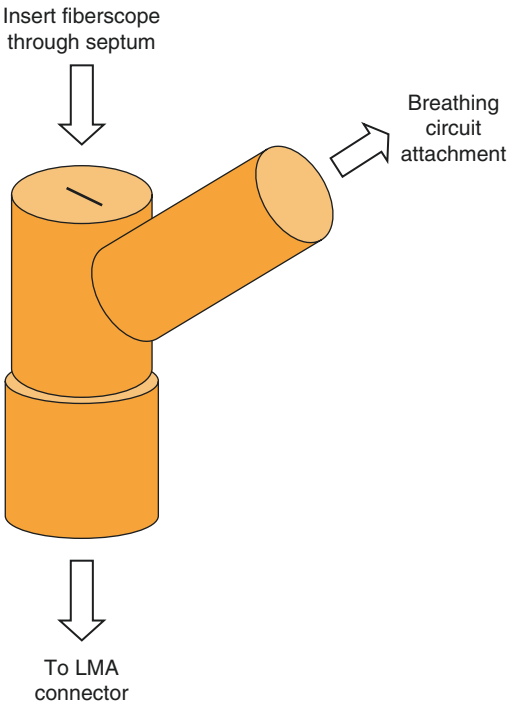

Fig. 17.5 Bodai swivel connector for use of fiberscope through an LMA

Review Questions

1. How would you assess a 3 year old child who may have inhaled a small bead and is booked for bronchoscopy?
2. What are the differences in anesthesia for rigid bronchoscopy in adults in children?
3. Why are peanuts particularly dangerous as inhaled foreign bodies in children?
4. What are some causes of stridor in infants?
5. What are the possible causes if a child coughs and then desaturates during a rigid bronchoscopy for removal of a bronchial foreign body? How would you manage this situation?

Further Reading

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Anesthesia for Dental Procedures in Children

18

Lisa Khoo

Dental procedures are the third commonest reason for general anesthesia in children. These procedures vary in duration from a few minutes for removal of a tooth, to a few hours for dental restoration procedures. Anesthesia for pediatric dental procedures can be challenging because it involves sharing the airway with the dentist, care of a pediatric patient and management of an uncooperative child who was unable to have their treatment while awake in the dental chair.

Dentists gain the cooperation of children during dental procedures in the dental chair with a combination of behavioral techniques, local anesthesia, and inhalational sedation with nitrous oxide through a nose (Wesson) mask. A proportion of children do not tolerate treatment despite these techniques, and deeper sedation or general anesthesia is required. If a sedated child is not alert enough to hold open their mouth, then they are more sedated than 'conscious sedation'. Office-based sedation of children that is deeper than conscious sedation is fraught with hazard and is not recommended. In the United Kingdom, there were deaths in children being sedated in the dental chair, and now sedation of children younger than 16 years with anything other than nitrous oxide can only be performed in a hospital. In Australia and New Zealand, there are ANZCA Guidelines regarding sedation. These guidelines mandate broadly the same staffing, monitoring and facilities as would be present for general anesthesia in a hospital. Apart from reasons of safety, dentists may opt to treat a child requiring extensive treatment under general anesthesia in a hospital to avoid several separate treatments in the dental chair and possible psychological trauma to the child.

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18.1 Nasal Endotracheal Intubation

Nasal intubation is performed in children for two groups of reasons. The first is for ventilation in intensive care or for transport—a nasal ETT is more secure than an oral ETT. For example, when postoperative ventilation is planned for a child, a nasal tube is inserted. The second is for some procedures requiring access to mouth (not tonsillectomy however). Nasal intubation is often used during dental procedures to allow unrestricted access to the child's mouth and teeth. ETTs used for oral intubation can be used for nasal intubation. The depth of insertion is best judged by observing the depth of the ETT during laryngoscopy and noting the marking at the nose. Alternatively, a formula or table can be used, by adding 20% to the distance from the oral formula. So, for children over the age of 1 year, the depth at the nose for nasal intubation is:

$$Depth\ (cm)\ in\ children\ older\ than\ 1\ year = age/2 + 15$$

For dental procedures, a preformed, nasal (north-facing) RAE impinges least on the dentist's work (Fig. 18.2). These tubes are inserted until the pre-formed curve is against the child's nose. There is limited availability of pediatric, cuffed nasal RAE tubes. Some tubes are too long and likely to cause endobronchial intubation if inserted with the curve against the nose, and uncuffed nasal RAE tubes are often used instead. An alternative is to use a wire reinforced ETT and curve the ETT upwards away from the mouth. The tubes have a slightly larger outside diameter than a standard tube with the same size internal diameter. They are also expensive and may place pressure on the nostril as the tube curves upwards.

Preparation for nasal intubation includes spraying the nasal mucosa with vasoconstrictor after induction, softening the ETT with warm water and lubricating the outside of the ETT. The same sized tube is used for nasal and oral intubation in children—the diameter of the cricoid determines the size of the ETT in children, whereas the nose limits the size of the ETT in adults. Nasal intubation is often more difficult than oral intubation, with three areas that can cause problems during passage of the ETT (Fig. 18.1).

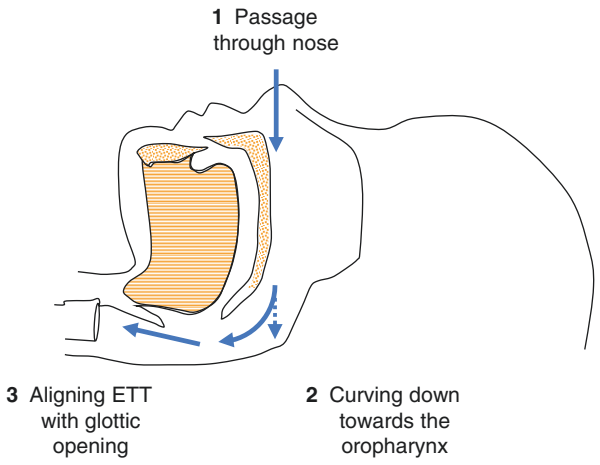

Fig. 18.1 The three sites of difficulty during a nasal intubation—passing the ETT through the bony part of the nose, making the ETT turn downwards into the oropharynx towards the larynx, and aligning the axis of the ETT with the trachea

Note
The same sized ETT is used for oral and nasal intubation in children.

The first area is the bony turbinates in the nose. The patency of the nostrils can be assessed before induction, but the child needs to be cooperative to do this. Resistance at the turbinates can be overcome by firm but careful, constant pressure. Rotation of the tube to change the orientation of the bevel may also help. Passing the endotracheal tube along the nasal floor, under the inferior turbinate, avoids the complications of passing it above the inferior turbinates. The middle turbinate, which sits above the inferior turbinate, is porous, fragile and vascular, and trauma from an endotracheal tube may result in fracture, CSF leak and olfactory nerve dysfunction. Inserting a suction catheter as a guide for the endotracheal tube increases the chances of passing below the inferior turbinates.

The second area that may cause problems is the nasopharynx, as the ETT often hits the posterior wall of the nasopharynx or adenoidal tissue in its passage towards the larynx. Softening the tube by placing it in warm water helps it to curve downwards with gentle pressure. Orientating the tube so the bevel is facing the posterior wall may also help. It is important not to just push harder—forcing the tube may traumatize the posterior pharyngeal wall, and there even are case reports of nasal ETT's entering the brain in neonates. If the tube will not curve downwards towards the larynx, the most successful strategy is to insert a suction catheter through the ETT and use it as a guide (Fig. 18.2). The catheter is passed through the nose and into the oropharynx, then the ETT can then be "railroaded" over the catheter. The catheter may also prevent mucus and tissue from plugging the lumen of the ETT. Some use this technique routinely for nasal intubation because of these advantages.

The third problem is aligning the ETT with the laryngeal opening. Sometimes, the Magill forceps will bring the ETT tip into the opening between the vocal cords, but the ETT will not pass into the trachea—the tube becomes caught on the posterior

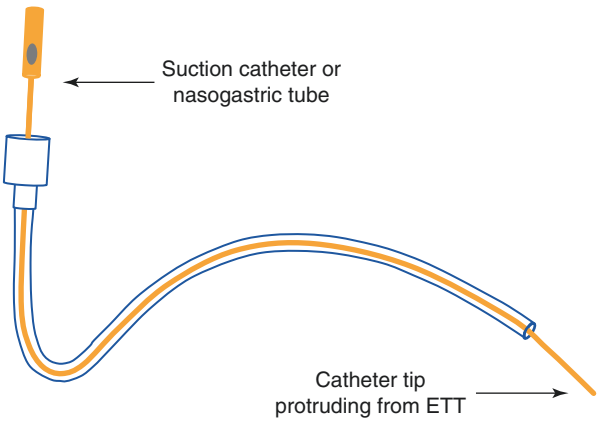

Fig. 18.2 A suction catheter passed through the nasal (north-facing) RAE tube to act as a guide. The free end of the catheter is passed through the nose into the oropharynx, and then the ETT is railroaded over it. This minimizes trauma from the ETT to the posterior wall of the nasopharynx, and prevents nasal secretions entering the lumen of the ETT

arytenoids or the anterior wall of the trachea. There are three alternatives to align the axes of the trachea and the ETT. The first is to apply external laryngeal pressure to alter the angle between the ETT and larynx. The second is to lower the laryngoscope (the view of the larynx is temporarily lost) to help align the larynx and ETT then gently pushing the ETT inwards. A third option is to change the direction of the bevel by rotating the ETT to stop it catching on the vocal cords or arytenoids.

Tip
Sometimes during nasal intubation, the ETT will not curve downwards from the nose towards the larynx. The best strategy is to insert a catheter through it, pass the catheter through the nose and into the oropharynx, then railroad the ETT over it.

Another reason for difficulty passing the ETT through the larynx is that the ETT may be the wrong size. If there is concern that the ETT may be too large, it can be 'sized' by intubating orally first to assess ease of passage through the cricoid ring, and then reinserted nasally. If an uncuffed tube is used, a throat pack may tamponade small leaks. A throat pack is routinely used during dental procedures to prevent aspiration of blood and solid fragments, and to stop blood entering the stomach and possibly causing vomiting later. A small child needs a small pack—it is useful to cut the pack and shorten it. If an adult-sized pack is inserted into a child's mouth, it takes up a lot of space, pushes the tongue forward and restricts access to the mouth for the dentist. The entire throat pack is placed within the mouth and there should be an alternate visual cue that it has been inserted. Each anesthetist must take steps to ensure the pack is removed before extubation. The role of throat packs is being questioned, with concerns there is little evidence for any benefit, but real risks to their continued use.

Tip
Throat packs risk being left behind after anesthesia. Follow strategies to ensure they are removed. The greatest risk is when no part of the pack is protruding from the mouth. Minimize this—if there is an ETT coming out of the mouth, then the 'tail' of the pack can also come out of the mouth.

18.2 Dental Extraction

Removal of teeth may be needed for impacted teeth, dental trauma or dental abscess. There may be blood in the airway or stomach after dental trauma, but this is rarely an issue with the falls and accidents that damage children's teeth.

Dental abscesses may reduce mouth opening due to pain, but rarely cause airway problems in children. Children's deciduous teeth are more anterior and higher in

the mandible than permanent teeth. The mandibular bone is thin, and the abscess usually ruptures through the buccal side into the mouth or facial and neck tissues (Fig. 18.3). It is rare for a young child's dental abscess to rupture into the submandibular or other deep tissue layers that may affect the airway. Nevertheless, it is wise to assess the child's airway, checking the floor of the mouth and neck tissues are soft, and that there are no signs of obstructed breathing.

In older children and adults on the other hand, abscesses of the third (wisdom) molar are posterior in the mandible and usually rupture at the apex of the root. They spread into the submandibular space and deep tissue planes (Ludwig's angina). In this case, the airway is at high risk, and intubation is difficult—infection and edema of the floor of the mouth stop tongue compression during laryngoscopy, and edema in the laryngopharynx may obstruct the airway. Some of these patients need tracheostomy before induction.

Some permanent teeth require removal of bone using a low-speed drill to free their roots. If a high-speed drill designed for dental restorations is used for this, air from the drill may enter the tooth sockets and cause surgical emphysema of the face and neck.

The anesthetic technique for dental extraction in children is dependent on the number and position of teeth to be removed. A nasal mask can be used, or even a facemask (removed briefly to allow access to the mouth) for short procedures on anterior teeth. Nowadays however, the LMA is a better option as it stops blood and fragments entering the airway from the mouth, and allows ongoing anesthesia without time limits or theater pollution. A throat pack is not usually needed when an LMA is used. A nasal ETT may be required for multiple or difficult extractions in a small mouth. Dental extractions are usually brief, straightforward procedures in generally well children. Problems are more likely if anesthesia is not adequate, when laryngospasm may occur due to strong surgical stimulation (Table 18.1). The

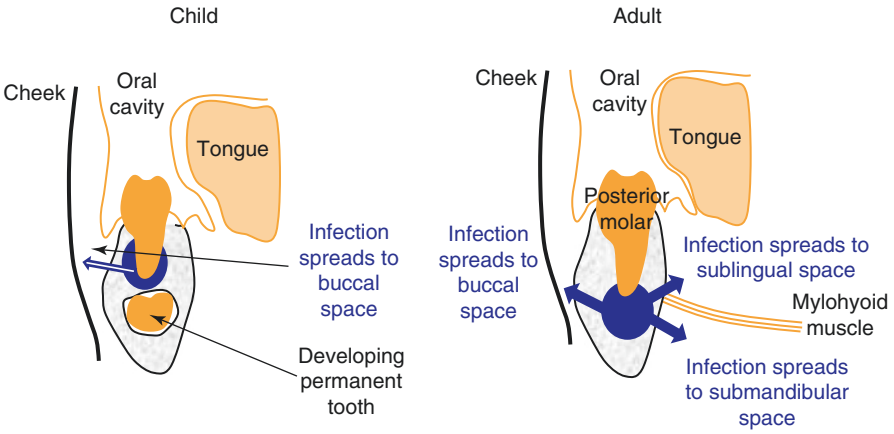

Fig. 18.3 Different patterns of spread from dental abscesses in young children compared to older children and adults (adapted from Morosan et al.)

Table 18.1 Keypoints for anesthesia for dental extraction in children

Keypoints for anesthesia for dental extraction in children
Common procedure—abscess or trauma
Strong surgical stimulation may cause laryngospasm if inadequate anesthesia
Shared airway
Blood in the airway

airway must be carefully monitored as the LMA may become dislodged during the procedure. The LMA can be removed either deep or awake after suctioning the pharynx with the child in the lateral position.

Local anesthesia used by the dentist reduces pain, but may cause distress in small children because of the lip numbness. Some small children will also bite their numb lip or chew at sutures while the local anesthetic is working, causing traumatic ulcers. A small dose of opioid may be used for analgesia instead, and simple analgesics such as paracetamol and ibuprofen provide adequate postoperative analgesia for most children.

18.3 Restorative Dental Treatment

Nasal intubation with a nasal (north-facing) RAE tube allows unlimited access to the patient's mouth and enables accurate x-rays. A throat pack is usually placed to prevent soiling of the airway by blood, secretions and water from the dental hand-piece. These procedures may last a few hours, and care of pressure areas is needed. These areas include the ETT at the nares and forehead, and the child's eyes to prevent injury should the dentist rest on them. Patients who are very young or underweight should have their temperature monitored and be actively warmed if required. IV fluids are infused to replace the patient's deficit and maintenance requirements.

There is a moderate amount of trauma to the gums during the procedure, and a small dose of opioid decreases pain and emergence delirium. Reducing minor morbidity is important to facilitate same-day discharge, and antiemetics such as dexamethasone and ondansetron may be helpful. Dexamethasone also decreases swelling and pain following extractions.

18.4 Antibiotic Prophylaxis in Children with Cardiac Disease

Bacteremia may occur even with tooth brushing, although these bacteria do not cause infective endocarditis. More serious bacteremia, most commonly with streptococcus viridans, occurs with invasive dental procedures, and antibiotic prophylaxis may be required to prevent infective endocarditis. Invasive dental procedures in children include extractions, clamping dental dams onto teeth, and fitting stainless steel crowns. These procedures disrupt the gingiva or periapical region of teeth. Treatment such as scaling and cleaning, or injecting local anesthetic are not considered invasive. Endocarditis prophylaxis is required for some children with cardiac conditions having invasive dental treatment (Table 18.2).

Table 18.2 Cardiac conditions in children requiring antibiotic prophylaxis during invasive dental procedures

Cardiac condition
Unrepaired cyanotic congenital heart disease, even if palliated with a shunt or conduit
Repaired congenital heart disease either with prosthetic material within last 6 months or with a residual defect next to the repair (preventing endothelialization)
Prosthetic valve or valve repair with prosthetic material
Previous infective endocarditis
Cardiac transplantation recipients with valvulopathy

Guidelines for prophylaxis in Australia include rheumatic heart disease in indigenous children and others at significant socioeconomic disadvantage.

In the UK, the guidelines of the National Institute for Health and Care Excellence are less prescriptive. They state that the vast majority of patients at increased risk of infective endocarditis do not need prophylaxis, but prophylaxis should be considered for some patients in consultation with the patient and their cardiologist. These patients have the conditions listed in Table 18.2, similar to Australia and the rest of Europe.

Intravenous prophylaxis is with amoxycillin 50 mg/kg IV (max 2 g) at induction, or cefazolin 50 mg/kg (max 1 g) IV if non-anaphylactic allergy to penicillin. If the child has had anaphylaxis to penicillin in the past, clindamycin 20 mg/kg IV (max 600 mg) over 20 min is recommended.

Review Questions

1. A 6 year old child is having restorative dental treatment under general anesthesia. A nasal endotracheal tube is required. What size tube will you use?
2. A 6 year old child with Trisomy 21 is having dental treatment which includes extractions and stainless steel crowns to four teeth. A nasal endotracheal tube is required. Past history includes a fully repaired atrio-ventricular septal defect during infancy. Does this child require endocarditis prophylaxis? What size tube will you use?

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Anesthesia for Orthopedic Surgery in Children

19

Martyn Lethbridge and Erik Anderson

Children commonly need anesthesia for orthopedic surgery, either urgently because of limb fractures in previously well children, or electively in children who often have coexisting diseases such as cerebral palsy or myopathies. These medical issues are dealt with elsewhere in this book, and this chapter focuses on issues unique to orthopedic surgery. It also outlines the management of anesthesia for scoliosis surgery, so that trainees who are involved with these cases will understand some of the background to their care.

19.1 Emergency Anesthesia for Forearm Fractures

Fractures of the upper limb are a very common reason for a child to have emergency anesthesia. Greenstick fractures only occur in young, preschool aged children. These fractures are nearly always reduced in the Emergency Department using an analgesia technique described in Fig. 19.1.

Complete fracture-displacements may be reduced with a variety of techniques in either the ED or the OR. Many of the techniques require skill and patience to perform in frightened young children, and depend on local expertise, preferences and practical issues relating to staff and theatre availability. All of the techniques require proper monitoring, safety guidelines and ability to resuscitate the child if necessary.

Although fasting beforehand to ensure an empty stomach would seem wise, fasting requirements vary from center to center, depending on the anesthetic technique

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Technique to facilitate fracture reduction
Hematoma block
Axillary block
IV regional anesthesia
IV or IM ketamine with or without other agents
Nitrous oxide
IV or intranasal fentanyl
General anesthesia

Fig. 19.1 Anesthesia and analgesia techniques used for reduction of forearm fractures in children

used. Many emergency departments accept fasting durations much shorter than those for anesthesia. The safety of intravenous sedation in the emergency department and the point at which sedation becomes anesthesia are controversial subjects. Nevertheless, general anesthesia is still very commonly used during fracture reduction because it always results in satisfactory conditions for the procedure and has a high level of safety.

19.1.1 General Anesthesia

Children needing surgery for a forearm fracture are usually fit and healthy, and pulmonary aspiration of stomach contents is the main concern. Evidence about minimizing the risk of aspiration for this procedure is scarce and anecdotal, and it would be simple to recommend rapid sequence induction and intubation for all cases. Rapid sequence induction however, is not without risks, does not entirely protect against aspiration, and can be technically challenging to perform for a brief procedure such as this. Although not formally studied, stratification of the risk of aspiration can be attempted by considering several factors. These include the fasting periods before and after injury, the amount of pain and use of opioid analgesics, the age and level of anxiety of the child, and presence of hunger or bowel sounds.

In children undergoing closed reduction of forearm fractures, experience shows children anesthetized with a facemask rarely vomit, even if they have significant stomach contents. This presupposes that an adequate depth of anesthesia is maintained during fracture manipulation to avoid any coughing, straining, or triggering a vomiting reflex. A laryngeal mask airway (LMA) is commonly used for this procedure, and it would seem prudent to use a second generation LMA with an esophageal drainage tube to mitigate the risk of gastric reflux. Intubation should still be considered for patients who are thought more likely to regurgitate. Identifying those children with a forearm fracture who are more likely to regurgitate relies on factors such as a short interval between food and injury, short fasting time or ongoing pain and opioid requirement. As discussed in Chap. 1, an inhalational induction may be an acceptable option even in this group of children when there is difficult venous access.

Fractures above the elbow (supracondylar fractures) are more painful, frequently require opioid analgesia, and tend to be brought to theater sooner than children with forearm fractures. These patients are more at risk of aspiration, and are more commonly intubated—possibly requiring a rapid sequence induction.

19.1.2 Compartment Syndrome

In adults, compartment syndrome is said to be associated with the five 'P's of symptoms (pain, paresthesia, paralysis, pallor, pulselessness). In young children, it is said to be associated with the three 'A's: anxiety, agitation and analgesia requirements that are increasing. Children are often unsettled after surgery and analgesia is increased in response, and compartment syndrome can easily be missed. It is particularly a concern after supracondylar and tibial fractures, but can occur after other orthopedic and non-orthopedic procedures. Regional analgesia using low concentrations of local anesthetic probably do not prevent the detection of compartment syndrome.

Tip
Children at increased risk of gastric aspiration for fracture manipulation include short interval between food and injury, children in more pain or with anxiety, opioid use and supracondylar fractures. Coughing while lightly anesthetized is the most likely mechanism for regurgitation and aspiration during facemask or LMA anesthesia.

19.2 Common Orthopedic Procedures

19.2.1 Procedures for Hip Dislocation and Dysplasia

Hip dislocation can occur in children for congenital reasons such as breech position in-utero, or for acquired reasons such as muscular imbalance around the hip joint. This can occur in children with neuromuscular disorders such as cerebral palsy. The femoral head can be immobilized in the acetabulum in infants using a SPICA cast. General anesthesia may be required for this. The child is positioned at the end of the theater bed and elevated on a box that allows the cast to be placed circumferentially from the umbilicus to the knees or feet. The cast must be applied to allow unimpaired abdominal movement. Because it is awkward to manipulate the airway while the infant is elevated on the box, tracheal intubation is often best.

Open surgical procedures for hip dislocation include the Salter pelvic osteotomy, and the varus de-rotational osteotomy (VDRO). Both procedures carry risks of significant blood loss, although rarely require transfusion. Post-operative pain and muscle spasms can be significant. Regional techniques, such as caudal block or a lumbar epidural are useful if not contraindicated. Sometimes a SPICA cast is

applied, limiting access to an epidural site for inspection and catheter removal. If this is the case, a single-shot caudal and opioid infusion may be preferred. Muscle relaxants such as diazepam are useful for controlling spasm, but with caution as the child is also receiving opioids.

19.2.2 Procedures for Talipes Equino Varus

Talipes or 'club foot' can be managed with serial casting but surgically releasing the Achilles tendon is often required. This operation is commonly performed transcutaneously under either local or general anesthesia. Factors in considering the best approach to anesthesia include the age of the child, whether the procedure is unilateral or bilateral, and local practice. Local anesthesia for this procedure avoids exposure to general anesthesia and a possible risk of neurotoxicity, and fasting may be avoided. A local anesthetic cream can be applied to the medial side of the Achilles tendon before injection of a mixture of quick acting (lidocaine) and longer lasting (ropivacaine) local anesthetic. Care must be taken to calculate the maximum combined dose of local anesthetic. Other techniques such as awake spinal anesthesia have been described.

19.2.3 Slipped Upper Femoral Epiphysis (SUFE)

The upper femoral epiphysis is prone to subluxing on the femoral neck in adolescence, threatening the vascular supply of the femoral head. It is more common in obese children. The traditional surgery to stabilize the femoral head included placement of pins or screws through the femoral neck into the femoral head. This procedure is performed using a traction table, and anesthetic management requires consideration of the airway in patients with increased body mass, risk of aspiration, comorbidities such as obstructive sleep apnea, and post-operative pain. Femoral nerve blocks are useful for controlling post-op pain, in combination with multi-modal analgesia and the use of judicious doses of opioids. Some recent surgical techniques for the condition are more extensive and prolonged, but require similar anesthetic considerations.

19.3 Cerebral Palsy and Orthopedic Surgery

Orthopedic surgery is required by children with cerebral palsy for three main reasons—to correct hip dysplasia, to relieve limb contractures and improve posture, and to improve gait. Surgery often involves tenotomies, tendon transfers or osteotomies. Pain and muscle spasms can be significant issues after these procedures. Anesthetic care of children with cerebral palsy is discussed further in Chap. 12, Sect. 12.1.

19.4 Scoliosis

Scoliosis consists of spine curvature, rotation of the vertebrae and rib cage deformity. The commonest form is idiopathic scoliosis in otherwise well adolescent girls, but the most difficult form is caused by neuromuscular disease. The spinal curvature is usually 'S' shaped in idiopathic cases, but neuromuscular cases tends to involve whole thoracolumbar spine in a long 'C' shaped curve. The degree of curvature is measured from the angle of the vertebral bodies (the Cobb angle). Surgery is considered if the spinal curve is greater than 40°, or less in neuromuscular cases. The anesthetic considerations are summarized in Table 19.1, and discussed below.

19.4.1 Lung Changes

A restrictive lung defect commonly results from the rib cage and vertebral changes, especially if the spinal curvature is greater than 65°. Ventilation-perfusion mismatch and pulmonary hypertension may also occur, but usually only in severe cases with a curvature greater than 100°. Patients with neuromuscular disease are at greater risk of respiratory complications: they also have parenchymal lung disease from recurrent lung infections as a result of a weak cough, aspiration and immobility. Surgery stops, but does not reverse, the progression of lung changes. It also improves the wheelchair posture in adolescents with neuromuscular disease.

19.4.2 Surgical Approach

Surgery is most commonly via a posterior approach with the patient prone. An anterior approach (via thoracic or abdominal incisions) is used along with the posterior approach in severe cases. Anterior and posterior surgery can be performed as a staged or single procedure. Surgery is extensive and causes blood loss from bone and soft tissue. It carries a 0.3–0.6% risk of spinal cord damage from implant related trauma, spinal ischemia, distraction injury or epidural hematoma. The risk of spinal cord ischemia may be greater for more severe curves and curves associated with spinal

Table 19.1 List of issues that need to be considered during anesthesia and surgery for correction of scoliosis

Anesthetic considerations for scoliosis surgery
Risk of poor respiratory function postop
Risk of rhabdomyolysis in neuromuscular cases
Prone position
Spinal cord monitoring: – SSEP, MEP, CMAP – Wake up test
Blood loss and transfusion
Hypothermia
Postop analgesia and respiratory function

cord tethering. Spinal ischemia may be caused by direct vascular injury, reduced perfusion from hypotension, stretching of the cord or epidural hematoma. To reduce the risk of spinal cord damage, intraoperative spinal cord monitoring is routine, although cord ischemia may cause neurological problems up to 48 h postoperatively.

19.4.3 Spinal Cord Monitoring

Neurophysiological monitoring continuously assesses the spinal cord and has replaced the 'wake-up test' in many centers. Monitoring has limitations of low signal strength, interference from background electrical noise and anesthetic agents, and false negative results. Somatosensory evoked potentials (SSEP) are performed by stimulating the peripheral nerves and detecting either a spinal response with epidural electrodes, or a cortical response with scalp electrodes. It monitors only the sensory path (posterior columns), not the more vulnerable motor path in the spinal cord (anterior columns). Motor evoked potentials (MEP) monitor motor pathways by transcranial stimulation of the motor cortex and detecting either a signal in the spinal cord with epidural electrodes or a compound muscle action potential (CMAP) with a skin electrode. CMAP monitoring is the most commonly used technique as it assesses the motor pathway, avoids cumbersome epidural electrodes and detects problems affecting the nerve roots.

In the past, a wake-up test was used to assess lower limb function and may still occasionally be required in cases of neurophysiological monitoring failure. In this test, the patient is woken up during surgery by reducing anesthetic agents while maintaining analgesia with remifentanil. The aim is to have the child cooperative and able to move their toes on command. It is challenging to avoid excessive movement but be awake enough to cooperate, and there are concerns that spontaneous ventilation during the test may predispose to venous air embolism. Also, the test only assesses the spinal cord at one point in time and irreversible damage may have already occurred before the test. The clonus test can be performed as anesthesia is lightened for a wake-up test, as clonus is easy to elicit at this stage due to the lack of cortical inhibition. It can also be used as a way of deciding if a full wake up test is needed.

19.4.4 Preoperative Assessment for Scoliosis Surgery

Respiratory and cardiac function affect the risk of complications. Exercise tolerance is a good measure in otherwise well patients with idiopathic scoliosis. Asymptomatic mitral valve prolapse is present in 25% of these patients. Cardiorespiratory assessment in children who are wheelchair-bound or developmentally delayed is more difficult, and consultation with the child's respiratory team and cardiologist may help to optimize the child's condition preoperatively. Performance of activities of

daily living, and need for assisted ventilation and cough-assist machines are two indicators. Spirometry commonly shows a mild restrictive defect. Postoperative ventilation is more likely to be needed if the forced vital capacity is less than 30% of predicted. Muscular dystrophy patients may have cardiomyopathy that may not be detectable by a resting preoperative echocardiogram.

19.4.5 Anesthesia Techniques

The patient's condition and requirements of the neurophysiological monitoring affect the anesthesia technique for scoliosis surgery. Muscle relaxants, especially suxamethonium, are used with caution in children with underlying neuromuscular disease, and volatile agents are avoided if the child has muscular dystrophy. The SSEP and MEP are suppressed in a dose-dependent manner by volatile agents and propofol, but may be enhanced by ketamine and etomidate. They are also suppressed by nitrous oxide, but this can be overcome with epidural recording. Opioids and dexmedetomidine do not effect monitoring. Motor evoked potentials are abolished by profound muscle relaxation, but not by lesser degrees of relaxation (train-of-four count equaling 2 or 3) and may be useful for reducing background noise. A common anesthetic technique is to use remifentanil and low dose volatiles or propofol infusion. Invasive arterial pressure monitoring is essential and central venous pressures monitoring is commonly performed. Prone positioning can place pressure on the sternum, which can impair an already reduced cardiac function. Trans-esophageal ECHO may assist in guiding fluid and inotrope use during scoliosis surgery.

19.4.6 Blood Loss

The amount of blood loss depends on the number of segments operated on, but is typically more than 50% of the blood volume. About a third of the blood loss occurs in the postoperative period. Patients with neuromuscular disease lose more blood because surgery is longer and more extensive; they often have subclinical coagulation abnormalities; and they have osteopenic bone that needs more instrumentation. Surgical technique is the most important determinant of blood loss, but patient positioning to minimize epidural venous congestion is helpful. Controlled hypotension is not used because of concerns about spinal ischemia, but instead blood pressure aims to be normalized (MAP 70) and hypertension avoided. Tranexamic acid reduces blood loss, especially in neuromuscular disease patients. Blood transfusion is commonly needed during scoliosis surgery. Techniques to reduce transfusion include autologous pre-donation, acute normovolemic hemodilution, and cell savers. With these techniques, some patients with idiopathic scoliosis avoid donor blood, but losses are so large in patients with neuromuscular disease that transfusion of donor blood is usual.

19.4.7 Postoperative Management

Respiratory problems are the main postoperative concern. Analgesia and chest physiotherapy are important in optimizing respiratory function. The analgesic requirements for these children are high and for a prolonged duration. Intravenous opioids are often required for the first 5–7 days, followed by oral opioids for a further 1 or 2 weeks. Intrathecal opioids and analgesic doses of ketamine are also options. Bony fusion after surgery is critical and some surgeons prohibit the use of NSAIDS.

Review Questions

1. A 11 year old boy with Duchenne muscular dystrophy presents for correction of scoliosis. What complications from anesthesia is he particularly at risk of, and how can the risk of these be minimized?
2. A 4 year old girl presents for MUA of forearm fracture at 6 pm after having fallen off the swing at 1:30 pm. She has been assessed in ED and given three doses of morphine for pain. Discuss how you are going to proceed and the reasons for your choice.
3. You are scheduled to anesthetize a 15 year old girl with idiopathic scoliosis. What are the key issues in your anesthetic management of this patient?

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Congenital Heart Disease

20

Serge Kaplanian

Congenital heart disease occurs in 6–10 per 1000 births and is one of the most common congenital defects.

Ninety percent of children born with congenital heart disease survive into adulthood and will present for non-cardiac surgery having had varying levels of surgical correction. This chapter focuses on the management of children for non-cardiac surgery, and the assessment of a child with a murmur.

20.1 Types of Congenital Heart Disease

There are numerous classifications of congenital heart disease, but the most useful for anesthetists is based on physiology. Lesions fall into one of four groups as shown in Table 20.1.

20.1.1 Shunting of Blood Between the Systemic and Pulmonary Circulations

20.1.1.1 Left-to-Right Shunts

Blood flows through a defect from the high pressure systemic side of the circulation to the lower pressure pulmonary side. This increases pulmonary blood flow in proportion with the size of the defect and the difference in resistance between the systems. This occurs in lesions such as a ventricular septal defect (VSD) (Fig. 20.1). Oxygenated blood from the left side of the heart enters the right side of the heart

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Table 20.1 Classification of congenital heart disease by main physiological defect

Types of congenital heart disease
1. 'Simple' left-to-right shunt with **increased** pulmonary blood flow
Atrial septal defect (ASD)
Ventricular septal defect (VSD)
Patent ductus arteriosus (PDA)
Atrioventricular septal defect (AVSD)
2. 'Simple' right-to-left shunt with **decreased** pulmonary blood flow
Tetralogy of Fallot (TOF)
Pulmonary atresia (with shunting of blood through associated defect
Tricuspid atresia (with shunting of blood through associated defect)
Ebstein's anomaly (Tricuspid obstruction with ASD or patent foramen ovale)
3. 'Complex' shunts: mixing of pulmonary and systemic blood flow causing cyanosis
Transposition of the Great Arteries (TGA)
Truncus arteriosus
Total anomalous pulmonary venous drainage
Double-Outlet Right Ventricle (DORV)
Hypoplastic Left Heart Syndrome (HLHS)
4. Obstructive lesions
Aortic stenosis
Pulmonary stenosis
Coarctation of the aorta
Hypoplastic aortic arch

Commonly used abbreviations are in parentheses

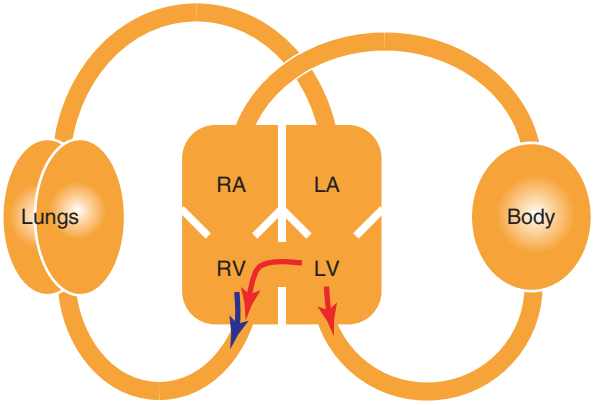

Fig. 20.1 VSD with left-to-right shunting of blood. Oxygenated blood from the left ventricle (LV) enters the right ventricle (RV) and increases pulmonary blood flow

and lungs, and arterial oxygen saturations are normal. Pulmonary blood pressure increases because of the higher pulmonary flow, but pulmonary vascular resistance is relatively normal in the short term and not problematic. Eventually however, muscle in the walls of the pulmonary vasculature hypertrophies and pulmonary vascular resistance rises, causing Eisenmenger's syndrome. This is a major problem, and surgical treatment is timed to avoid this. Left-to-right shunts cause a volume overload of the right ventricle that is relatively well tolerated. Anesthesia is also well tolerated provided myocardial contractility is not significantly depressed.

20.1.1.2 Right-to-Left Shunts (Cyanotic Heart Disease)

De-oxygenated blood from the right side of the heart bypasses the lungs and mixes into the systemic circulation, causing cyanosis. This occurs in lesions such as a Tetralogy of Fallot (TOF). This is a more debilitating condition than left-to-right shunting as pulmonary blood flow is often reduced. Most cyanotic heart conditions have complex defects allowing variable mixing of blood between the right and left side of the heart, and the degree of mixing is affected by the balance between the pulmonary and systemic vascular resistances. If pulmonary vascular resistance increases, pulmonary blood flow decreases. However, the pulmonary blood flow is also affected by the systemic vascular resistance. If the systemic vascular resistance falls, more blood is shunted to the left side of the heart and pulmonary blood flow decreases. The balance between the pulmonary and systemic vascular resistances is the critical factor with anesthesia for children with cyanotic heart disease.

Anesthesia for this group of patients is much more problematic than for children with left-to-right shunts because pulmonary blood flow must not be reduced any further. Right-to-left shunts slow inhalational induction due to a reduction in pulmonary blood flow (Table 20.2). Intravenous induction is rapid and with a danger of overdose because a proportion of the induction agent bypasses the lungs and is immediately available to the cerebral circulation. Air bubbles from the IV line can cross to the arterial circulation and must be avoided. Filters are available for IV lines to prevent air bubbles entering the patient.

Keypoint
The balance between the pulmonary and systemic vascular resistances is the critical factor in anesthesia for children with cyanotic heart disease.

20.1.1.3 Duct-Dependent Heart Disease

Some children with cyanotic heart disease have very little blood flow from the right ventricle into the pulmonary artery and lungs. Although this is not a problem while the placenta is in the circulation, after birth it results in poor oxygenation and may not be compatible with survival. Some of these children rely on

Table 20.2 Differences between the two types of pulmonary-systemic shunting of blood

Shunt type	Example	Effects
Left-to-right	VSD	Normal arterial SaO_2 Inhalational induction faster IV induction slower Risk from IV air bubbles slightly raised Anesthesia generally well tolerated
Right-to-left	TOF	Cyanosed, minimal improvement with high FiO_2 High risk from IV air bubbles Inhalational induction slower IV induction faster, reduced dose required

the ductus arteriosus that directs blood from the aorta into the pulmonary artery. This oxygenated blood from the aorta mixes with any de-oxygenated blood already in the pulmonary artery and then passes into the lungs. Although this is not efficient for oxygenation, it often permits survival, albeit with persisting cyanosis. These babies have duct-dependent cyanotic heart disease, and their ductus is kept open with prostaglandins until other methods of augmenting pulmonary blood flow can be achieved. These methods depend on the underlying cardiac problem but include atrial septostomy (in transposition of the great arteries) or a modified Blalock-Taussig shunt (modified BT shunt). A modified BT shunt connects the left or right subclavian artery to the left or right pulmonary artery with a synthetic graft.

Note
If an infant has a modified BT shunt, pulmonary blood flow depends on the systemic blood pressure. Increasing the SVR and blood pressure will improve the child's saturation.

20.1.2 ASD and VSD

Children with an atrial septal defect (ASD) or ventricular septal defect (VSD) have a predominantly left-to-right shunt that increases pulmonary blood flow and causes volume overload of the right ventricle. The size of the defect and difference in chamber pressures determine the amount of shunting. Patients with small restrictive defects have minimal left to right shunting and minimal increase in pulmonary blood flow. On the other hand, patients with large non-restrictive defects have greatly increased pulmonary blood flow.

Both defects are associated with a systolic murmur maximal at the left sternal edge. Small defects may eventually close without treatment. Others require either surgical closure under cardio-pulmonary bypass or using a transvenous approach in the catheter lab.

As long as pulmonary hypertension has not developed, anesthetic management is relatively straightforward. Preload should be maintained, and the fall in systemic vascular resistance that tends to accompany anesthesia reduces left-to-right shunting. Although increasing pulmonary vascular resistance also reduces shunting, PVR is not deliberately manipulated. Inhalational induction is very rapid because of the increase in pulmonary blood flow, but intravenous induction is delayed because of recirculation of agent through the shunt and pulmonary circulation (Table 20.2). In practice however, the change from the normal speed of induction is not great. Paradoxical air embolism can occur during ventilation if high airway pressures are used—IPPV and PEEP increase right atrial pressure and can induce R-to-L shunting.

20.1.3 Tetralogy of Fallot

Tetralogy of Fallot (TOF) is the commonest 'simple' right-to-left defect resulting in cyanosis. It consists of four abnormalities:

1. VSD
2. Overriding aorta (the aorta is positioned over the VSD, communicating with the left and right ventricles)
3. Right ventricular hypertrophy
4. Right ventricular outflow tract obstruction (subvalvular, valvular and/or supravalvular)

Obstruction of the right ventricular outflow tract increases right ventricular pressure. Deoxygenated blood passes through the VSD and into the overriding aorta, causing cyanosis. Obstruction at the level of the pulmonary valve (valvular) or pulmonary artery (supravalvular) is constant, and the child is always cyanosed. The classical outflow tract obstruction in Tetralogy is due to hypertrophy of the infundibular myocardium at the subvalvular level (Fig. 20.2). The obstruction is dynamic and behaves in a similar fashion to hypertrophic obstructive cardiomyopathy—if myocardial contractility increases or the right ventricular volume decreases, the opposing ventricular walls at the level of the obstruction become closer and the outlet obstruction worsens. Outlet obstruction diverts blood from the right ventricle through the VSD, away from pulmonary artery and the lungs. Cyanosis worsens, and a hypercyanotic spell or 'Tet spell' occurs. The intensity of the systolic murmur also decreases during a Tet spell. Children with a dynamic obstruction may be acyanotic between spells.

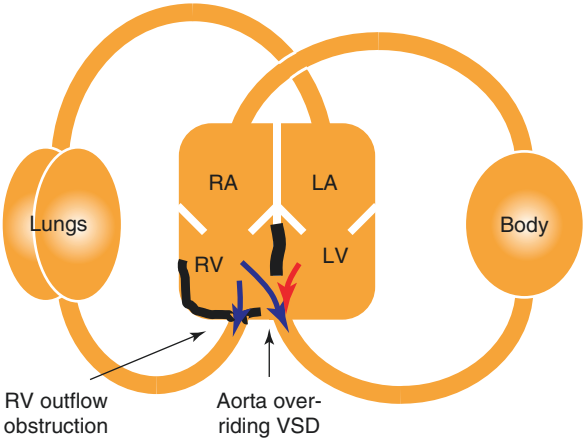

Fig. 20.2 Tetralogy of Fallot during 'Tet spell'. RV pressure is increased by the dynamic RV obstruction causing right-to-left shunting, reduced pulmonary blood flow and cyanosis

Table 20.3 Perioperative management of hypercyanotic 'Tet spells' in TOF patients

Management of hypercyanotic 'Tet spell'
100% oxygen
Fluid bolus (consider repeating)
Pressure on the groins to compress the femoral arteries and increase afterload
Reduce sympathetic stimulation with opioids and deepening anesthesia
Peripheral vasoconstriction with phenylephrine
Reduce infundibular contraction with a short acting beta blocker such as esmolol

Spells are triggered by reduced right ventricular volume (dehydration), and by increased myocardial contractility (sympathetic stimulation from hypothermia, hunger or pain). The first aim of anesthetic management is to stop spells occurring, as they can be frighteningly severe and difficult to reverse. Treatment includes fluid to increase the volume of the right ventricle, opioids and beta blockers to reduce contractility of the infundibular myocardium, and peripheral vasoconstriction with a pure alpha agonist agent (e.g. phenylephrine) to increase the left ventricular pressure above the right ventricular pressure to reduce shunting (Table 20.3).

20.1.4 Fontan Procedure

A Fontan circulation is created when a child is born with complex heart disease and a biventricular repair is not possible. The Fontan procedure is a multi-stage operation that uses the child's single functioning ventricle to supply the systemic arterial system, and creates a passive venous conduit for blood from the systemic circulation to pass through the lungs to be oxygenated (Fig. 20.3). This procedure is the last of three stages. A complete Fontan operation is not possible in the first several months of life as the pulmonary vascular resistance is too high. The first step therefore is to increase pulmonary blood flow with a modified Blalock-Taussig shunt where a Gore-tex graft is used to connect the subclavian artery to the ipsilateral pulmonary artery. This shunt permits survival and growth of the child.

The second stage is at approximately 6 months when pulmonary vascular resistance has fallen. Typically, the superior vena cava and right pulmonary artery are joined so that venous return from the upper body passively enters the pulmonary circulation without a pumping chamber. It is also during this stage that the BT shunt is taken down. The final stage takes place at approximately 1–5 years of age, when the inferior vena cava and right pulmonary artery are joined via an extracardiac conduit, or occasionally an intra-atrial baffle. All systemic venous return now passes passively through the lungs to be oxygenated—the systemic and pulmonary circulations are now in series. However, if the pulmonary vascular resistance were to rise, forward (passive) flow of blood through the lungs would stop, and cardiac output would fall. To minimize the impact of a rise in pulmonary vascular resistance, some Fontan repairs are 'fenestrated' between the conduit and the atrium, which creates a shunt path between the systemic and pulmonary circulations. If pulmonary vascular resistance increases, blood can pass through the fenestration to

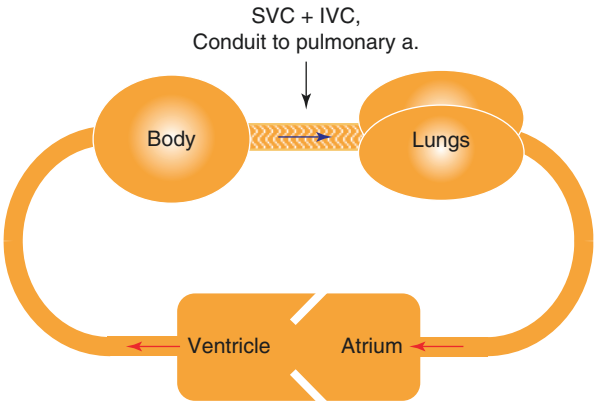

Fig. 20.3 Schematic representation of Fontan circulation. The child's single ventricle supplies the systemic circulation. Venous return from the body passively returns to the lungs through a Gore-tex graft joining the great veins and pulmonary artery. There is no ventricle supplying the lungs. The low pressure in the graft is not able to overcome any increase in pulmonary vascular resistance

Table 20.4 List of important management goals in anesthesia of child with Fontan circulation

Goal of anesthetic management	Reason
Avoid hypovolemia, use fluid load	The Fontan circulation is very preload dependent. Maintain CVP to maintain pulmonary perfusion
Keep pulmonary vascular resistance low – Avoid hypoxia, hypercarbia, acidosis	Prevent resistance to pulmonary blood flow
Keep intrathoracic pressure as low as possible – Consider spontaneous ventilation; minimize PEEP and aim for low inspiratory pressures if IPPV	Prevent extrinsic compression of pulmonary vasculature; negative intrathoracic pressure during breathing may help blood flow through lungs
Avoid myocardial depression	Function of ventricle supplying systemic circulation may be marginal

the single ventricle of the heart and maintain cardiac output, albeit with deoxygenated blood. The existence of the fenestration allows some level of mixing, hence a degree of slight desaturation. Many patients with a Fontan circulation do well for some years, while others fare less well. Complications are common and include diminished ventricular function, thromboembolic events, conduction disturbances, peripheral edema and protein losing enteropathy.

20.1.4.1 Anesthesia and the Fontan Circulation

Anesthesia in children after a Fontan procedure can be difficult and is best done in a tertiary center. In the child with Fontan circulation, the pulmonary vascular resistance must stay low to allow the entirely passive flow of blood through the lungs. The pressure gradient for the pulmonary circulation is the difference between the CVP and common atrial pressure, and it cannot rise to overcome an increase in resistance. Spontaneous ventilation may help blood flow through lungs because of negative intrathoracic pressure, but controlled ventilation is usually well tolerated and facilitates an anesthetic technique that minimizes myocardial depression (Table 20.4).

20.1.5 Eisenmenger Syndrome

Children with large left-to-right shunts have increased pulmonary blood flow. The vessel walls in the pulmonary circulation hypertrophy leading to a rise in pulmonary vascular resistance. Over time, pulmonary hypertension develops. Eventually, pulmonary arterial pressures are so high that the pressure in the right ventricle becomes higher than the pressure in the left ventricle. Blood now shunts from right-to-left and cyanosis develops. Pulmonary hypertension with a reversed central shunt is termed Eisenmenger syndrome. Anesthesia in patients with this syndrome carries an extremely high risk.

20.1.6 Obstructive Lesions

The left ventricular outflow tract can be obstructed at the subvavular, valvular or supravalvular level. Congenital aortic stenosis, hypoplastic aortic arch and coarctation of the aorta are the most common lesions. The pathophysiology is similar to that seen in adults with relatively fixed cardiac output, myocardial hypertrophy causing reduced ventricular compliance and cardiac failure, and a predisposition to arrhythmias. Anesthetic management also follows the same principles as in adults and aims to maintain a balance of myocardial oxygen supply and demand. This is achieved by maintaining normal heart rate and systemic vascular resistance and avoiding myocardial depression.

20.2 Perioperative Approach to the Child with Congenital Heart Disease

The preceding sections give background information about the common types of cardiac defects. This section focuses on anesthesia in a child with congenital heart disease for non-cardiac surgery. Utilizing a perioperative approach to their management simplifies the process and involves going through three steps:

1. What type of disease does the child have and what are the anesthetic implications?
2. Does this child have major long-term consequences of congenital heart disease?
3. Are there any special concerns?

20.2.1 What Type of Disease Does the Child Have and What Are the Anesthetic Implications?

Children with congenital heart disease fall into one of four categories:

- Children who have never had surgical correction
- Children who have undergone reparative surgery with no residual sequelae

- Children who have undergone reparative surgery with residual sequelae
- Children who have undergone a palliative procedure (e.g. Fontan circulation)

20.2.1.1 Children Who Have Never Had Surgical Correction

These children have uncorrected heart defects shown in Table 20.1. Management depends on the underlying lesion and whether any of the long-term consequences of congenital heart disease have developed.

20.2.1.2 Children Who Have Undergone Reparative Surgery with No Residual Sequelae

These are children with some of the most common congenital abnormalities, such as a PDA or small ASD. Correction of the defect returns the circulation to a physiologically normal state, and anesthetic management is no different to a non-cardiac patient. Antibiotic prophylaxis is not required.

20.2.1.3 Children Who Have Undergone Reparative Surgery with Residual Sequelae

In these children, the main defect has been corrected but there is a residual defect. Residual defects are common after corrective surgery, particularly if the original defect was complex or if repair was later in life than is optimal. Table 20.5 lists some of the more commonly repaired congenital cardiac lesions and their residual sequelae.

20.2.1.4 Children Who Have Undergone a Palliative Procedure

Palliative procedures do not reconnect the heart and vessels into a normal sequence with a normal circulation, but they create adequate systemic and pulmonary blood flow for survival. Palliative surgery is performed for complex heart defects such as univentricular heart, in which there is atresia of one of the ventricles. These patients are the most complicated and challenging group. The Fontan procedure is one of the most common palliative procedures.

Table 20.5 Residual sequelae after some types of cardiac surgery

Disease	Residual sequelae after repair
ASD, VSD	Arrhythmias Residual shunt Pulmonary hypertension (if delayed repair)
Coarctation of the aorta	Residual gradient or re-stenosis Systemic hypertension Inaccurate blood pressure & SpO_2 on side of shunt if subclavian artery divided for repair
Tetralogy of Fallot	Ventricular dysfunction, arrhythmias, pulmonary regurgitation Residual VSD or RV outlet obstruction
Transposition of the great arteries	Stenosis at great vessel anastomoses Ventricular dysfunction Coronary artery stenosis Arrhythmias

Although surgery has reconnected the elements of the circulation into a normal arrangement, the patients remain at risk from short- and long-term changes to the heart and circulation

Keypoint
Children with cyanotic heart disease should be managed in specialist pediatric centers.

20.2.2 Does this Child Have Any of the Major Long-Term Consequences of Congenital Heart Disease?

The next step in the perioperative approach to the child with congenital heart disease is to assess if any long-term consequences of congenital heart disease are present. Pulmonary hypertension, arrhythmias and heart failure are not uncommon, and chronic cyanosis has long term complications of its own.

20.2.2.1 Pulmonary Hypertension

Pulmonary hypertension is defined as a mean pulmonary arterial pressure greater than 25 mmHg at rest or more than 30 mmHg during exercise. Large left-to-right shunts are the most common cause of pulmonary hypertension in children. Echocardiography is able to quantify pulmonary pressures, and children with supra-systemic pulmonary pressures have high risk of complications under anesthesia. The main goal of anesthesia in these children is to avoid triggering a pulmonary hypertensive crisis by avoiding hypoxia, hypercarbia, acidosis, stress, pain, or hypothermia. Treatment includes controlled hyperventilation with 100% oxygen, correcting acidosis, minimizing sympathetic stimulation and considering inhaled nitric oxide.

20.2.2.2 Arrhythmias

Children who have undergone reparative or palliative surgery are the most likely to develop arrhythmias. Atrial surgery often leads to supraventricular arrhythmias while children who have undergone ventriculotomies are more likely to develop ventricular arrhythmias. Some of these children may have permanent pacemakers that require checking perioperatively.

20.2.2.3 Heart Failure

Heart failure is most common in infants with large unrestrictive left-to-right shunts or in the child with the terminal phase of their cardiac disease. Treatment with diuretics and converting enzyme inhibitors as well as consultation with a pediatric cardiologist is essential.

20.2.2.4 Cyanosis

Chronic cyanosis (SaO_2 <85% and >50 g/L deoxy-Hb) induces multiple coagulation factor deficiencies, thrombocytopenia, and abnormalities in prothrombin and partial thromboplastin times. Cyanotic children have an increased risk of bleeding,

Table 20.6 Chronic hypoxia in cyanotic heart disease affects several systems of the body

Effects of chronic cyanosis
Coagulation factor deficiencies and risk of bleeding
Thrombocytopenia
Polycythemia (increased erythropoietin) and risk of cerebral thrombosis
Neurodevelopmental changes
Renal dysfunction

and clotting studies should be reviewed and fresh frozen plasma and platelets organized preoperatively. Polycythemia is also common in cyanotic congenital heart disease as a result of overproduction of erythropoietin. This increases the risk of thrombosis and stroke, particularly if the child is dehydrated. Some children are taking aspirin for this reason. Blood flow is redistributed to the brain and heart, and renal dysfunction common. Chronic hypoxia may also affect neurodevelopment (Table 20.6).

20.2.3 Are There Any Special Concerns?

The third and final step in the perioperative approach to the child with congenital heart disease is to consider any special concerns that may be specific to the child or procedure. These children have often had multiple anesthetics, and the parent will know about their child's preferred induction, behavior at induction and need for premed.

20.2.4 Infective Endocarditis Prophylaxis

Some children with congenital heart disease having certain procedures require endocarditis prophylaxis (Table 20.7). Congenital heart disease with left-to-right shunt, including ASD and VSD, generally don't require prophylaxis. Some of these conditions are closed with a device using transcatheter technique, and children with these devices will need prophylaxis for at-risk procedures for the first 6 months, until the device is endothelialized. Children with cyanotic heart disease are a high-risk group whether unrepaired, palliated with a shunt or conduit, or repaired but with a residual defect. A child with a Fontan circulation is in a high risk group, whereas a child with a repaired Tetralogy of Fallot with no residual defect would not need prophylaxis from six months after any repair using prosthetic material.

Only certain procedures necessitate endocarditis prophylaxis. Prophylaxis is not required during upper and lower gastrointestinal procedures including gastroscopy and colonoscopy, genitourinary or reproductive tract procedures. Adenotonsillectomy is considered an indication for prophylaxis in most countries, but not the United Kingdom.

Table 20.7 Groups of children with congenital heart disease that need to be given endocarditis prophylaxis for procedures with a risk of causing bacteremia

Cardiac conditions needing prophylaxis for certain procedures
Unrepaired cyanotic congenital heart disease, even if palliated with a shunt or conduit
Repaired congenital heart disease either with prosthetic material within last 6 months or with a residual defect next to the repair (preventing endothelialization)
Repaired CHD with residual defect at or adjacent to prosthetic patch or device
Prosthetic valve or valve repair with prosthetic material
Previous infective endocarditis
Cardiac transplantation recipients with valvulopathy
In Australia: Rheumatic heart disease in indigenous children and others at significant socioeconomic disadvantage
⬇
Procedures needing endocarditis prophylaxis if one of the cardiac conditions above is present
Dental procedures involving manipulation of the gingival tissue or the periapical region of teeth or perforation of the oral mucosa
Procedures on the respiratory tract involving mucosal incision (includes tonsillectomy and adenoidectomy, but not bronchoscopy without biopsy), or infected skin, skin structures or musculoskeletal tissue

In the United Kingdom, ENT procedures are not considered an indication for prophylaxis

20.3 Preoperative Assessment of the Child with Congenital Heart Disease

As with adults, assessment of the functional state is an important component in determining risk. Adult measures such as the New York Heart Association classification are not usually applicable to children. Exercise tolerance can be easily assessed in older children, often by asking about their performance compared to their peers at school. Functional state in preschool-aged children is assessed by information from the parents. In infants, cardiac symptoms manifest as poor feeding or failure to thrive. Children with defects that shunt blood through the lungs are predisposed to respiratory infections. Many children have had multiple procedures or complex cardiac conditions. A hospital record review and deliberation about the physiology of the child's cardiovascular system and its response to changes in pulmonary and systemic vascular resistance is vital.

Physical examination includes observation for dysmorphic features, as about 1 in 5 children with congenital heart disease have other anomalies or syndromes. Routine observations include the oxygen saturation while breathing room air, blood pressure, and the pulses in all extremities to detect reduced distal pulses from coarctation of the aorta. Tachypnea, tachycardia, a gallop rhythm, hepatomegaly, and pulmonary congestion are all indicative of heart failure in the infant. Mottling is a sign of severe disease. Clubbing and peripheral edema are more relevant in the older child.

The most useful investigation is echocardiography, as it will give an indication on function, anatomy, shunting and evidence of pulmonary hypertension. Coagulation studies should be performed in children with cyanotic heart disease. Other investigations depend on the child's pathology, functional state, procedure, and recent investigations.

20.3.1 The Child with an Incidental Murmur

Cardiac murmurs are commonly noted when assessing children before surgery. Up to 70% of infants and 50% of school age children may have a murmur, but the majority are innocent and not caused by any cardiac pathology. Innocent murmurs are common throughout childhood and adolescence, but particularly common in children aged 7 years and younger. The commonest type of innocent murmur is a vibratory (Still's) murmur, but other types are the pulmonary flow murmur and venous hum. The latter is due to flow in the systemic great veins and is a continuous murmur that is sometimes confused with a patent ductus arteriosus (PDA). A venous hum murmur, however, varies with respiration and disappears when supine. It is important to differentiate these innocent murmurs from the relatively uncommon pathological murmur. In most cases, the anesthetist is able to distinguish between the two types from a detailed cardiac-specific history and examination (Table 20.8).

When taking a cardiac-specific history in the child with a murmur, the important points are family history of congenital heart disease, co-existing syndromes, symptoms and a functional assessment. Respiratory problems such as cough, wheeze or recurrent respiratory infections can be caused by cardiac dysfunction but are also very common in all children. Physical examination assesses the child's general appearance, and observations include SpO_2 and pulses in the upper and lower extremities. Pathological murmurs are loud, have a harsh quality, may radiate and are associated with an early or mid-systolic click or an abnormal second heart sound. The timing of the murmur is also important-pathological murmurs tend to be pansystolic (VSD) or diastolic, whereas innocent murmurs are soft early systolic or ejection systolic. If the child is less than one year old or has features suggestive of a pathological murmur, then referral to a pediatric cardiologist is warranted.

Table 20.8 Clinical features that suggest either innocent or pathological cause for murmur in a child

Innocent	Likely to be pathological
Asymptomatic Soft, no associated thrill Ejection systolic Lower sternal edge and does not radiate	Child has chromosomal abnormality or syndrome Cardiac symptoms, frequent respiratory symptoms Failure to thrive Family history Infant <12 months Harsh, loudness 3/6 or more Pansystolic or diastolic

20.3.2 The Pediatric ECG

The ECG is different during infancy and early childhood due to the significant cardiac and circulatory changes compared to adults. The anatomical dominance of the right ventricle during neonatal life is responsible for many of these changes. Apart from the normal, faster heart rate, a smaller cardiac muscle mass leads to a shorter PR interval and QRS duration in infants and young children compared to adults. There is also a shift from right ventricular dominance in the newborn period (reflecting the neonate's elevated pulmonary vascular resistance) to left ventricular dominance by 1 year of age.

Review Questions

1. A 4 year old girl with Trisomy 21 had an VSD repaired while an infant. She is active and well and is scheduled for a dental procedure. Could her procedure be performed in a regional hospital? Does she need endocarditis prophylaxis?
2. A 6 month old infant with hypoplastic right ventricle had a modified Blalock Taussig shunt performed soon after birth and is now scheduled for surgery. Why would this child have had a shunt so soon after birth? What factors will affect the child's SpO_2 during anesthesia?

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Anesthesia for Thoracic Surgery in Children

21

Neil Chambers and Siva Subramaniam

This chapter outlines the differences between children and adults undergoing thoracic surgery and discusses some aspects of applied physiology and clinical practice. Anesthetic management of these cases requires an understanding of the relevance of age and pathophysiology, and knowledge of the risks of surgery and anesthesia. These risks include equipment problems, perioperative loss of airway and ventilation problems, bleeding, pneumothorax, and lung soiling.

21.1 Background

Pathologies in children requiring thoracic surgery involve congenital, neoplastic, infective, traumatic and cystic lesions (Table 21.1). Congenital lung malformations are a collection of uncommon conditions that primarily present in childhood and are not commonly seen in adult practice (Table 21.2).

Thoracic surgery is carried out by thoracotomy or thoracoscopy (Video Assisted Thoracoscopic Surgery, VATS). Thoracic surgery in adults almost always requires lung isolation and one-lung ventilation (OLV), usually with a double lumen tube. Children's lungs are usually healthy and respond differently to surgical intervention compared to chronically diseased adult lungs, and one-lung ventilation is not always needed. Thoracoscopy with a low intrapleural pressure (below 8–10 mmHg) is well tolerated by children, who do not usually get significant mediastinal shift or cardiovascular changes. Although two-lung ventilation has been used for many years in children, and can be used during some procedures such as thoracoscopic

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Table 21.1 Indications for thoracic surgery in children of different age groups

Age group	Indication
Neonate and infant	PDA and coarctation of the aorta Congenital lung malformations Tracheo-esophageal fistula
Child	Tumor
Adolescent	Tumor Scoliosis anterior repair Correction chest wall deformity

Table 21.2 Congenital lung malformations likely to require surgery

Condition	Abnormalities
Congenital pulmonary airway malformations (CPMA; formerly called CCAM)	Cystic or solid mass connected to a bronchus, usually within one lobe of the lung. Commonest congenital lung malformation.
Bronchial mucocele (bronchial atresia)	Focal narrowing or obliteration of distal segment of bronchus causing a mucous-filled cyst.
Bronchogenic cyst	Embryologic duplication cyst filled with mucous and not communicating with a bronchus. Can compress adjacent structures.
Congenital lobar emphysema	Hyperinflation of one or more lobes. Symptoms if large; may cause pneumothorax.
Pulmonary sequestration	Non-functioning lung tissue supplied by anomalous systemic artery and not communicating with a bronchus

sympathectomy, surgical access is often better if one-lung ventilation is performed. Some of the equipment issues for one-lung ventilation in children have been addressed, and one-lung ventilation is being increasingly used in children.

21.2 One-Lung Ventilation in Children

The indications for one-lung ventilation in children are similar to those for adults, although no indication can be regarded as absolute in children (Table 21.3). One-lung ventilation can be technically difficult in small children and has potential risks such as airway trauma or obstruction. These risks need to be balanced against the potential gain in surgical access. It is generally well tolerated in children, although reinflation of the lung is associated with a mild acute lung injury. Distribution of ventilation in the lateral position during IPPV is similar in children and adults. During spontaneous ventilation however, the compressible thoracic cage and reduced effect of gravity on lung perfusion has the potential to worsen ventilation-perfusion mismatch in the dependent infant lung. There are three different techniques for one-lung ventilation in children, each having their own advantages and disadvantages.

Note
One-lung ventilation for VATS in small children is not always necessary, and its risks and benefits should be discussed with the surgeon.

21.2.1 Double-Lumen Tubes (DLT)

The smallest double lumen tube available is size 26F, and this can be used for children over 8 years of age or 35 kg (Table 21.4). The size of the DLT can be estimated with the formula Size (in FG) = (age × 1.5) + 14, or the tracheal diameter measured on CT. A left-sided tube is usually selected because of the rarity of peri-hilar pathology and young elastic tissues in children, and it is usually easy to position. Placement is best confirmed using a fiberoptic bronchoscope. The advantages of the double lumen tube in older children include a good safety record, ease of insertion, stable positioning, and the ability to suction, oxygenate and apply CPAP to the upper lung. It remains the gold standard when absolute lung isolation is required to prevent contralateral soiling. The disadvantages of double lumen tubes are the lack of small sizes, an inability to ventilate during placement, the need to replace the tube for post-operative ventilation and their potential to cause tracheo-bronchial injury.

Keypoint
Double lumen tubes are less likely to shift during patient positioning and surgery, and allow suction and CPAP to the collapsed lung. They are usually the best choice for OLV. Their problems however, are their large size and high incidence of sore throat.

Table 21.3 Indications and contraindications for one-lung ventilation

Indication	Comments
Major indications	Air leak (actual or potential) Risk of contamination with pus or blood Differential ventilation
Other indications	Surgical exposure
Contraindications	Inability to maintain oxygenation Technical or equipment problems

Table 21.4 Devices available to achieve one-lung ventilation in children

Tube	Smallest device size	Minimum age/ weight	Comments
Double lumen tube (DLT)	26F	8 years/35 kg	Usually left-sided tube used
Bronchial blockers			
Fogarty embolectomy etc	3F	Infants and older	Technically difficult and prone to complications
Arndt	5F	18 months	Most widely used. Positional stability may be a problem
Univent	3.5 mm (7.5 mmOD)	6–8 years	Similar age group to DLT (which is preferable to use)

21.2.2 Endobronchial Intubation

Selective endobronchial intubation of the dependent lung is a simple technique that may be the one of choice in emergencies such as airway hemorrhage or major bronchopleural fistula. A tube that is normal sized or a half size smaller is inserted with its bevel angled towards the lung intended for ventilation. Turning the child's head in the opposite direction helps guide the tube. Using a cuffed tube can potentially improve the seal. Confirmation of correct placement is made clinically or by bronchoscopy. Problems with this technique include failure to achieve an adequate seal in the bronchus (preventing deflation of the contralateral lung or failing to protect the lung from soiling), upper lobe orifice obstruction, and inability to deflate, suction or provide CPAP to upper lung.

21.2.3 Endobronchial Blockers

Endobronchial blockers are placed either inside or outside the lumen of the endotracheal tube and occlude the mainstem bronchus of the operative lung. Their position is checked with either the fiberoptic bronchoscope or image intensifier. Various types of catheters have been used as endobronchial blockers, and the technique is suitable for children from infancy onwards (Table 21.4). Historically, catheters designed for other purposes, such as embolectomy, urinary, pulmonary artery and atrial septostomy catheters have all been used. They share the significant problems of being difficult to position and their high-pressure cuffs may shift to occlude the tracheal lumen. Furthermore, suction is not possible through any blocker and the size of the central lumen of most is too small to be useful. Other blockers, such as the Cohen® blocker, do not have pediatric sizes available.

The Arndt endobronchial blocker is designed specifically for one-lung ventilation and is now the most popular because it has a large central lumen to allow lung deflation and oxygenation to the non-ventilated lung, as well as a low pressure endobronchial cuff that has a lower risk of displacement. The blocker is positioned while observing through a small diameter bronchoscope (Fig. 21.1). The smallest Arndt blocker is 5FR, which requires an endotracheal tube of at least 4.5 mm ID (using a 2.2 mm diameter bronchoscope) to accommodate the catheter and a bronchoscope to position it. This means that they can only be used in children over about 18 months, depending on the child's size. The blocker can be used outside the endotracheal tube, allowing its use in even younger children but risking localized pressure from the catheter on the cricoid cartilage.

The Univent® tube (Fuji) is a single lumen ETT with moveable bronchial blocker incorporated into the side of the tube. It is easy to place and allows both one- and two-lung ventilation. It is easier to place compared to the double lumen tube if laryngoscopy is difficult, and there is no need to change the tube if post op ventilation is required. However, they have a large external diameter and are only suitable for older children, in whom a double lumen tube is preferable.

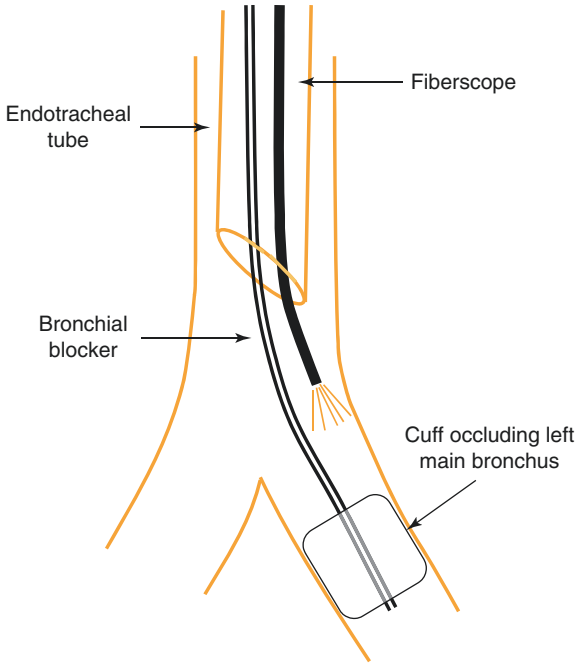

Fig. 21.1 The Arndt endobronchial blocker positioned in the left mainstem bronchus. A fine fiberscope passed alongside the blocker is used to visualize the cuff of the blocker

21.3 Anesthesia Maintenance

Intraoperative management of anesthesia during thoracic surgery is based on the underlying pathophysiology and planned surgery. Invasive arterial monitoring can be helpful but is not essential in children undergoing one-lung ventilation. The lack of pulmonary and cardiovascular disease in most children means that both thoracotomy and one-lung ventilation are generally well tolerated. $ETCO_2$ can be an unreliable indicator of arterial CO_2 during one-lung ventilation, but trends and changes are still useful. Positioning of the child for surgery or intraoperative surgical maneuvers can alter the precisely positioned endobronchial blocker, which is not as secure as a DLT. For this reason, a fiberoptic bronchoscope needs to be readily available throughout surgery.

Most children undergo surgery for a focal lesion and otherwise have normal lungs. They usually tolerate one-lung ventilation well, and may need only a small increase in FiO_2. Nevertheless, there should be a plan to manage hypoxemia during one-lung ventilation (Table 21.5). If constant pressure ventilation is being used, airway pressure will not increase during one-lung ventilation, but the tidal volume will fall. The respiratory rate and inspiratory pressure will need adjusting. Blood loss and fluid shifts during surgery may be considerable, and heat loss is large. Fluid replacement should match losses, but excessive fluid may cause lung edema and postoperative respiratory complications.

Table 21.5 Causes and management of hypoxemia during one-lung ventilation in a small child

Hypoxia during one-lung ventilation	
Causes	Bronchial tube too far in or out, or blocking trachea Tube lumen obstructed Under-ventilation Diminished hypoxic pulmonary vasoconstriction
Management	Increase FiO_2 Check tube position and equipment function Oxygenate operative lung (O_2 insufflation, CPAP, intermittent re-expansion) Optimize ventilation (hand ventilate, tidal volume, I:E ratio, PEEP) Suction Ensure optimal cardiac output Ask surgeon to wait until oxygenation is adequate

21.4 Postoperative Management

Thoracotomy is a painful procedure in children as it is in adults. It is less painful in infants however, due to their cartilaginous ribs and costovertebral junctions. Postoperative analgesia in children follows the same principles as adults: multimodal, incorporating a regional or local technique when possible, and aiming to facilitate extubation and postoperative recovery.

Children with previously good lung function can usually be extubated in theatre. Postoperative ventilation may sometimes be required if there is underlying lung pathology, atelectasis or soiling, or if management of the child is facilitated by maintaining sedation for a period of time. Recovery and return to normal function is generally faster in younger children compared to adolescents and adults.

Review Questions

1. How would you manage hypoxemia during one lung ventilation in children?
2. What are the signs of significant mediastinal shift during videoscopic assisted thoracic surgery?

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Anesthesia for Plastic Surgery in Children

22

Rohan Mahendran

Anesthesia is often required for small traumatic injuries such as lacerations, which would be treated under local anesthesia in an adult. It is also required for plastic surgery to correct congenital deformities, sometimes in children with other congenital anomalies that affect anesthesia.

22.1 Anesthesia for Cleft Lip and Palate Repair

Cleft lip and palate is the most common craniofacial disorder in children, with an overall incidence of 1 in 600 births. It occurs from the failure of fusion of the components of the nasal and maxillary prominences during early gestation. Children can have an isolated cleft clip, cleft palate only, or both cleft lip and palate. Babies with cleft lip and palate are usually otherwise well. Babies with cleft palate alone are less common (about 1 in 2000 births), but are more likely to have other congenital anomalies including cardiac disease (5–10%) or other syndromes including Trisomy 21, or Robin sequence. The cleft varies in severity and may be unilateral or bilateral. It can involve the nose, philtrum, lip vermillion, gum, hard and soft palate, uvula and Eustachian tubes.

There are many subsequent effects of the cleft. These include cosmetic and maternal attachment issues, sucking and feeding, hearing and speech development, and dental issues. Children with cleft palate are managed by a team including plastic surgeons, geneticists, ENT and speech pathology, dentistry and orthodontics, and nutritionists. An early issue for babies with cleft palate is developing an effective suck for feeding. Specialized teats or squeezy bottles are used for feeding.

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Orthodontic plates are used before surgical repair to align the gum margins. Infants with syndromes in association with cleft are particularly prone to gastro-esophageal reflux, which in turn inflames the upper airway and affects surgery.

22.1.1 Surgical Repair

Surgical procedures optimize function and cosmesis. The first procedure is lip repair at 3 months of age. Some centers perform this repair at ages as young as 1 week to reduce scarring, but this must be balanced against anesthesia and airway concerns. The anterior part of the gum is sometimes repaired at the same time as the lip, or otherwise later when the palate is repaired.

The cleft palate is repaired between 9 and 18 months of age. Repair at a young age improves speech development, whereas later repair allows more normal development of the midface. The age chosen for repair is a balance between these two opposing requirements. For this reason, some centers close the lip and soft palate early and leave the hard palate cleft until childhood. Repair is carried out using mucoperiosteal flaps, and intravelar veloplasty to re-orientate the muscles of the palate (Fig. 22.1). Particular attention is paid to the levator muscle of the soft palate because it is important for speech. The bony defect of the gum is corrected later with an alveolar bone graft, usually taken from the iliac crest.

22.1.2 Anesthesia for Cleft Lip Repair

The lip is repaired during early infancy to reduce scarring and help with maternal bonding and feeding. The airway is managed during general anesthesia with a south-facing oral RAE tube. Intubation can be awkward if the baby also has a cleft palate, and is discussed below. The surgeon will infiltrate the area with local anesthetic or perform bilateral infra-orbital blocks. Although this provides adequate

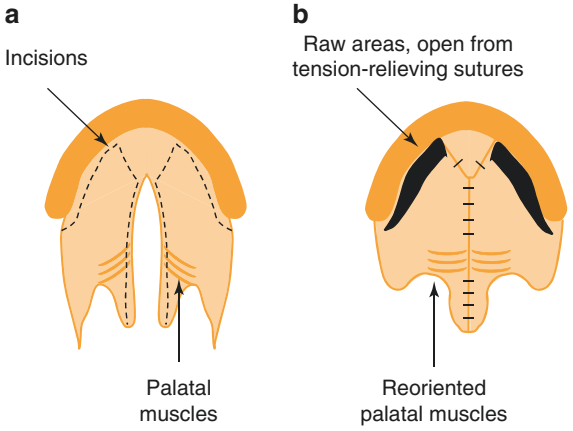

Fig. 22.1 Schematic of one of the surgical techniques used to repair cleft palate. (**a**) Isolated cleft of hard and soft palate, showing abnormal orientation of palatal muscles in the soft palate and surgical incision lines (dotted line). (**b**) Surgical repair of cleft palate using mucoperiosteal flaps and intravelar veloplasty. The repair leaves anterior raw areas that may bleed postoperatively

analgesia, intraoperative fentanyl may help to keep the baby settled and calmer in PACU. Although the lip defect has been closed, there is no major change to the infant's upper airway after surgery, which facilitates postoperative management.

22.1.3 Anesthesia for Cleft Palate Repair

There are several important issues for anesthetic care, mostly relating to the airway (Table 22.1). Intubation is usually straightforward, but may difficult in about 5% of cases—usually in children with a coexisting syndrome affecting the airway. Cleft palate babies are classically said to be awkward to intubate because the laryngoscope blade can fall into the cleft. However, this is not a common problem in practice, although it is more likely to occur if the cleft is left-sided. Techniques to avoid this problem include intubation using a laryngoscope with the broad Oxford cleft lip and palate blade, or using folded gauze to fill the cleft during intubation. Routine use of a videolaryngoscope would be a reasonable choice nowadays.

After intubation, the head is significantly extended to bring the hard palate almost parallel to the floor to facilitate surgical access. A mouth gag is inserted and the surgical site is extensively infiltrated with local anesthetic containing adrenaline (epinephrine) to reduce bleeding. Maxillary nerve blocks are used by some surgeons. Blood loss is usually low, but can be higher and a group and hold or crossmatch of blood is often performed before surgery. Tranexamic acid may be given, although without direct evidence of benefit.

Issues during surgery include the partial occlusion of the ETT by the gag, or desaturation due to coughing and poor ventilation. The latter occurs at a stage when the infant is no longer paralyzed, lightly anesthetized and surgical stimulation triggers reflex movement or coughing.

After surgery, the main concern is airway obstruction, which may occur for multiple reasons. Closure of the cleft results in a sudden and significant narrowing of the upper airway, especially in infants with a pre-existing syndromic airway—the nose is often blocked by secretions or blood, and there is usually bleeding into the mouth from the raw surfaces of the palate created when the oral mucosa is mobilized to close the cleft. Some centers place a nasopharyngeal airway or a cut nasal tube at the end of surgery to splint the nose and nasopharyngeal airway.

At the end of surgery, the aim is to extubate the infant awake but settled to minimize coughing and crying, which can worsen venous congestion and bleeding.

Table 22.1 Anesthetic issues for infants undergoing cleft palate surgery

Anesthetic issues for cleft palate repair
Infant anesthesia, possible coexisting syndrome
Difficult/awkward intubation
Occlusion of ETT by oral gag during surgery
Dramatic change in airway patency and resistance after surgery
Bleeding into mouth and airway during and after repair
Analgesia after surgery

Opioid analgesia during surgery will facilitate this, but must not make the baby too sedated or apneic. Clonidine or dexmedetomidine may be useful adjuncts. Arm splints are used to prevent the infant picking at the repair, but they often irritate the baby and make it more difficult to settle. An opioid infusion is commonly required for analgesia during the first 24 h. Infants are usually admitted to a higher-care area after cleft palate surgery to allow close observation for airway obstruction, bleeding and adequacy of analgesia.

22.1.4 Subsequent Surgeries

Children born with cleft lip and palate often require a series of procedures during childhood and adolescence (Table 22.2). They have often had a lot to do with hospitals, and some may benefit from premedication before induction, particularly children for alveolar bone graft who are older and more aware of their procedure.

About 15–20% of children with cleft palate require pharyngoplasty. This is performed in children with nasal-sounding speech and velopharyngeal incompetence. There are two common types of pharyngoplasty. In the first, a flap is raised from the posterior pharyngeal wall and is attached to the middle part of the soft palate, leaving two small, lateral passages for nasal breathing. In the second, the Jackson pharyngoplasty, the posterior tonsillar pillars are freed and rotated onto the soft palate, leaving a small, central passage. Children are older and larger at the time of this procedure, reducing the postoperative risk of airway obstruction from surgical narrowing of the airway. A longer-term effect of pharyngoplasty is obstructive sleep apnea.

Pharyngoplasty may affect subsequent nasal intubation. Some of these children subsequently require restorative dental treatment under anesthesia, and this treatment is facilitated by a nasal endotracheal tube. The pharyngeal flap can be badly damaged by the ETT as it passes through the nose. If nasal intubation is required in

Table 22.2 Children with cleft lip and palate often need a series of procedures during childhood and early adulthood

Typical age at time of procedure	Procedure	Comments
3 months	Cleft lip repair	Anesthesia of young infant
8–12 months	Cleft palate repair and ear tubes	Airway changes after surgery
5–6 years	Pharyngoplasty	
5–6 years	Revision palatoplasty	Soft palate lengthened with Z-plasty as alternative to pharyngoplasty
8–10 years	Alveolar bone graft	Pain from iliac crest donor bone graft site
18–20 years	Maxillary advancement	Complex maxillofacial surgery, at age when facial growth finished
22 years+	Rhinoplasty	Young adult, blocked nose and blood in airway postop

However most children do not need all these procedures

a child who has had a pharyngoplasty, consider contacting the previous surgeon who can describe the flap's robustness and the size and location of the orifice into the oropharynx. Guiding the ETT with a fiberscope is usually recommended, but this technique can still traumatize the flap if the scope is not advanced gently and under direct vision. An alternative is to pass a soft suction catheter through the nose into the oral cavity and railroad a softened and lubricated ETT over it.

Tip
If planning a nasal intubation in a school-aged child who has had a cleft palate repair, check if they have also had a pharyngoplasty.

22.2 Craniosynostosis Repair

Craniosynostosis is the premature fusion of one or more of the cranial sutures, stopping normal growth of the skull. This causes cosmetic changes and increased intracranial pressure, and may cause neurodevelopmental changes. Although commonly an isolated abnormality, 20% are associated with an identified syndrome or genetic disorder. Such syndromes include Crouzon's, Apert's, Pfeiffer's, and Saethre-Chotzen's. These usually involve multiple sutures and may affect the cranial vault and face, and are often associated with increased intracranial pressure.

Surgery for craniosynostosis is usually performed before the age of 12 months. Infants with a single, fused saggital suture may undergo spring cranioplasty, in which calibrated springs are applied across a strip craniectomy of the suture. These springs are normally removed 4–6 months later. Children with multiple sutures involved or abnormal bone shape are managed with cranial vault reconstruction. Although some children having this procedure have syndromes affecting the airway, the biggest challenge with these cases is managing blood loss that may equal one or two blood volumes. Venous air embolism is also a risk during surgery.

Keypoint
Early replacement of blood loss with non-crystalloid replacement (albumin/blood/blood products) is prudent to prevent a dilutional coagulopathy and maintain normovolemia.

Reconstruction of the cranial vault is performed with bifronto-orbital advancement, which involves an extensive incision and exposure of the cranium along with a frontal craniotomy and removal of a band of bone above the orbits. These bones are then individually cut, shaped and repositioned using wires and resorbable plates and screws. Posterior cranial vault reconstruction is performed for saggital synostosis presenting later in childhood. The child is prone during surgery, and sections of the skull are removed and reshaped before being repositioned.

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Pediatric Neuroanesthesia

23

Mairead Heaney

Despite the evolution of anesthetic and surgical techniques over time, the goals of pediatric neuroanesthesia remain unchanged—to provide effective anesthesia and analgesia, reduce intracranial pressure, maintain cerebral perfusion pressure, and to allow rapid recovery after surgery.

23.1 Anatomy

The child's brain and central nervous system is the fastest growing organ in the body. As in adults, brain tissue and extracellular fluid occupy 80% of the intracranial compartment, and cerebrospinal fluid (CSF) and blood occupy 10% each. The brain can grow during infancy because the cranial suture lines are not fused. The child's skull however, is pliable and incomplete, and offers less protection than an adult's. The posterior fontanelle closes by the second month of life. The anterior fontanelle stays open until approximately 18 months and it allows assessment of intracranial pressure (ICP) or ultrasound imaging of intracranial structures. The child's brain is incompletely myelinized, has a higher water content than an adult's, and is more homogenous and susceptible to diffuse axonal injury and cerebral edema. The blood brain barrier is freely permeable to water, and rapid changes in plasma osmolarity greatly affect the water content of the brain.

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23.2 Physiology

Compared with adults, neonates have lower, and children higher, cerebral blood flow (CBF) and cerebral metabolic oxygen consumption ($CMRO_2$) (neonate < adult < child) (Table 23.1). The pediatric brain is probably less tolerant to reduced cerebral blood flow than the adult brain. Cerebral autoregulation occurs, but the pressure limits of regulation are not known with certainty. In neonates and infants, the lower limit of autoregulation is closer to the baseline mean arterial pressure than in older children—a fall in neonatal blood pressure is likely to reduce cerebral blood flow.

Intracranial pressure in neonates and infants is normally between 0 and 6 mmHg. In older children and adults, the range is between 13 and 15 mmHg. In infants, a gradual increase in intracranial volume will expand the head with only a small increase in ICP, such as with hydrocephalus. If volume rises rapidly, however, the non-elastic pericranium and dura mater means ICP rises rapidly, ultimately causing herniation of the brain stem through the foramen magnum. In infants, an increase in intracranial volume of only 10 mL results in a 10 mmHg increase in intracranial pressure, which is the reason children rapidly deteriorate after intracranial hemorrhage. The cerebral perfusion pressure is lower in younger children than adults (Table 23.4).

Keypoint
When intracranial pressure gradually rises in an infant, the fontanelles bulge, the suture lines open and the increase in ICP is accommodated. When intracranial pressure suddenly rises in an infant, the inelastic pericranium cannot suddenly stretch, and just as in adults, the ICP suddenly increases.

23.3 Pharmacology

The inhalational and intravenous anesthetics have broadly the same effects on cerebral blood flow and $CMRO_2$ in children and adults. All inhalational agents increase CBF and reduce $CMRO_2$. Low concentrations of isoflurane and sevoflurane (less

Table 23.1 Differences between adult and pediatric brain blood flow

	Brain mass (% body weight)	Cerebral blood flow (mL/100 g brain tissue/min)	Percentage of cardiac output	$CMRO_2$ (mL/100 g/min)
Adult	2	55	15	3.5
Child	10	100	25	5.5
Term neonate	15–20	40		Lower than adult
Preterm neonate	15–20	12		Lower than adult

than 1 MAC) with ventilation to maintain normocarbia minimally affect CBF and ICP. Propofol is a cerebral vasoconstrictor that reduces CBF and $CMRO_2$ while preserving autoregulation in both children and adults. Ketamine does not increase ICP when ventilation is controlled, has favorable effects on cerebral perfusion pressure and may have neuroprotective effects. Fentanyl and remifentanil have only minor effects on CBF and $CMRO_2$ in children and adults.

23.4 Pediatric Brain Tumors

Intracranial tumors are the second commonest childhood cancer after leukemia.

23.4.1 Background

Most pediatric brain tumors are primary tumors and more than half occur in the posterior fossa. The peak incidence is between 3 and 8 years of age. The commonest types in the posterior fossa are medulloblastoma, pilocytic (low grade) astrocytoma, glioma and ependymoma (Table 23.2). Supratentorial tumors are more common in infants and older children.

Because of their location, childhood tumors present differently from adults. Children will often present with the triad of headache, nausea and vomiting (especially in the morning) and gait imbalance. Infants and young children may present with macrocephaly, or with fairly non-specific symptoms including vomiting, irritability, lethargy, failure to thrive, loss of developmental milestones or torticollis.

23.4.2 Assessment

The preoperative assessment focuses on identifying raised intracranial pressure and cranial nerve abnormalities. The preoperative MRI scan and the operative strategy

Table 23.2 Types of brain tumors in children and their incidence

Tumor type	Incidence
Posterior fossa tumors	55–60% (usually children 3–8 years)
Medulloblastoma (PNET of cerebellum)	20%
Pilocytic (low Grade) astrocytoma	20%
Brain stem glioma	15%
Ependymoma	5%
Supratentorial tumors	40–55% (usually infants and older children)
Astrocytoma	15%
Glioblastoma	10%
Midline	
Craniopharyngioma	5%
Optic glioma	3%

PNET primitive neuroectodermal cell tumor

should be discussed with the neurosurgeon, including positioning and potential complications. Posterior fossa tumors can delay gastric emptying and involvement of the cranial nerves can lead to an impaired gag reflex. Potential issues during surgery include the need for reduction in brain mass, blood loss, hemodynamic changes and electrolyte abnormalities. Supratentorial tumors are usually resected in the supine position with the head slightly elevated, whereas posterior fossa tumors are resected in the prone position. The sitting position is now rarely used in children, as they are even more likely than adults to have air embolism in this position.

It would be easy to say that sedative premedication should be avoided due to the potential for respiratory depression in children with brain tumors. These children however, have often been through multiple procedures in a short period of time, and the child and their parents are justifiably anxious about the neurosurgery procedure. Judicious use of premedication can often be considered in all children except those with critically raised ICP, who often have a depressed level of consciousness in any case.

23.4.3 Induction

Anesthesia may be induced by the IV or inhalational route. Although an IV induction might be desirable in a child with raised ICP, a smooth gas induction is preferable to repeated attempts to obtain an IV in an upset child with raised intracranial pressure. In addition to standard monitoring, an arterial line, large bore IV access and urinary catheter are inserted once the child is asleep. A central venous catheter is often inserted, most commonly in the femoral vein to avoid obstruction to cerebral venous drainage. A nasogastric tube may be inserted to drain gastric secretions during prolonged anesthesia. A south facing oral endotracheal tube (ETT) or armored orotracheal tube is used if the child is supine during surgery. An armored ETT will affect MRI scans if they are planned during or after surgery.

If the child will be prone for surgery, meticulous attention is paid to fixing the ETT in position. A nasal ETT can be more securely fastened than an oral tube, and is commonly used in prone children. In infants, a throat pack may be inserted to help stabilize the tube within the pharynx and to stop secretions loosening the tapes on the ETT. The pack is left part way out of the mouth so it is not left in after anesthesia. Ventilator tubing is secured to the operating table so that its weight does not dislodge the endotracheal tube. The head is placed in pins for prone positioning in children older than 3–4 years, but younger children have a thin cranium and the headrest is used instead.

23.4.4 Maintenance

Both volatile and intravenous anesthetic techniques are commonly used. There is no evidence to recommend one volatile agent over another in children. However, the volatile should be maintained at less than 1.0 MAC to minimize the effect on cerebral blood flow. There are concerns with high-dose propofol in children for

prolonged periods (propofol infusion syndrome), but the dose can be reduced with concomitant remifentanil or volatile agent. Dexamethasone and anticonvulsants should be continued intraoperatively.

A potentially life-threatening complication of posterior fossa surgery is venous air embolism. Venous air emboli are detected very commonly when sensitive Doppler techniques are used. These techniques are so sensitive however, that even microbubbles in IV fluid are detected and cause false positives. The majority of venous air emboli are too small to be clinically significant. If hemodynamic compromise occurs (hypotension and loss of end tidal carbon dioxide) the surgical field should be flooded with saline, and air may be aspirated if there is a central venous line positioned in the right atrium (although this is not commonly successful at removing air). Negative intrathoracic pressure should be avoided and muscle paralysis ensured.

Surgery in the region of the pituitary, such as resection of a craniopharyngioma, may cause intraoperative diabetes insipidus. This will cause polyuria and if the urine output cannot be matched with dextrose-saline solutions and the serum sodium and osmolality increase, intravenous DDAVP or a vasopressin infusion may be required. Surgery around the brain stem may cause bradycardia or blood pressure changes.

Unless the brain is very edematous and surgery very complicated, patients are generally woken and extubated at the end of the case. Whatever anesthesia technique is employed, a rapid smooth emergence is desirable to allow early neurological evaluation. Posterior fossa surgery is much more painful than supratentorial surgery and painful muscle spasms occur postoperatively. Some children develop posterior fossa syndrome for a period of time after surgery. It includes combinations of cortical blindness, mutism, ataxia, irritation and nerve palsies.

23.5 Anesthesia for Children with Traumatic Brain Injury (TBI)

Injury is the leading cause of death of children in most developed countries, and 40% of these deaths are due to traumatic brain injury. There are two phases to traumatic brain injury. The first is the mechanical damage occurring at the time of injury. The secondary injury is caused by an inflammatory process resulting from a complex interplay of several events including hypoxia, raised ICP, cerebral edema, hydrocephalus, hyperglycemia and infection. The brain of a young child has incomplete myelinization and a high water content. As a result, blunt head trauma in children often results in diffuse axonal injury and diffuse cerebral edema. This diffuse process can be worsened by physiologic insults, most often hypoxia and hypotension.

Intracranial and extracranial collections are much less common in children than in adults. Children nevertheless undergo surgical procedures after brain trauma, including insertion of an external-ventricular drain (EVD), evacuation of extradural, subdural or intracerebral hematomas, or decompressive craniectomy for management of refractory intracranial hypertension. They also undergo surgery for extracranial injuries. The most important aspect of anesthesia is control of ICP and maintenance of cerebral perfusion pressure. Hypoxia and hypotension have been

shown repeatedly to worsen outcome in head injured patients. Glycemic control is also important as hyperglycemia has been shown to worsen neuronal injury. These children will generally not have had their cervical spines cleared (see Chap. 25, Sect. 25.4) and therefore maintenance of spinal precautions is vital.

Note

Brain trauma in children tends to cause a diffuse axonal injury with subsequent edema and raised ICP. Intracranial and extracranial collections of blood are much less common than in adults.

23.5.1 Control of Intracranial Pressure

If measured, ICP should be maintained below 20 mmHg. If a monitor is not in place it may be estimated from the imaging studies. Steps to control ICP are outlined in Table 23.3. Cerebral perfusion pressure should be maintained at an appropriate level for the child's age (Table 23.4). This may require fluid boluses, central venous access and administration of pressors such as noradrenaline (norepinephrine) 0.1–0.5 μg/kg/min. If ICP is refractory medical therapy, a decompressive craniectomy may be considered.

Table 23.3 Overview of steps that can be used to control ICP in children

System	Steps to control ICP
Physical	Confirm raised ICP: ensure transducers are correctly positioned and zeroed Head up 30° Avoid neck vein obstruction: head in neutral position, no constricting ETT tapes Drain CSF if EVD in situ Ensure ETT is not obstructed by secretions and no bronchospasm
Physiological	Temperature control: avoid hyperthermia and in emergency consider active cooling 33–35 °C Maintain adequate oxygenation Maintain CO_2 low normal (35–40 mmHg; 4.7–5.3 kPa). In emergency consider hyperventilation CO_2 25–30 mmHg; 3.3–4 kPa (temporizing measure only) Avoid hyponatremia, in emergency consider hypertonic saline 3% 3mL/kg Avoid hypovolemia
Pharmacological	Ensure adequate sedation and paralysis Seek and treat seizures Osmotherapy: hypertonic sodium chloride 3% 3mL/kg, or mannitol 20% 0.25–0.5 g/kg (given slowly to avoid hypotension) Steroids if brain tumor, avoid steroids if TBI (increase mortality) Consider barbiturate coma if standard treatments fail
Surgical	Drain any intracranial collection Consider decompressive craniectomy

Table 23.4 Target cerebral perfusion pressure (CPP) in children of different ages

Age	CPP target (mmHg)
Infant	>40
Child (1–10 years)	50
Adolescent (10–16 years)	50–60
Adult (>16 years)	50–70

23.6 Neural Tube Defects (Spina Bifida)

Neural tube defects are birth defects of the brain and spinal cord. They include spina bifida (myelomeningocele), in which the fetal spinal column fails to close during the first trimester. Maternal antenatal folate supplements have reduced the incidence of neural tube defects. Spinal nerve involvement causes at least some paralysis of the legs. Some defects are covered by skin and have less neural involvement (lipomyelomeningocele, lipomeningocele and tethered cord). Neurosurgery and plastic surgery are performed within the first day or two of life to cover the defect and prevent infection or rupture. Induction can be in the lateral or supine position (as long as the lesion is surrounded by padding to prevent rupture).

Surgery is performed in the prone position. Large lesions may require rotational flaps with the potential for significant blood loss. Wound infiltration with local anesthetic and paracetamol are sufficient for analgesia and these infants can usually be extubated postoperatively. Postoperative apnea is a concern and these infants are all monitored in the NICU.

Most children with myelomeningocele have Chiari malformation and require a ventriculo-peritoneal shunt for hydrocephalus. More than 70% of children with neural tube defects are sensitive to latex, possibly due to immune changes rather than direct exposure to latex. These children will frequently have multiple surgeries (VP shunt, orthopedic, scoliosis, bladder, bowel) during childhood and latex precautions should always be observed (See Chap. 12 Sect. 12.11).

23.7 Hydrocephalus

Hydrocephalus is due to an imbalance between CSF production and absorption. Most hydrocephalus in children is congenital and causes include aqueductal stenosis, hemorrhage, infections, and Arnold-Chiari malformation. Over 50% of infants with intraventricular hemorrhage and 20% of children with posterior fossa tumors develop permanent hydrocephalus requiring shunting. The ventricles become dilated, and in infants there is a disproportionate increase in head size. Patients with hydrocephalus will present to theatre for insertion of a ventriculoperitoneal shunt (lateral ventricle to peritoneum) or endoscopic ventriculostomy.

23.7.1 Anesthesia for Ventriculoperitoneal (VP) Shunt Insertion

A large proportion of children having surgery for a VP shunt are neonates and babies having their initial shunt. The ICP is not markedly raised because of the compliance of the infant skull, and routine volatile anesthesia is commonly used. Intubation may be awkward if the head is large but this can be overcome by raising the infant up from the table on a rolled towel ensuring the neck is not flexed. Older children with a blocked VP shunt needing revision are often unwell and have raised ICP. In this group of patients, increases in ICP during anesthesia and intubation are minimized. Hypotension and bradycardia may occur when the shunt is inserted and the CSF pressure suddenly relieved. Tunneling the shunt's catheter from the head down through the neck to the abdominal wall may cause tachycardia and hypertension. The entire length of the abdominal component of the shunt is inserted to allow for linear growth of the child, and as CSF circulation changes significantly in the first few years of life shunts now have a programmable valve which allows adjustments to be made to titrate the shunt's flow rate to the growing child's need. An important point to remember is that patients with VP shunts in situ who present unwell to hospital should be considered to have a blocked shunt until proven otherwise and may require emergency shunt revision.

23.7.2 Chiari Malformation

There are several types of Chiari malformation, which are a spectrum of congenital hindbrain abnormalities affecting the structural relationships between the cerebellum, brainstem, cervical spinal cord, and the bones of the base of the skull. Type II Chiari malformation is usually associated with spina bifida—the posterior fossa is shallow and the cerebellar tonsils, fourth ventricle and brainstem herniate through the foramen magnum into the upper cervical canal. These changes obstruct CSF flow, causing a syringomyelia of the spinal cord, as well as brainstem compression causing respiratory and cardiovascular changes. Treatment is craniectomy with expansion of the foramen magnum and a laminectomy of the first cervical vertebra (C1) (Fig. 23.1). The neck is still stable after this procedure.

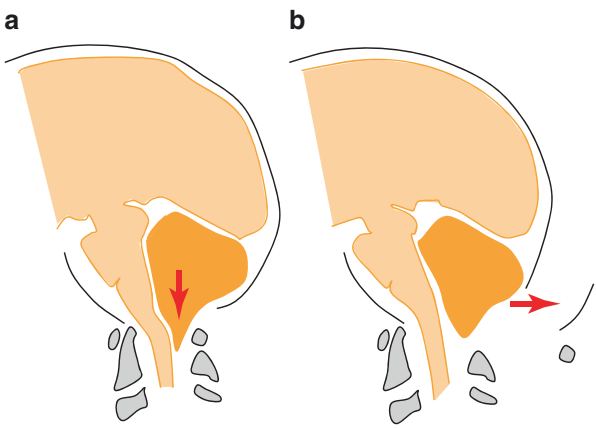

Fig. 23.1 (**a**) The Type II Chiari malformation with herniation of the cerebellum and brainstem into the upper cervical spinal canal. (**b**) After craniectomy with widening of the foramen magnum and C1 laminectomy, relieving pressure on the brainstem

Review Question

1. A 10 year old boy has been knocked unconscious by a blow to the head with a hockey stick and has arrived at your pediatric hospital. After appropriate initial management, a CT scan has shown an extradural hematoma. Discuss your anesthetic management for craniotomy.

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Anesthesia for Ophthalmic Surgery

24

Elaine Christiansen

Children may need general anesthesia for procedures that would be performed awake in adults, such as examination or refraction of the eyes, removal of superficial foreign bodies and cataract repair. Common procedures include strabismus surgery, tear duct surgery and management of the penetrating eye injury. Most of these children are well, but some may be very young or have associated syndromes. Anesthesia depth affects the intraocular pressure and eye position.

24.1 Airway Management

The airway can often be managed with an LMA. Considerations are size of the child, access to the airway should a problem arise during the procedure, duration of the procedure and adequacy of the airway obtained if an LMA is chosen initially. Full-head draping is often used during eye surgery and its removal to urgently access the airway is awkward and introduces the risk of wound infection.

24.2 Oculocardiac Reflex

The oculocardiac reflex is bradycardia, junctional rhythm or even asystole caused by traction on the extraocular muscles or compression of the eyeball. It occurs most commonly during strabismus surgery or enucleation. Anecdotally, the reflex is most likely to be triggered when traction is applied to the medial rectus muscle. The

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afferent path of the reflex is via the trigeminal nerve to the motor nucleus of the vagus nerve, from which efferent impulses affect the sino-atrial node. The incidence is increased when propofol is used for maintenance of anesthesia.

The oculocardiac reflex is very common, but severe bradycardia (30–40 bpm) is less common. Bradycardia gradually improves over a minute or two and usually resolves quickly if the stimulus is stopped. Sometimes, atropine or glycopyrrolate may be required. Pharmacologic treatment is not always needed and depends on the severity of the bradycardia or arrhythmia and the child's hemodynamic state. Treatment, particularly with atropine, often results in tachycardia and hypertension unless small, judicious doses are titrated over a short period. Although some would routinely use anticholinergics to prevent the oculocardiac reflex developing, this is not generally necessary due to the potential for side-effects from these drugs and the potential for masking heart rate responses as an indicator of depth of anesthesia or analgesia requirements.

Tip

The oculocardiac reflex can be frightening—there may only be one or two QRS complexes on the ECG screen! Ask the surgeon to stop traction on the muscle and check that there is still a plethysmograph trace from the oximeter to indicate a pulse is present. Prepare to give atropine 10–20 μg/kg if the heart rate does not quickly improve, or if the reflex recurs despite more gentle muscle traction next time.

24.3 Examination Under Anesthesia of the Eyes

Examination of the eyes under general anesthesia (EUA) may be required when a child is too young or uncooperative to allow examination while awake. EUA may be done to assess conditions such as retinoblastoma and congenital cataracts, or to screen for glaucoma or refraction errors. An inhalational technique with spontaneous ventilation is used, and the procedure is usually performed in a darkened room. Most anesthetic drugs, including sevoflurane and propofol, reduce intraocular pressure (IOP) by several mmHg. The effect on IOP is maximal soon after induction, when anesthetic depth is maximal. Some ophthalmologists will allow for this while measuring the IOP and others will measure IOP as the child awakens. Ketamine increases IOP by 2–3 mmHg. It is an alternative for anesthesia because some consider the IOP after ketamine is more reflective of the IOP in the awake child. Ketamine is not an ideal anesthetic agent because it may cause dysphoria and nausea. Children being screened for glaucoma often have multiple check-ups over time, and a pleasant anesthetic experience is important to maintain the child's cooperation with subsequent anesthetics. Hypoxia and hypercarbia also increase intraocular pressure but mild changes produce clinically insignificant effects.

24.4 Tear Duct Surgery

Blocked lacrimal ducts are relatively common in babies and young children. Patency is restored by probing and syringing the tear duct. This is a short procedure allowing good access to the airway so an LMA is often used. Saline or fluoroscein is used to syringe the duct and enters the pharynx, so this needs to be suctioned away at the end of the procedure. Dacrocystorhinostomy is sometimes performed to create a patent tear duct if attempts at probing fail. It is often a long procedure with fluid and blood entering the pharynx so endotracheal intubation is often used.

24.5 Strabismus Surgery

Strabismus, or squint, is caused by an imbalance of the extraocular muscles so that the visual axes of the two eyes are not parallel. Surgical correction involves shortening or changing the insertion position onto the globe of one or more of the extraocular muscles. The airway can be managed with either an LMA or an ETT, but access to the airway during surgery is limited. The advantages of the LMA include a smoother induction and emergence and less postoperative coughing.

The oculocardiac reflex (OCR) is common in squint surgery. It is a trigeminal (ophthalmic division)-vagal reflex. It most commonly causes a sinus bradycardia, but can also cause junctional or other brady-arrhythmias. It is less likely if traction on the eye muscle by the surgeon is gentle and gradual, and the reflex fades over time. It is more common with anesthetic techniques that are associated with a reduced heart rate, including propofol, remifentanil and fentanyl. It is more likely during light planes of sevoflurane anesthesia compared to deep planes. Atropine given prophylactically causes a tachycardia, making assessment of depth and response to surgery more difficult. If OCR occurs, the surgeon can be asked to temporarily release the muscle, and atropine given if required. Small, incremental doses of atropine are preferable, as larger doses may cause severe hypertension and tachycardia.

Nausea and vomiting (PONV) occur in 50–70% of children when no antiemetic is given, and prophylaxis is routinely given. The greater the number of eye muscles repaired, the greater the likelihood of PONV. Ondansetron 0.15 mg/kg with dexamethasone 0.15 mg/kg decreases the incidence of PONV (Fig. 24.1). Propofol anesthesia is as effective as the administration of dexamethasone and ondansetron in the prevention of PONV, but the incidence of the oculocardiac reflex is higher in propofol-based techniques. In practice, the oculocardiac reflex is not a great problem, and propofol anesthesia together with antiemetics and IV fluids facilitate day-stay strabismus surgery.

Effective analgesia is required as the eyes are sore and itchy after surgery. Opioids can be avoided to reduce PONV, but this may result in the child being very unsettled afterwards—there is usually ointment in the eyes and the child cannot see

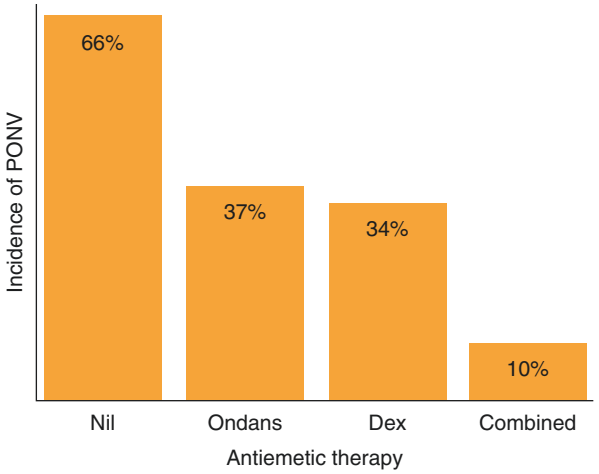

Fig. 24.1 Incidence of PONV after strabismus surgery in children with no antiemetic, ondansetron alone, dexamethasone alone, or ondansetron combined with dexamethasone. Based on data from Shen YD et al. Pediatr Anesth 2014;24: 490–8

Table 24.1 Concerns during anesthesia for strabismus surgery

Anesthesia for strabismus surgery
Head drape and limited access to airway
Oculo-cardiac reflex is common, increased by TIVA
High incidence PONV—double antiemetic, IV fluids, propofol anesthesia beyond toddler age group
Multimodal analgesia to reduce opioid dose

clearly for a short while after awakening. Therefore, opioids are usually given during surgery to aid emergence. The important concerns for anesthesia of children for strabismus surgery are listed in Table 24.1.

Note
Strabismus surgery is associated with the oculocardiac reflex and PONV. Propofol is often used for maintenance to reduce PONV, but may increase the oculocardiac reflex.

24.6 The Penetrating Eye Injury

Anesthesia for the repair of a penetrating eye injury may need to proceed without adequate preoperative fasting. The management of these unfasted patients has been a controversial issue due to long-held concerns regarding the potential for extrusion of intraocular contents with anesthesia induction and suxamethonium weighed against the need to secure the airway as quickly as possible. The controversy of this issue has declined with the acceptance of modified rapid sequence induction, in which the airway is secured at the time of best conditions rather than after a predetermined time (see Chap. 1, Sect. 1.6.3).

Suxamethonium increases intraocular pressure for up to 10 min, but there have been no documented cases of extrusion of ocular contents after its use in patients with an open globe. Non-depolarizing relaxants do not increase IOP, but there are concerns about the child coughing if intubation is attempted too soon. Laryngoscopy and intubation also increase IOP, and this increase can be attenuated by a short acting opioid such as alfentanil. In practice, it is thought that the problem of IOP increasing with anesthesia may have been overstated. After all, children with a penetrating eye injury have usually cried and rubbed their eyes, both of which increase the IOP. A reasonable approach to anesthesia in these children is a modified rapid sequence induction using a dose of propofol at the upper end of its dose range, a non-depolarizing relaxant, gentle ventilation during cricoid pressure with high concentration of volatile agent while taking care that the face mask is not pressing against the eye. The aim is to avoid light anesthesia and incomplete paralysis and coughing.

Review Questions

1. A 3 years old penetrated his eye with sharp scissors 3 h ago, soon after finishing his dinner. The child has an IV in situ and is otherwise well. How will you anesthetize this child?
2. What are the anesthetic issues in a healthy child undergoing squint surgery? The child develops a sinus bradycardia rate 38 during surgical traction on the eye muscle. What will you do?
3. Would an LMA be reasonable as airway management during anesthesia of a 1 year old undergoing EUA of the eyes?
4. Would an LMA be reasonable as airway management during anesthesia of a 1 year old undergoing an intraocular lens replacement?

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Trauma and Burns

25

Mary Hegarty

Trauma is the leading cause of morbidity and mortality in children aged over 1 year, accounting for 40% of all deaths. Children who survive serious injuries are often left with permanent disabilities which may be life-changing for the child and their family. Whilst the management of children after trauma follows the same principles as adults, there are unique features of pediatric trauma.

Children are at risk of injury because of their curiosity, risk taking behavior and lack of fear. Their small size means trauma is more likely to impact on multiple organs. Children have greater elasticity of their connective tissue, so shearing forces may cause tearing of major blood vessels and mediastinal structures. The flexible nature of a child's skeletal system means that greenstick fractures are more common, and significant organ damage can occur with no overlying fractures. For example, blunt chest wall trauma may not result in rib fractures, but the force sustained during trauma may cause extensive injury to the thoracic organs. The abdominal wall of a child is less protected by fat and subcutaneous tissues so intra-abdominal organs are more prone to injury than in the adult population.

Physiological compensation may mask clinical signs of deterioration. This can lead to a delay in the recognition of injury and failure to respond appropriately to subtle clinical signs, particularly when there may be little external evidence of injury. Children may rapidly decompensate if these subtle signs are missed, so continual reassessment is required (Table 25.1). Caution is therefore advisable when administering opioids and anesthetic drugs, which have the potential to cause cardiovascular instability in the injured child with unrecognized and untreated shock.

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Table 25.1 Normal values for physiological variables in children. Expected systolic blood pressure = 80 + (age in years × 2) mmHg

Age (years)	Heart rate (bpm)	Systolic blood pressure (mmHg)
<1	110–150	70–90
2–5	95–140	80–100
5–12	80–120	90–110
>12	60–100	100–120

Keypoint
The flexible skeleton of children allows them to withstand severe forces without incurring fractures. There may be few outward signs of injury when in fact there are severe internal injuries. Repeated reassessment of the child's clinical condition is imperative.

Keypoint
Children possess robust compensatory mechanisms, so a high index of suspicion for serious injury should be maintained even when a child appears initially stable. Once clinical signs of injury become evident this is often at a late stage when cardiac arrest may be imminent.

25.1 Types of Injury

Injuries in children tend to follow set patterns according to age and gender. As children grow, they increase in size and their body proportions change. With age, muscle mass increases and the body is able to withstand the effects of blunt trauma better.

Falls and transport-related incidents are the leading overall causes of injury, followed by accidental poisoning and burns. In children under 5 years, suffocation, drowning and burn injuries are more prevalent, whilst intentional self-harm, suicide and assaults are an increasing problem in adolescents. The commonest traumatic injuries in children are falls and transport-related incidents, and children have the highest death rates of occupants in motor vehicles (Table 25.2). In pedestrian incidents, younger children hit by a car are more susceptible to thoracic and abdominal trauma than adolescents because of their low center of gravity, whilst older children are more likely to incur to limb injuries as their center of gravity is higher. Children are less visible to drivers, and driveway-reversing accidents are relatively common in pre-school age children. Head injuries cause the greatest mortality in children. Infants are particularly vulnerable as they have large heads with thin cranial bones, less head and neck control and incomplete myelination of brain tissue. Falls from a height, suffocation, drowning and burns are more likely to occur in children younger than 5 years. Two thirds of trauma related injuries occur in males, which may be related to a higher incidence of risk taking behavior.

Table 25.2 Causes of pediatric trauma

Causes of trauma
Transport related injuries
Falls
Drowning
Burns
Accidental poisoning
Non-accidental injury
Self-harm/suicide
Assaults

Keypoints

Pediatric trauma is different because:

Children have a smaller body size resulting in different patterns of injury.

Internal organs are less protected and more vulnerable to trauma.

There are anatomical differences e.g. airway, cervical spine.

They have a large body surface area and are more likely to lose heat and fluids.

Greater distribution of force is more likely to result in multi trauma than a single organ injury.

Increased metabolic rate and smaller functional residual capacity makes them more vulnerable to hypoxia.

Greater airway resistance and smaller airway diameter makes respiratory impairment more likely.

The large head in comparison to body makes head injuries more common.

Because they are able to increase systemic vascular resistance and heart rate to compensate for losses, children maintain their blood pressure until >30% blood volume is lost, causing sudden irreversible shock if not recognized early.

25.2 Initial Management

Advance preparation of drugs and equipment can be done if there is sufficient warning of an incoming trauma patient. Some centers use Broselow tapes to estimate the child's weight and to determine drug doses and equipment sizes without any calculations (see Chap. 7, Sect. 7.1.4). The initial evaluation should identify life-threatening problems, using a primary survey followed by a secondary survey. The primary survey starts with assessment and control of the airway including cervical spine control followed by assessment of breathing and circulation. Appropriate life-saving interventions, such as endotracheal intubation, should be performed during the primary survey if indicated.

It is vital to uncover the child to ensure that a thorough secondary survey is performed and that no injuries are missed, but hypothermia from prolonged exposure must also be avoided. Infants have impaired thermoregulation and children have a larger surface area to body mass ratio so are more susceptible to heat loss than adults. Consider the use of warmed fluids, cling wrap, space blankets, forced air warmers and passive humidification of ventilator gases.

Keypoint
The important first steps during the initial management of the child with trauma are to establish a clear airway, give oxygen, immobilize the cervical spine, control any bleeding and immobilize any fractures to minimize blood loss.

Table 25.3 Indications for intubation and ventilation in pediatric trauma

Indications for intubation and ventilation in pediatric trauma
Airway obstruction unrelieved by simple airway maneuvers
Risk of aspiration due to loss of airway reflexes
Inadequate ventilation (e.g. secondary to chest trauma)
Hypoxia
Control of $ETCO_2$ in head injuries
Transfer of patient (e.g. CT scan, inter-hospital transfer)
Anticipated airway obstruction (e.g. burns)

25.2.1 Airway

Intubation is needed if there is airway obstruction, depressed conscious state or if the child is combative and unmanageable (Table 25.3). Children are more at risk than adults from edema of the upper airway caused by burns for example. A common problem is the use of an uncuffed endotracheal tube (ETT) that is too small and has an excessive leak preventing effective ventilation. Cuffed tubes are now more commonly used. When planning to intubate, it is important to prepare the appropriately sized equipment and to consider the choice of anesthetic agent that will be used to induce anesthesia. In the child with shock, ketamine may be preferable to propofol, or otherwise propofol in reduced doses. Suxamethonium is safe to use in children with head injuries and children with burns less than 24–48 h old.

25.2.2 Breathing

Chest trauma is usually caused by blunt trauma and there are usually associated injuries. Severe intra-thoracic injuries can occur without any obvious external signs on the chest. The main cause of cardiac arrest is respiratory failure. Children have a small respiratory reserve and may tire easily. Children who are tired will eventually have a decreased respiratory rate as a sign of an impending respiratory arrest. In children with chest trauma, respiratory compromise may be from direct injury to the chest wall or indirectly from shock or head injuries. Gastric distension may be caused by bag-mask ventilation and impedes ventilation, avoided by the insertion of gastric tubes to decompress the stomach early in resuscitation.

25.2.3 Circulation

Children have excellent compensatory mechanisms and will remain normotensive until they have lost 25–40% of their blood volume. Consequently, hypotension

indicates severe blood loss. Tachycardia and peripheral vasoconstriction are earlier signs of hypovolemia—an important early sign is cool, clammy and mottled extremities (Table 25.4). The blood volume should be calculated early in resuscitation (Table 25.5). An algorithm for the initial management of hypovolemia is shown in Fig. 25.1.

Table 25.4 Hypotension is a late sign of hypovolemia in children due to their low resting sympathetic tone and excellent compensatory mechanisms

Signs of impending circulatory failure in children
Altered mentation (irritable, confused, combative, lethargic.)
Cool, clammy and mottled extremities
Prolonged capillary refill time >3 s
Poor urine output
Tachycardia or bradycardia
Poor pulse volume
Sunken fontanelle in children <1 year

Earlier signs of hypovolemia should be sought

Table 25.5 Normal blood volumes in children of different ages

Age group	Blood volume (mL/kg)
Preterm babies	100
Neonates	90
Infants and children	70–80

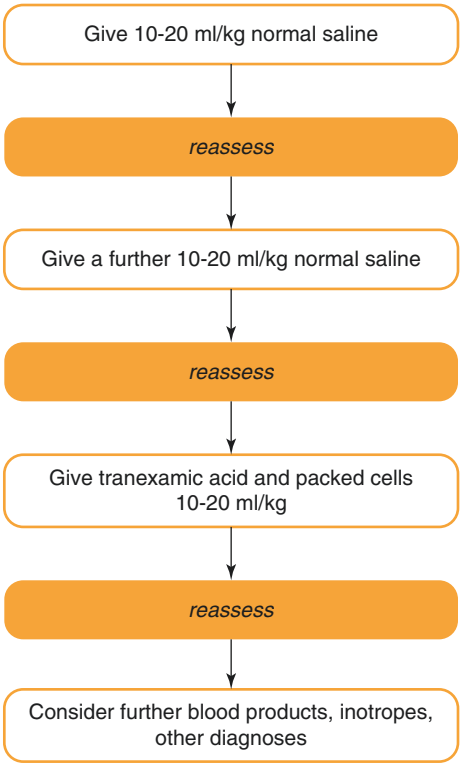

Fig. 25.1 An algorithm for the initial management of hypovolemia in children

Keypoint
Blood pressure measurements are an unreliable indicator of shock in the pediatric patient. Children can compensate for 25–40% loss of their blood volume. Hypotension indicates severe blood loss.

Intravenous access in the arms or legs may be difficult, and an intraosseous needle inserted in the tibia if not fractured, should be considered early. The saphenous vein at the ankle is a vein that can be cannulated by landmarks alone—it is found just in front of the medial malleolus (there is a groove in the malleolus where the vein runs). Central venous access should only be performed by those skilled and familiar with the technique, but the femoral vein is a possible site for the occasional operator as it has a low risk of complications at the time of insertion (see Chap. 28, Sect. 28.4).

Massive transfusion in children is defined as red cell transfusion of 50% of the total blood volume (TBV) in 3 h. Most hospitals now have a critical bleeding protocol to facilitate the supply of large amounts of blood products to a critically bleeding child. In time-critical situations, uncross matched O-negative blood or type-specific blood should be considered to avoid delay (see Chap. 5, Sect. 5.8.2). A fluid warmer is added to the IV fluid system as early as possible. As blood loss continues, coagulation is monitored with point of care devices such as ROTEM.

In a critical bleeding situation, tranexamic acid (TXA) should be administered early, with a loading dose of 15 mg/kg followed by an infusion of 2 mg/kg/h. Packed red blood cells are given at a dose of 10–20 mL/kg with cryoprecipitate at 5 mL/kg or human fibrinogen concentrate 70 mg/kg. Guided by laboratory tests, the patient may then require further packed red blood cells at a dose of 20 mL/kg with platelets at 10 mL/kg with or without fresh frozen plasma (FFP) 15 mL/kg (Table 25.6). It is important to consider the critical triad of massive blood loss—hypothermia, acidosis and coagulopathy. In addition, calcium gluconate 30 mg/kg may be required to treat hypocalcemia.

Tip
Always remember to keep the child WARM, SWEET and PINK—remember to exclude hypoglycemia and avoid hypothermia.

Table 25.6 A guide to blood product administration in children

Administration order	Blood product	Dose
1	TXA	15 mg/kg
2	Cryoprecipitate	5 mL/kg
3	Platelets	10 mL/kg
4	FFP	15 mL/kg

25.3 Head Injuries

Half of children with major trauma have a head injury, and head injuries cause up to 40% of trauma deaths in children. Head injuries are common in children as they have a large head, prominent occiput and weaker neck muscles. Their brains are less able to tolerate acceleration and deceleration forces due to poor buoyancy within the CSF, thinner craniums and the delayed closure of the fontanelle at 12–18 months of age. The injury in children tends to be a diffuse axonal injury with cerebral edema rather than the focal collections seen in adults. Signs of raised ICP are similar to those in adults (Table 25.7). Head injury outcomes are better in children than in adults with similar pathology, so aggressive early management is essential (see Chap. 23, Sect. 23.5).

The Glasgow Coma Score is not well validated in children, and is not reliable in children younger than 1 year. There is a modified version for pediatric trauma, which takes into account the age and the developmental stage of the child (Table 25.8). An alternative scoring system is the AVPU (Table 25.9).

Table 25.7 Signs of increased ICP in children

Signs of raised ICP
Decreased level of consciousness—be wary of the silent child
Irritability
Unequal pupils
Dysconjugate gaze
Vomiting
Seizures
Cushing's response

Table 25.8 The Glasgow coma scale, modified for children

Modified pediatric GCS scoring system		
Motor response	Verbal response	Eye opening
6. Spontaneous	5. Babbles, coos	4. Eyes open spontaneously
5. Localises to pain	4. Consolable cry	3. Eye opening to shouting
4. Withdraws to pain	3. Inconsolable cry	2. Eye opening to pain
3. Flexion to pain	2. Grunts or moans	1. No eye opening
2. Extension to pain	1. No verbal response	
1. No motor response		

Table 25.9 The AVPU scoring system is used as an alternative to the GCS to assess head injuries in children

AVPU scoring system
A: alert
V: responds to voice
P: responds to pain
U: unresponsive

Management of head injury in children follows the same principles used for adults. Children most at risk should be identified early and child with a GCS <9 should generate a trauma call and retrieval to the nearest pediatric neurosurgical center.

25.4 Cervical Spine Clearance

Cervical spine injuries only occur in 1–2%. In children under the age of 8 years, transport-related accidents are the most common cause of neck injuries. At this age, they have a large, heavy head on a neck with poorly developed muscles and lax ligaments. This affects the upper cervical spine especially, so spinal injury in children usually occurs at the higher level of C1 or C2. Many of these high cervical injuries result in death at the scene of the accident, so it is rare to see them in the hospital setting. Children older than 8 years tend to have a more adult pattern of injury with cervical spine injuries affecting the lower cervical vertebrae, and most commonly from sports-related activities. Non-accidental injuries involving shaking can lead to whiplash type injuries and are more likely to occur in babies.

Keypoint
Unconscious children with an injury to the head, neck or upper torso area and all children involved in high speed motor vehicle accidents should be assumed to have a spinal injury until proven otherwise.

To assess a child for a C-spine injury, they must be alert, cooperative and of a sufficient developmental age for assessment (Table 25.10). After taking a history to elicit symptoms of pain or neurological deficit, a gentle palpation of the neck in the posterior midline and lateral regions of the neck is undertaken. Active range of neck movements can be performed by the patient if there is no midline tenderness or

Table 25.10 Indications for C-spine immobilization in children

Indications for C-spine immobilization
Fall from height >3 m
Pedestrian or cyclist collision >30 km/h
Passenger in MVA >60 km/h
Fall from horse
Reverse driveway collision
Ejection from vehicle
Severe electrical shock impact
Neck pain and/or limited neck movement
Suspicious mechanism of injury i.e. significant head, neck or upper torso injury
Traumatic torticollis
Distracting injury with suspicious mechanism
Neurological deficit
Reduced level of consciousness
Substance affected, with suspicious mechanism
Prior history of C-spine injury or neck problem

Table 25.11 Technique for immobilization of C-spine in children

Immobilization technique
Apply manual in-line immobilization
Apply an appropriately sized collar
Collars may be inadvisable in the uncooperative child, where the correctly sized collar is unavailable and in children with torticollis
In the intubated patient, lateral bolsters e.g. rolled up towel can be placed either side of the collar

Table 25.12 Steps required to clear the cervical spine in children

C-spine clearance
Alert, asymptomatic children with normal examination can be cleared without need for radiology
Children with symptoms and/or signs require plain X-ray (AP, lateral and Odontoid peg views)
Children with impaired level of consciousness require careful evaluation and discussion with pediatric radiologist
Children with a neurological deficit or who are intubated require neurosurgical consult
Plain X-rays may need to be supplemented by CT ± MRI

abnormal neurological findings on the initial examination. If the child can move their neck without pain or neurological symptoms then the collar may be removed and the C-spine cleared. All C-spine assessment, clearance and radiological investigations should be performed in conjunction with an experienced senior clinician. If the C-spine is unable to be cleared, then immobilization is necessary (Table 25.11).

Keypoint
Manual in line stabilization (MILS) should be performed until a collar can be applied. The use of sandbags and tapes is no longer recommended. The choice between a hard or soft collar varies in different institutions.

The C-spine can be cleared once a history and examination have been done and the relevant investigations have been performed (Table 25.12). There is a low probability of injury if on examination the child has no midline tenderness and no focal neurological deficit, but the child must be alert, asymptomatic and have no distracting injuries to make this assessment. Clinical assessment is often difficult in young patients, however, and interpretation of C-spine x-rays requires knowledge of pediatric normal variants. For example, pseudo-subluxation at C2/C3 is a normal finding in 24% of children under the age of 8 years. It may therefore be necessary to seek advice from a pediatric radiologist, as important injuries to exclude are fractures, ligamentous injuries and spinal cord injuries.

The best decision-making assessment tool to determine when imaging should be utilized in children under the age of 16 years is NEXUS (National X-ray Utilization Study). The Canadian C-spine rule is not validated for use in children. Current recommendations for imaging in patients who cannot be cleared are for 2-view radiographs in children <9 years and for 3 view radiographs in children >9 years of age. CT imaging is recommended as the first line investigation in obtunded children

<10 years. MRI is indicated for obtunded children with a suspicious mechanism of injury, in those with a neurological deficit and in the presence of equivocal radiographs or CT images.

Tip
In the uncooperative child, attempting to enforce rigid immobilization can cause more harm to the spinal cord. In this instance, apply a collar if possible and allow the child to adopt their own position until they are comfortable.

25.4.1 Spinal Cord Injury Without Radiographic Abnormality (SCIWONA)

SCIWONA is an injury in children defined as the presence of objective signs of cervical spinal cord damage without radiological evidence of fracture or ligamentous instability of the cervical spine. This occurs due to the elasticity of the spinal cord and a more tenuous blood supply to the spinal cord in the pediatric population. It is more common in children than adults, and accounts for about two thirds of severe cervical injuries in children younger than 8 years. It is primarily caused by flexion and extension injuries, but a combination of lateral bending, axial loading, rotation and distraction may also be implicated. MRI is the investigation of choice for investigation of soft tissue injuries of the C-spine and should be requested if there is evidence of a focal neurological deficit.

Tip
In children with SCIWONA, a normal X-ray or CT scan does not exclude a spinal cord injury.

The mechanism of injury provides a clue to an increased risk of C-spine pathology—for example children injured as a result of falls from height, diving accidents, high speed motor vehicle accidents and any children with head, neck or back trauma are at risk of having a C-spine injury. An MRI of the spine may reveal SCIWONA, particularly if there is hemorrhage or edema of the spinal cord or evidence of subluxation. This type of spinal cord trauma is generally regarded as a stable injury and management involves specialized multidisciplinary care with immobilization of the C-spine in the immediate period and thereafter for up to 3 months. Some cases will require surgical stabilization.

Tip
When intubating a child, it is preferable to remove the collar and perform MILS until the airway has been secured. The collar can then be replaced.

25.5 Non-accidental Injury

Child abuse is a common cause of traumatic injury in small children, especially babies under 6 months of age. The affected child may be undernourished and unkempt with signs of neglect. There may be evidence of multiple bruising and old injuries. The patient is often withdrawn and difficult to engage (Table 25.13). In cases of suspected non-accidental injury, a detailed history, examination and documentation of the reported injury is mandatory. If non-accidental injury is suspected it is the responsibility of all health care workers to report their findings to the appropriate authorities (see Chap. 29).

25.6 Burns

Burn injuries are very common in children, but the commonest type of burn is different in different age groups. There are several differences of children affecting burn management in them compared to adults (Table 25.14).

25.6.1 Type of Injury

Seventy percent of burns in children are due to scalds caused by hot drinks or from hot water immersion. Scald injuries tend to be superficial and may often be managed conservatively. Contact burns occur in ambulant children, such as toddlers, who may place their hands onto an electric heater or sustain friction burns from devices such as treadmills. Older children are more likely to suffer from flame burns, which

Table 25.13 Indicators of non-accidental injury in children with trauma

Non-accidental injury in trauma
Injuries inconsistent with history
Child reports adult harm
Multiple injuries of differing ages
Delayed presentation
Unusual injuries (significant bruising, well demarcated burns, perianal or genital injuries, retinal hemorrhages, multiple fractures, intra-oral injuries)
Subdural hematoma
Injury to internal organs with no history of major trauma

Table 25.14 Differences in children affecting burn management compared to adults

Difference in children
Prone to airway edema
Vascular access more difficult
At risk of hypothermia
High metabolic rate and may become very catabolic
Prone to hyponatremia

Table 25.15 Burn types suspicious of non-accidental injury

Burn Injury pattern in NAI
Burns to sole, palms, buttocks, perineum
A well demarcated burn or burns in a pattern
No splash marks with a scald burn
Symmetrical burns
Restraint marks or bruises on limbs
'Doughnut sign'—area of spared skin surrounded by scald burn
Other signs of neglect or previous trauma

may be associated with inhalational injuries and concomitant trauma. These types of burn are more likely to be full thickness and require surgical intervention. Up to 10% of burns are due to non-accidental injury, so a high index of suspicion is necessary when taking the initial history and examining the child. Detecting NAI is important as repeated injuries are common and up to 30% of these children will subsequently die (Table 25.15).

25.6.2 Physiology of Burns in Children

Large burns, greater than about 10–15% of body surface area (BSA), cause a systemic response due to the release of cytokines and other inflammatory mediators. The larger the burn area, the larger the systemic response. There is an initial fall in myocardial contractility and cardiac output, and systemic vasoconstriction that may affect the perfusion of essential organs. Capillary permeability is increased and there is loss of intravascular proteins and the development of interstitial fluid edema. Pulmonary pathology results from direct inhalational injury or indirect systemic effects which may cause interstitial edema, impaired cilia function and inactivation of surfactant. Inflammatory mediators can cause bronchoconstriction, even in the absence of inhalational burns, and in severe cases ARDS. The systemic response includes formation of extra-junctional receptors on muscle membranes and a hyperkalemic response to suxamethonium.

Basal metabolic rate increases threefold a few days after large burns. The child enters a catabolic state and early enteral feeding is important to counter this. It is vital to ensure that repeat visits to theatre for dressing changes, debridement and grafting do not interrupt nutrition unnecessarily. In children with large burns requiring numerous surgeries, continuous naso-jejunal feeding may be more appropriate as this allows anesthesia with shorter fasting intervals than oral intake. Some children develop burn encephalopathy, which may cause hallucinations, agitation and delirium. This can also be associated with raised intracranial pressure and hypertension.

25.6.3 Assessment of Burn Injury

Estimation of the burnt area is important because it determines the need for specialist referral and transfer of the child. Children who need referral for specialist plastic surgical assessment include those with more than 5% full or partial thickness burns,

chemical and electrical burns, inhalational injury, children with pre-existing medical conditions or concomitant trauma, and infants and children with burns to the face, hands, perineum or feet.

The size of the burnt area also guides fluid requirements in resuscitation. However, estimating the size of a burn in children can be difficult. In adult burns the rule of nines is often used, but for children and infants the head is proportionately larger (nearly 20% of BSA), and the trunk and legs proportionately smaller. Age-specific burn diagrams are available to assess area (such as the Lund and Browder chart), but the easiest method is to use the palm of the child's hand (palmar aspect including fingertips) as an estimate of 1% BSA. More recently, free smartphone apps have been developed (e.g. BurnMed® or Mersey Burns®) to estimate burn area and guide fluid resuscitation.

25.6.4 Airway Assessment in Burns

Airway assessment should begin with the history surrounding the injury and an examination to identify the patients at risk of airway compromise. Children with burns need regular observation of their respiratory rate and work of breathing. A history of inhalational burns in enclosed spaces should alert to the possibility of carbon monoxide poisoning or cyanide toxicity. Pulse oximetry may be inaccurate if there is carboxyhemoglobin present in the blood. Normal carboxyhemoglobin level is <13% and toxic levels >25%.

Management of the compromised airway in a burns patient includes oxygen, early intubation and transfer to a specialist pediatric burns center. There should be a low threshold for intubation in children with evidence of airway compromise. It is important to remember that in children with large burns not involving the airway there may be still be airway compromise as a result of systemic effects on pulmonary physiology. Cuffed endotracheal tubes may be preferable in these children, as their airway diameter may change as swelling occurs. Also, pulmonary pathology and decreased lung compliance mean that higher ventilation pressures may be required which will be difficult to achieve in the presence of a large leak around an un-cuffed tube.

Tip
When selecting an endotracheal tube for intubation of the child with burns, allow for later airway swelling. A cuffed tube may be preferable. There is no need to shorten endotracheal tubes for children, particularly in burns children who may develop marked facial swelling.

25.6.5 Fluid Management in Burns

Fluid management in burns aims to maintain adequate circulating volume and organ perfusion, particularly renal function. Electrical burns or crush injuries add the possibility of myoglobinuria and the risk of renal failure. Intravenous access may

become more difficult when swelling occurs in the burnt areas, so it is important to obtain access at an early stage. It is preferable to place the cannula through unburnt skin if possible or to consider alternatives such as intraosseous access if the child has large areas of burns.

Fluid therapy consists of resuscitation and maintenance fluids. In infants, the maintenance fluids should contain dextrose, and blood glucose monitored regularly. IV fluids should be started in all children with burns more than 10% BSA and should be calculated from the time of injury. There is no clear evidence as to whether crystalloids are better than colloids in the fluid management of burns. Most burns centers currently use crystalloid for initial resuscitation in the first 24 h, adding colloid (usually albumin) thereafter.

The volume of fluid required is estimated using various formulae. These formulae are only guides and require ongoing clinical assessment using acid base status, urine output, CVP, blood pressure measurements and the arterial waveform. Generalized edema is a significant problem in major burns, and the aim of fluid management is to maintain euvolemia and avoid excessive fluid. Assessment of fluid status is done hourly in the early stages of fluid management. Resuscitation is adequate when the child is comfortable, easily roused, with warm distal extremities, an adequate systolic blood pressure (80 mmHg + 2 × age in years), pulse rate 80–160, and urine output of 0.5–1 mL/kg/h.

The modified Parkland Formula (3–4 mL × kg × % burn; Table 25.16) is commonly used, with 50% of the estimated fluid requirements given in the first 8 h since the time of the burn and the remaining 50% given in the next 16 h. However this formula commonly underestimates fluid requirements in children under 10 kg—more fluid is needed in younger children because they have higher fluid and calorie requirements relative to weight. Children with inhalational burns, electrical burns or delayed presentation to hospital may have increased fluid requirements. A urinary catheter should be considered in all children with moderate to severe burns and a urine output of 0.5–1 mL/kg/h should be the aim. A nasogastric tube may also be useful to prevent gastric distension and for nutritional purposes later on.

Most children with burns injuries can tolerate oral fluids, and after the initial resuscitation intravenous fluids can be converted to oral. After the initial 24 h of fluid resuscitation, fluid replacement therapy should be guided by urine output,

Table 25.16 Modified Parkland formula to estimate fluid resuscitation volume for children with burns

Modified parkland formula
3–4 mL/kg Hartmann solution × % burn
Therefore, for a 20 kg child with 25% burns: Resuscitation fluid = 4 × 20 × 25 = 2000 mL in 24 h from the time of the burn 50% should be given in the first 8 h = 1000 mL in 8 h = 125 mL/h Maintenance fluid = 100 mL/kg for first 10 kg + 50 mL/kg for second 10 kg = 1500 mL in 24 h = 62.5 mL/h Therefore, in the first 8 h, fluid requirements = 125 mL + 62.5 mL = 187.5 mL/h

serum electrolytes and hemoglobin. Children with more severe burns may require longer term IV therapy. Care should be taken to avoid hyponatremia, particularly in younger children.

Blood losses during burns surgery can be large and difficult to monitor, with blood loss being proportional to the amount of necrotic tissue that is to be removed. It is estimated children can lose approximately 3% of their blood volume for every 1% burn surface area excised. Blood should be cross matched preoperatively and potential losses should be discussed with the burns surgeon. Measures to reduce intra-operative blood loss during burns surgery include the use of tourniquets, infiltration with adrenaline (epinephrine) containing local anesthetic solutions, electrocautery and good surgical technique.

25.6.6 Anesthesia and Pain Relief for Burns

Children with burns may require frequent visits to theatre for dressing changes, debridement and grafting. Early wound excision and grafting has been shown to improve survival rates. A thorough pre-operative assessment, with particular emphasis on airway assessment, fluid volume status and aspiration risk (burns patients are at increased risk of gastric stasis due to their injury and opioid analgesia) should be done. Pre-operative hemoglobin and electrolyte levels, coagulation studies and cross match will be required for major burns surgery. For some children, the experience of frequent procedures can cause anxiety and distress. This may be alleviated by explaining the process to the child in language they understand and having a low threshold for using premedication (see Chap. 9, Sect. 9.3.4).

Suxamethonium may be used in the first 24–48 h after a burn, but should be avoided thereafter for up to 2 years post burn injury to prevent hyperkalemia. Children with burns have an increased dose requirement for non-depolarizing muscle relaxants. The optimal first dose is 30–50% higher than the normal dose and is related to the depth and size of the burn. Consideration should also be given to intra-operative monitoring, temperature control and IV access which may be challenging in children with larger burns.

Tip
Children with burns commonly require anesthesia. Have a low threshold to use premedication, and a low threshold to use an opioid infusion for postoperative analgesia.

Children with burns benefit from multi-modal analgesia, with intravenous morphine being the first line treatment. Their analgesia requirements are often surprising high. Management is aided by ensuring analgesia is adequate before the child wakes up from anesthesia, and liberal use of IV rather than oral analgesic techniques. A caudal block is often useful to cover the donor site for skin grafts.

25.6.7 Psychosocial Issues

Families may feel guilt after their child has had a burn injury or trauma injury. It is important to keep the family involved and informed about what is happening during the management of their child. Allow the parent or guardian to be with the child as much as possible. This has benefits both for the child and the family member. It is often a frightening time for a child who may have a fear of strangers, suffer separation anxiety and will often have a poor understanding of what is happening to them.

Review Questions

1. A 20 kg child suffered 20% full thickness burns 6 h ago. What would be the optimum volume of crystalloid fluid resuscitation for the first hour?
   (a) 160 mL
   (b) 260 mL
   (c) 360 mL
   (d) 460 mL
   (e) 660 mL
2. A 2 year old child has burns to lower body from immersion into a hot bath. Describe your assessment and management of pain in the first 24 h following injury. Describe your assessment of a 5 year old child, who has been rescued from a house fire.
3. A 4 year boy was injured in a traffic accident. On arrival at hospital, he has weak pulses and an unrecordable BP. Peripheral IV cannulation was unsuccessful. What are the alternative routes of vascular access and outline the disadvantages and complications of these routes?

Further Reading

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Malignancy and Treatment of Malignancies in Children

26

Bruce Hullett

Children with cancer have multiple anesthetics during their treatment. Their clinical state may be related directly to the cancer or to the complications of therapy and they may be very unwell at times. The children and their families are under considerable stress and require an empathic approach from all of their health care providers

Cancer is uncommon in children compared to adults—15% of all cancer occurs in children, half of which occurs in children 4 years and younger. Cancers however are the second commonest cause of death in children after trauma (road accidents and drowning). One third of all cancers are leukemia, and 1 in 5 cancers are CNS tumors, although the different cancers occur at different rates in various age groups (Fig. 26.1). Childhood cancers have a survival rate higher than for adults, approaching 85% for hematological malignancies.

Although the commonest cause of pain in children with cancer is chemotherapy treatment, these children report that medical procedures or surgery cause the

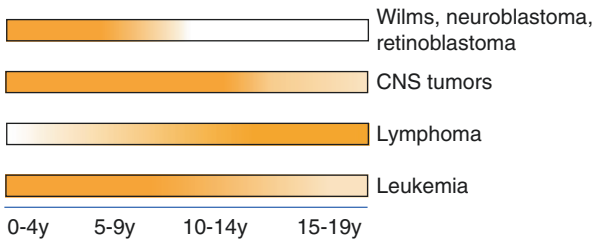

Fig. 26.1 Incidence of the commonest tumor types in different age groups. Darker shading indicates higher incidence. Adapted from Steliarova-Foucher E. Lancet Oncology 2017;18: 719–31

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worst pain during their treatment. General anesthesia during medical procedures such as lumbar punctures and bone marrow biopsies avoids this pain—anesthetists can make a huge contribution to the care of these children by reducing the most severe pain during cancer treatment. Anesthetists may also provide IV access, anesthesia for imaging procedures, surgical tumor resection, radiotherapy and pain management.

The issues arising in the oncology patient vary over the course of their treatment. Direct effects of the tumor give way to systemic effects of treatment—particularly hematopoietic effects of chemotherapy that can result in potentially life-threatening complications. Pain is often present at the time of diagnosis, but its character may change as therapy is begun and pain from procedures and mucositis become predominant. Many children participate in oncology trials that follow set treatment protocols. These protocols may be compromised by issues such as anesthesia not being available at the correct time in the treatment cycle, or simply by using dexamethasone as an antiemetic.

26.1 Chemotherapeutic Agents

Chemotherapy is based on the age of the child and the type and stage of the tumor. It may be used alone or in conjunction with surgery or radiotherapy. Chemotherapy has significant side effects, and multiple agents are usually used to improve outcome and reduce toxicity. Chemotherapeutic agents may be considered either as conventional agents directed at rapidly dividing cancer cells by various mechanisms, or as more modern molecularly targeted agents directed at tumor cell receptors or specific processes such as angiogenesis or immunomodulation. Conventional agents are commonly used at maximally tolerated doses, whilst molecular target agents have greater specificity with possibly fewer side effects. Many of these drugs, however, are in early development and their full potential is yet to be realized. Corticosteroids are also commonly used in treatment for their cytotoxic, immunosuppressive and antiemetic properties. Suppression of the hypothalamic-pituitary axis is common.

Chemotherapy is used to treat the commonest childhood leukemias—acute lymphatic leukemia (ALL) and acute myeloid leukemia (AML). The treatment for ALL is more protracted than for AML and has 3 phases—induction and intensification lasting about 1 month each, followed by a maintenance phase lasting 1 or 2 years. Treatment includes intrathecal methotrexate or cytarabine, which has decreased the need for central nervous system radiotherapy and its longer-term effects on neurodevelopment and body growth. The treatment of AML requires more aggressive chemotherapy with an increased risk of complications, but treatment is shorter and without a maintenance phase. Hematological malignancies with poor prognostic features or that have relapsed may be considered for a stem cell transplant if a suitable donor can be found.

26.1.1 Toxicity

Chemotherapeutic agents cause myelotoxicity with anemia, neutropenia and thrombocytopenia, as well as gastrointestinal toxicity with nausea, vomiting and mucositis. Toxicity may also affect every other organ system in the body. Myelotoxicity often causes anemia that may require transfusion before surgery, depending on the clinical status of the child. Transfused blood is usually leucodepleted to reduce fevers and infection, and irradiated to stop donor T-cell replication and reduce graft vs. host disease. Thrombocytopenia may delay procedures such as lumbar puncture or line insertion. Platelet levels of 30,000/μL or higher are usually acceptable in these children, although the lower acceptable limit varies as evidence-based guidelines are lacking. Children with severe leucopenia are vulnerable to infection and sepsis, and strict attention should be paid to aseptic techniques during anesthesia care. Many of these children have long term surgical IV lines (Hickman, Broviac, Portacath, Infusaport) that need to be accessed carefully to avoid infection—the anesthetist should wash their hands, clean the access point, wear gloves and use a no-touch technique to access the device. Early placement of indwelling venous devices reduces the need for multiple peripheral IV lines, reduces the child's anxiety, and allows recovery from the surgical insertion before the effects of chemotherapy become problematic.

Fortunately for anesthetists, the oncology team are very experienced with the toxicity and problems from these chemotherapeutic agents and are careful to monitor for them and manage them. The anesthetist is usually alerted to their presence. Some chemotherapeutic agents have specific effects on organ systems—the most important are outlined in Table 26.1.

26.1.2 Tumor Lysis Syndrome

This syndrome results from the massive release of intracellular contents from tumor destruction at the start of chemotherapy. It most commonly occurs with leukemias

Table 26.1 Effects of chemotherapy on specific organ systems side effects

System	Drug	Comment
Cardiac	Doxorubicin Daunorubicin Cyclophosphamide Cisplatin, 5-fluorouracil	Rhythm abnormality, cardiomyopathy
Pulmonary	Bleomycin	Pneumonitis, non-cardiogenic edema (may be increased by supplemental oxygen) Fibrosis
	Mitomycin	
	Methotrexate	Pneumonitis, bronchospasm, effusion
Nervous system	Cisplatin	Sub-clinical neuropathy

and high-grade lymphomas where there is high tumor mass and rapid early response to treatment. It results in hyperkalemia, hypocalcaemia, hyperphosphatemia and hyperureacemia, which in turn can cause arrhythmias, seizures, multi-organ failure and death. A lactate dehydrogenase level (LDH) greater than 1000 U/L indicates tumor lysis in children. It is prevented with hyperhydration, urinary alkinization and supportive measures. Allopurinol inhibits xanthine oxidase and reduces the conversion of xanthine and hypoxanthine to uric acid, and may be used preventatively. Rasburicase is used to treat hyperuraecemia. It is a recombinant form of urate oxidase which converts uric acid to allantoin, which is readily excreted in the urine. Steroids should be avoided in newly diagnosed children at risk of tumor lysis, because it can be precipitated by even a single dose of dexamethasone.

26.1.3 Mucositis

Mucositis is the inflammation of gastrointestinal mucosa as a result of chemotherapy, or of radiation to the head and neck. The inflammation may occur anywhere in the GI tract from the mouth to the anus, causing ulceration and pain. The pain can be severe and usually begins after 3–5 days of chemotherapy, peaking a few days later before gradually subsiding. It can be severe enough to require IV opiates at high doses and possibly supplementation with adjuncts such as ketamine. The ulcerated and inflamed mouth and oropharynx means instrumentation of the airway should be done with care. It can rarely be so severe that airway obstruction becomes a concern.

26.1.4 Stem Cell Transplant

Anesthesia is usually required to harvest bone marrow from an allogenic, HLA-matched donor. Autologous transplants are possible but carry the risk of reintroducing malignant cells to the patient. Short-term side effects of stem cell transplant are related to bone marrow ablation from high dose chemotherapy. Late complications include graft versus host disease, endocrine changes, bone damage affecting growth, and secondary cancers.

26.2 Radiotherapy

Radiotherapy usually requires frequent, or even daily, treatments for 2–6 weeks. Treatment occurs in an environment that is often not familiar to the anesthetist, and not normally equipped to deal with anaesthetized patients, let alone children. The radiotherapy beam is highly focused and requires careful positioning of the child. If the radiation is to the neck or head, a plastic stabilizing device placed on the head to guide the beam may limit access to the airway. The child needs to be completely still for a few minutes while the treatment is given, and monitored from outside the room because of the radiation dose.

Oral sedation can be given to the child to facilitate the procedure but there are problems with reliability of effect, onset of sedation relative to the time of procedure and prolonged sedation after the (brief) treatment. Furthermore, there are often time pressures on the treatment sessions, with limited ability to delay other cases while waiting for a child to become settled in the treatment room. Anesthesia is therefore usually required for children younger than 6 years. These children often have long term IV access in situ, and an intravenous anesthetic technique is often preferred as it avoids the need for anesthetic machine and issues regarding waste anesthetic gases. From a practical point of view, minimizing the number of staff involved provides some anesthetic consistency and a better experience for the child and parents.

26.3 Anesthesia for Short Oncology Procedures

Although some children with cancer will have major surgery for tumor removal, most children will have multiple anesthetics for short diagnostic or therapeutic procedures. These are procedures that would often be performed without anesthesia in adults, but for which children will not remain still or tolerate while awake. Leukemia and lymphomas are the most common of childhood cancers and children with these usually first undergo anesthesia for diagnostic bone marrow aspiration, lumbar puncture and central venous access.

26.3.1 Patient Welfare

The importance of the child's psychological welfare cannot be overstated. Many oncology patients will require multiple anesthetics during their therapy. The time around diagnosis is particularly difficult for the family and so it is important to make the process as smooth as possible right from the start. Some time spent by the anesthetist at this stage will benefit the child, family and health care providers down the track. It is important not to hurry assessment and discussion, and extra care taken with the behavioral management of the child. Oncology families become very informed about all aspects of their child's care, which can be very useful in summarizing a complex medical history for an anesthetist caring for the child for the first time. Newly diagnosed patients and families are obviously stressed and for 'routine' low risk anesthesia, a restrained discussion of anesthetic risks should be considered.

26.3.2 Anesthesia Techniques

Anesthetics will often involve a particular routine and special requests, as the child may have had many anesthetic experiences to compare. Inspection of previous records is useful in providing consistent care and avoiding pitfalls or recurrence of minor morbidity. This is best done before preoperative assessment where possible to help reassure the parents that you are up to speed with their child's case.

Most anesthetics are for short, stimulating diagnostic procedures. This facilitates an intravenous anesthetic technique which has a better recovery profile than volatile-based anesthesia (less emergence delirium, less PONV). Propofol with a short-acting opioid such as remifentanil or alfentanil improves immobility and reduces total propofol dose. Some children come to hate the taste or feel of IV propofol, and this can be reduced by giving it slowly, especially if via a central line.

Note
Take great care with aseptic technique when accessing surgical lines, and take great care to flush the line after anesthetic drugs have been given—about 20 mL is needed to completely flush an Infusaport. The line will also need to be flushed with heparinized saline if not being used after anesthesia. The concentration of heparin used depends on the length of time before next access is planned.

26.4 Anterior Mediastinal Mass

The anterior mediastinum is the space between the sternum and middle mediastinum. It contains the thymus and some lymph nodes. In the middle mediastinum are the heart, great vessels and tracheobronchial tree. Tumors in the anterior mediastinum surround and may compress the tracheo-bronchial tree, the SVC, or the pulmonary trunk or artery. These tumors can cause life-threatening problems at induction of anesthesia. Lymphomas are the commonest tumor in this location in children. The initial anesthetic in these children is of tissue diagnosis—usually either bone marrow aspiration or biopsy of a lymph node in the neck. This is a very high-risk anesthetic, and treatment to shrink the tumor usually cannot begin until the tissue diagnosis is made. The commonest cause of the mass, T cell (Hodgkin's) lymphoma, responds very quickly to chemotherapy, reducing the tumor mass and anesthetic risk. This rapid response raises the question of whether to begin treatment without a tissue diagnosis. In reality, treatment is rarely started before definitive diagnosis, for fear of never obtaining a satisfactory tissue sample to confidently direct treatment.

26.4.1 Consequences of Anterior Mediastinal Masses

Anterior mediastinal masses compress the structures in the middle mediastinum, particularly when the child is supine. The tracheobronchial tree and great vessels may all be compressed. The larger the mass, the more likely it will cause compression. Children younger than 1 or 2 years are at even higher risk due to their small

airway diameter and very compliant airways. Compression of the airway over time may lead to tracheo-bronchomalacia, which further predisposes to airway obstruction during anesthesia. The pulmonary artery is protected by the aorta, but may still rarely be compressed. The pericardium may be infiltrated by tumor, causing effusion or pericarditis. The aorta is usually spared because of its intraluminal pressure and location. Compression of structures is less of a problem in adults because the tracheo-bronchial tree is more calcified and rigid.

The symptoms of tracheal compression are stridor, reduced exercise tolerance, wheeze and especially orthopnea and supine cough. A child who is reluctant to lay flat is likely to have significant airway compression. Compression of the superior vena cava causes facial swelling and plethora, especially in the morning after lying flat during the night. Syncope during valsalva (such as during bowel action) is a particularly worrying sign, as it indicates inability to compensate for reduced venous return. A lack of symptoms is reassuring but does not does exclude serious risks from anesthesia.

Keypoint
Anesthesia for a child with an anterior mediastinal mass can be life-threatening. The risk comes from compression of the great vessels and airways. Muscle paralysis with the child supine is a consistent cause of problems.

26.4.2 Investigations

Chest X ray demonstrates the size of the mass and pleural effusions. Sometimes the tracheobronchial tree can be seen clearly enough to visualize any airway compression and pleural effusions. Many centers routinely perform echocardiography to search for great vessel compression, pulmonary outflow tract obstruction and pericardial effusion. It is an important investigation, as cardiovascular involvement increases the risk of morbidity and mortality. It gives dynamic information and can be performed in an upright position if the child is unable to lie down. A CT scan is useful to assess airway compression-if the trachea is compressed more than 50%, intraoperative airway obstruction is more likely. Unfortunately, CT scans usually require anesthesia in young children and the risk involved needs to be balanced against the additional information gained. New scanners are able to perform very fast, partial scans that may provide some information without the need for anesthesia. Respiratory function testing will reveal obstruction with flow-volume loops, but is seldom performed as it is difficult in small, uncooperative children, and has a poor correlation with the degree of airway obstruction. Clinical features that indicate extreme risk and high desirability to avoid general anesthesia entirely are listed in Table 26.2.

Table 26.2 Factors that indicate extreme risk of anesthesia in children with anterior mediastinal mass

Important risk factors
Stridor, orthopnea or syncope
Large tumor >4 cm or mass to mediastinal ratio >45%
Tracheal compression >50% or main bronchi compressed on CT
Signs of SVC obstruction or vessel compression on echocardiogram

General anesthesia is best avoided if at all possible if these factors are present

Table 26.3 Key considerations for safe anesthesia for cervical lymph node biopsy in a child with anterior mediastinal mass

Anesthesia for the child with anterior mediastinal mass
Communication and consultation with all specialties involved
Thorough assessment to allow risk stratification and planning
Consider performing biopsy awake with local anesthesia in older children
Maintain lung volume: – Consider semi-recumbent or sitting position for anesthesia and surgery – Avoid muscle relaxants – Maintain spontaneous ventilation with CPAP – Use local anesthetic to facilitate 'light' general anesthesia – Consider anesthesia using ketamine and dexmedetomidine to maintain FRC
Fluid load to maintain cardiac filling pressures in face of SVC obstruction – IV access in leg if SVC obstruction suspected
Plan for options if obstruction occurs – Lateral or prone positioning – Rigid bronchoscopy – Vasoconstrictors or inotropes for CVS collapse

26.4.3 Induction

General anesthesia usually requires the child to be supine, which is often poorly tolerated. Induction of anesthesia relaxes airway and chest wall muscles and reduces functional residual capacity (FRC) of the lung. If the child is positioned supine and muscle relaxation used, lung volume falls further and reduces forces that may have been holding the mass off vital structures while the child was awake. Induction may then precipitate airway obstruction or cardiovascular collapse. The key considerations for anesthesia are listed in Table 26.3. Maintaining lung volume is the over-arching principle, and of the techniques to achieve this, maintaining spontaneous ventilation is particularly important as it produces a negative intrapleural pressure that expands the airways. The requirement to maintain spontaneous ventilation means that many of these cases are performed using a LMA for airway maintenance.

If obstruction develops, there are several options. Changing to a lateral or prone position is simple and readily performed. Intubation is an option, but there are concerns that either the ETT will not be able to pass through the compressed trachea, or the site of compression may be distal and not able to be bypassed by an ETT. It

is therefore usually recommended that an ENT surgeon is available to perform rigid bronchoscopy. Cardiovascular collapse and cyanosis may respond to fluid loading, but vasoconstrictors to increase systemic vascular resistance and restore preload to both ventricles may be better. Cardiopulmonary bypass is not a realistic option given the speed at which deterioration occurs.

Review Questions

1. How do anterior mediastinal masses cause airway obstruction or cardiovascular collapse under anesthesia?
2. Why is it important to maintain spontaneous ventilation during anesthesia in children with an anterior mediastinal mass?
3. What are four factors which indicate higher risk in children with anterior mediastinal mass?
4. What procedures are followed at your hospital to reduce the risk of line infection when anesthetic drugs are given through central lines to oncology patients?

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Procedural Sedation: Anesthesia and Sedation of Children Away from the OR

27

Tanya Farrell

Young children often need sedation for diagnostic or therapeutic procedures. The number of procedures is increasing as technology improves and many are performed in areas away from the operating room. Demand for sedation is also increasing because of cultural changes suggesting it is not acceptable to restrain children or subject them to frightening or painful procedures whilst awake. In addition, children presenting for some diagnostic procedures may have poorly delineated pathology and be quite unwell. The demand for sedation places pressure on the resources of anesthetic services, and techniques that do not require an anesthetist are often used. This chapter discusses the issues and techniques to safely sedate children for medical procedures.

27.1 Remote Location

Many diagnostic or therapeutic procedures are performed remote from the OR in areas as diverse as radiology, neurophysiology or oncology wards. These areas are usually poorly designed for anesthesia, with bulky equipment, poor lighting and often limited access to the child. Staff in these locations may be unfamiliar with anesthetic protocols and priorities. Extra vigilance is required when checking patient preparation and fasting, equipment, emergency supplies and the recovery area. Occasionally, procedures on children are carried out in adult hospitals due to limited facilities and expertise in smaller children's hospitals. The lack of assistance and equipment on site and the transfer to and from the parent hospital add another element of risk.

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27.2 Typical Procedures Requiring Sedation

Procedures such as echocardiograms, MRI scans and EEGs are not painful, but require the child to remain still for extended periods of time in an uncomfortable and frightening environment. Older children can cooperate, particularly if they are distracted. Babies up to 3 months old can usually be fed and wrapped up warmly—most will fall asleep (incredibly!) during the examination. Some children, especially preschool aged, can be difficult to image adequately while awake. Other diagnostic and therapeutic procedures such as lumbar punctures, bone marrow biopsies, nephrostomy insertion, and endoscopies are painful and require analgesia as well as sedation. These procedures, particularly those that are intermittently painful, are more difficult to provide safe sedation for—doses of agents sufficient to make the child comfortable during painful stimulation may then leave them excessively sedated or even apneic when the stimulation is removed.

Keypoint
It is difficult to safely provide sedation for painful procedures in children, particularly when the pain is intermittent.

27.3 Sedation Versus General Anesthesia

The aims of sedation are to safely reduce fear and anxiety, increase compliance with the procedure and to control pain if necessary. Sedation has traditionally been described as a continuum from consciousness to unconsciousness (Table 27.1). The endpoints of the different levels of this continuum however, are arbitrary and subjective. Personnel involved in monitoring sedation may not appreciate the levels are not discrete and are difficult to assess in young children who are also susceptible to fluctuations between the levels. There is also a dilemma in assessing sedation in children—rousing a settled child to assess the level of sedation may cause the procedure to be abandoned if the child then doesn't settle again. Sometimes even inflating a blood pressure cuff may rouse the child, and so monitoring is sometimes more

Table 27.1 Levels of sedation in children (based on American Academy of Pediatrics guidelines 2016)

Level of sedation	Characteristics
Minimal sedation	Anxiolysis only (e.g. state induced by nitrous oxide at less than 50%)
Moderate sedation	Purposeful response to verbal command (also termed 'conscious sedation')
Deep sedation	Purposeful response after repeated verbal or painful stimuli. At risk of airway obstruction
Anesthesia	At risk of airway obstruction and may need ventilatory support

restricted than it might be for an adult. The development of a more objective model for sedation levels based upon cardiorespiratory monitoring rather than response to verbal or physical stimuli would allow closed medication loops and self-correction with automated algorithms. However, interindividual variation and argument over what constitutes moderate, deep sedation and general anesthesia have hampered progress in this area.

Note
The level of sedation is more difficult to assess in children—young children cannot talk and rousing a child to assess level might wake them completely. At the same time, they are more at risk of respiratory problems if sedation is not closely monitored.

Minimal and moderate sedation are rarely effective in children—small doses of sedation do not change a tired and hungry toddler into an awake yet co-operative patient. There is a tendency, especially in younger children, toward deeper sedation to produce the desired conditions. The increased risk of airway obstruction and cardiopulmonary depression, combined with problems associated with remote location and inexperienced staff can sometimes mean that general anesthesia is a safer option than sedation. This is especially pertinent for long procedures, medically compromised patients, or if procedures are painful or distressing.

There is an impression among non-anesthetists that sedation is safer than anesthesia. Many proceduralists will persist with attempts at deeper and deeper sedation, compromising safety that could otherwise be gained with more tightly controlled conditions and a protected the airway. Nevertheless, sedation, including sedation provided by non-anesthetic personnel, has advantages over general anesthesia in many children and for many procedures (Table 27.2).

Patient selection is critical to the success of sedation techniques (Table 27.3). In some cases, general anesthesia a quicker alternative than the preparation for

Table 27.2 Sedation versus general anesthesia for medical procedures-their advantages and disadvantages

	Sedation	General anesthesia
Advantages	Less staff and equipment required	May need less preparation of child
	May have faster recovery with less PONV or drowsiness	More reliable airway control
		Movement less likely and procedure always completed
Disadvantages	Child may need preparation	More staff and equipment
	May take time to titrate sedation to correct level	Extensive training required for personnel
	Procedure not always completed	Greater propensity for PONV

The actual levels of staffing and equipment required for sedation depends on the level of sedation used

Table 27.3 Contraindications to sedation (based on SIGN guidelines)

Contraindications to sedation
Abnormal airway (consider large tonsils, anatomical issues, sleep apnea)
Raised intracranial pressure or depressed conscious level
Reduced respiratory or cardiac function (including neuromuscular disease, active URTI)
Aspiration risk
Child too distressed despite adequate preparation
Older child with behavioral problems or informed refusal
Previous adverse reaction to sedative

sedation and the slow onset of sedation agents. Some studies have compared anesthesia with sedation and concluded that anesthesia is more cost effective when the total time for induction, procedure and recovery is considered. On the other hand, the supply of highly trained personnel required for provision of anesthesia or deep sedation is far outstripped by demand in most hospitals.

Keypoint
Moderate sedation to complete a scan or procedure without complication is difficult in preschool aged children.

If minimal sedation does not provide co-operation, it may be safer and more time effective to arrange general anesthesia with airway protection.

27.4 Principles of Good Sedation Practice

Complications of sedation in children are difficult to quantify—the population is a heterogeneous group undergoing procedures in many clinical areas and with sedation administered by many different groups of personnel, and there is a tendency to under report incidents. There are several published documents of consensus suggesting principles of good sedation practice (including the Scottish Intercollegiate Guidelines Network (SIGN), the American Academy of Pediatrics and NICE). Most of these highlight the following themes:

27.4.1 Assessment

Assessment before sedation detects cardio-respiratory problems, multi system disease, airway issues and drug history. There is a tendency to be less thorough in patients anticipated to require ‘just a little sedation’. Risks and benefits are discussed with the parents during the consultation.

27.4.2 Fasting

In general, fasting is the same for elective sedation cases as for general anesthetic techniques, and fasting patients in this manner has the advantage of flexibility to convert to general anesthesia if required. There is some evidence from emergency medicine however that shorter fasting times may be safe, and non-anesthetists sometimes follow these shorter times. Most studies conducted in this area, however, are underpowered and the true incidence of aspiration is not known.

27.4.3 Monitoring, Equipment and Personnel

The availability of equipment and drugs for monitoring, airway management and cardiopulmonary resuscitation are checked before starting sedation. More extensive monitoring and more personnel are required for deeper levels of sedation. Guidelines from colleges and professional societies outline these requirements. Pulse oximetry, respiratory rate, heart rate and sedation score is a minimum monitoring requirement, with access to NIBP measurement and ECG available if indicated. Facilities for emergency resuscitation are also essential, including two sources of oxygen, a self-inflating bag and mask of the correct size, suction equipment, equipment for IV access and airway management. Emergency drugs should be available (naloxone, flumazenil, atropine, suxamethonium, epinephrine (adrenaline), IV fluid).

27.4.4 Minimizing the Amount of Sedation

Techniques such as distraction, play therapy and guided imagery can be useful techniques to reduce the amount of sedation needed. Painful procedures may be converted to non-painful procedures with topical or local anesthetic agents. Most sedative agents are relatively safe when used on their own, but the success rate for single agents is lower than for drug combinations. The use of two or more agents however, causes greater inter-individual variation in effect and is associated with more adverse incidents. Not all attempts at sedation for a procedure will be successful—rather than persisting with other agents or higher doses, the child can be rescheduled for general anesthesia.

27.4.5 Competent Personnel

It is simply not possible for all sedation to be administered by anesthetists, non-anesthetic personnel give the majority of sedation for children. Besides placing an enormous workload upon stretched services, many procedures do not require the skill set of a specialist anesthetist. As a minimum, personnel administering

sedation must be aware of the benefits and side effects of drugs used. At least one person involved must be up to date in resuscitation techniques and airway management for children, and familiar with the equipment required for emergency procedures. Non-anesthetists using techniques with multiple or IV agents must be able to recognize contraindications to sedation, and to manage children's airways and resuscitation.

27.4.6 Recovery

Children should recover from sedation in a supervised area with access to monitoring, drugs and the equipment needed to deal with complications. Recovery of the child to the pre-sedated state with appropriate motor and verbal skills is witnessed and documented before discharge. Adequate recovery is important—the child may potentially be placed in a rear-facing car seat and could develop complications that aren't noticed because the parent is focused on driving. Written information about the procedure performed, drugs given, discharge instructions and contact details is given at discharge.

27.4.7 Documentation

Documentation of drugs and observations is made as during general anesthesia.

27.5 Agents for Sedation

Non-pharmacological methods are outlined in the Chap. 3, and include distraction techniques, guided imagery, hypnosis and parental presence.

27.5.1 Inhaled Agents

Nitrous oxide is widely used in children to facilitate procedures such as dental treatment, dressing changes and bone marrow biopsies. Small children are not able to use demand valves on intermittent flow machines (such as found in delivery suites), and continuous flow devices are used. Nitrous oxide is less useful in children younger than 2 or 3 years as they are often distressed by the face mask. Concentrations higher than 50% are considered a form of moderate or deep sedation. Problems include nausea and vomiting (8–20%) and scavenging of waste gas. Vitamin B12 metabolism does not seem to be affected, even with frequent use in children with burns. Methoxyflurane is a strong analgesic available in a small inhaler, but the problems of scavenging and renal toxicity limit its use.

27.5.2 Oral Agents

Oral sedative agents are simple to administer and commonly used. However, they are difficult to titrate, may have a slow or variable onset and may have a prolonged duration of action—the child may remain sedated for hours after a brief scan. Scheduling problems can occur while waiting for sedation adequate to begin the procedure. Oral agents include midazolam, chloral hydrate and barbiturates. Paradoxical hyperactivity or dysphoria is not uncommon.

27.5.3 Ketamine

Ketamine has a wide margin of safety, and is a good choice for painful procedures because of its analgesic properties. It is given by the oral, IM and IV routes, and Emergency Departments commonly use it for procedures. The minimum fasting period before ketamine can be safely used in the ED is not known. Fasting times shorter than general anesthesia are common, and there is no evidence of increased morbidity. The term 'dissociative sedation' is often used, but is confusing and unnecessary. Sedation is minimal at low doses of ketamine, moderate at higher doses, and deep (or anesthesia) at still higher doses. An IV dose of 1.5–2 mg/kg or intramuscular dose of 4 mg/kg is effective with a low rate of restraint to complete brief procedures. The IV route has a shorter recovery than the IM route. Dysphoria and hallucinations are less common in children than adults, but occasionally occur. If a benzodiazepine is given with ketamine, dysphoria and hallucinations are not reduced, but adverse respiratory events are more common. A benzodiazepine is therefore given only if needed to treat dysphoria or hallucinations. Occasionally, the antisialogues atropine or glycopyrronium bromide (glycopyrrolate) is required.

27.5.4 Fentanyl

Intravenous or intranasal fentanyl is useful for brief, painful procedures such as dressing changes or greenstick fracture reduction. Intranasal fentanyl 1.5 μg/kg by an atomizing device (to maximize mucosal absorption) is safe and effective.

27.5.5 Dexmedetomidine

Intravenous or nasal dexmedetomidine produces sedation and anxiolysis. It lowers heart rate (by prolonged atrio-ventricular conduction) and blood pressure. These effects are worsened by medications prolonging AV conduction such as digoxin, beta blockers and atropine. Apnea, airway obstruction and hypoxemia are less likely after dexmedetomidine than many other agents because it causes little respiratory depression. It is effective on its own or in combination with agents such as propofol

or ketamine. The IV dose is a loading dose of 2–3 μg/kg given over 10 min, followed by 0.5–2 μg/kg/h (not more than 0.5 μg/kg/h for prolonged periods such as ICU sedation). Intranasal dexmedetomidine is given using an atomizing device with a dose of 1–3 μg/kg (by aerosol) followed by 1 μg/kg rescue doses 30–45 min after the first dose.

27.6 Sedation and Anesthesia for Upper Endoscopy

Gastro-duodenoscopy is a common procedure performed under sedation, deserving individual discussion as it involves the airway. Although it can be performed in awake, non-sedated children, it is usually performed with intravenous sedation or general anesthesia.

Children are at risk of airway and ventilation problems during endoscopy. The endoscope partly occupies the upper airway and may compress the trachea. There is gastric distension from air insufflation, and there is a risk of regurgitation and pulmonary aspiration. Because of these concerns, general anesthesia with endotracheal intubation is common in infants and children younger than 2 or 3 years.

Endoscopy in older children does not require intubation. Oxygen can be given through a nasal catheter or using a blow-by technique, and a bite block inserted to protect the endoscope during IV anesthesia. The anesthetic depth must provide unconsciousness and immobility and prevent laryngospasm, but also avoid apnea. If positive pressure ventilation is needed, the scope must be withdrawn from the child.

Keypoint
Endoscopy in children: Shared airway may impede spontaneous respiration, the scope can compress the trachea, stomach distension affects ventilation, less reserve to deal with hypoventilation or apnea.

The LMA can be used during anesthesia for endoscopy. The proceduralist can negotiate the scope past a deflated LMA into the esophagus before the cuff is reinflated, but the LMA cuff can grip the scope and cause some difficulty with scope manipulation. The endoscope also causes a leak around the LMA cuff, which affects positive pressure ventilation and causes pollution of the room with volatile anesthetic agents. Nevertheless, IV anesthesia and an LMA is a useful technique because it permits some positive pressure ventilation if apnea occurs while the scope is in the child.

Children have strong pharyngeal and bite reflexes, and either deep sedation or general anesthesia is required to prevent movement, particularly during insertion of the endoscope. Propofol is often used, and its dose is reduced and the recovery time shortened by combining propofol with alfentanil or remifentanil.

Regardless of the technique employed, vigilance is required with regard to the airway throughout the procedure as the back and forth motion of the endoscope can easily dislodge an airway, and the deep sedation required to negotiate the scope past an oropharynx with an active cough and gag reflex can result in apnea. Topical anesthesia may reduce sedative dose, but the taste is often unacceptable to awake children, and may require fasting after the procedure if the gag continues to be suppressed.

27.6.1 Balloon Dilatation of the Esophagus

Some children undergo endoscopic balloon dilatation of the esophagus. These children may have had a tracheo-esophageal fistula repaired, in which case they will also have tracheomalacia, or an esophageal stricture after caustic ingestion. The inflated dilatation balloon occludes the trachea, and although intubation does not stop this, it assures ventilation when the balloon is deflated.

Tip
Propofol with alfentanil 25 μg/mL is a useful IV anesthesia agent for pediatric endoscopy.

27.6.2 Ingestion of Button Batteries

Small, flat circular batteries are common in consumer electronics. They can be swallowed by young children and require endoscopic removal. The positive and negative terminals of the battery are close together and bridged by tissue. Current flowing between the terminals quickly causes a burn and perforation of the tissue. Batteries in the gastrointestinal tract (or nose) are urgently removed without waiting for the usual fasting duration.

27.7 Sedation for MRI

The last 10 years have seen an increase in demand for MRI with improved access and the advantages of better images and less radiation than CT. However, MRI scans take significantly longer and the scanner tunnel is quite narrow and noisy—a confronting prospect for children.

Many children will not require sedation or anesthesia. Young babies can be fed and wrapped warmly, falling asleep for long enough for the scan. Selected children from the age of 5 will tolerate an MRI with preparation and distraction (many scanners are set up with audio-visual devices that can be viewed while the scan is underway). Experienced MRI staff are able to manage these children during their

scan and are able to determine which children will be suitable for these techniques, but significant amounts of scanner time will be lost establishing the technique in each individual instance.

There has been a great deal of work looking at the best method for obtaining scans in children who require sedation. Outcome measures are safety (with respiratory complications the most common) and completion of the scan with good quality images. For most services, the resources available and the factors considered in Table 27.2 determine the approach taken. The scarcest resources are MRI scanner time and specialist medical staff (anesthesia and radiology), and a balance needs to be struck to utilize these resources efficiently.

Potentially more scans can be completed in a given time with simple general anesthesia by an experienced anesthetic team. In this scenario, inhalational anesthesia and a supraglottic airway (unless contraindicated) is associated with the least number of complications and the quickest time to discharge. Sedation using agents such as propofol, dexmedetomidine, ketamine, and benzodiazepines have been described but with no particular advantage. They require IV access for induction, and pumps and lines for the scan. Children with complex medical issues having general anesthesia for an MRI scan represent an opportunity for specialist medical teams to carry out other investigations and procedures 'while the patient is asleep'. This has benefits for the child, but the scanner time saved using general anesthesia can be lost performing other procedures.

Regardless of the personnel or technique to facilitate MRI scanning, MRI-compatible equipment to safely deal with complications or emergencies must be available. Part of this is assigning a craft group (usually medical imaging specialists) to ensure staff and equipment are safe to enter the scanner room.

Keypoint
Several techniques achieve safe sedation for MRI, and the choice is determined by local factors and experience. Considerations include maintenance of a magnet-safe environment and effective resource utilization.

27.8 Nuclear Medicine Scans

Nuclear medicine scans are used to assess renal function (DTPA or MAG3 scan), to track tumors or before epilepsy surgery in children (PET scans). A radioactive tracer is injected at a predetermined time before the scan. Children need to be fasted and relatively still for approximately an hour following injection of a tagged glucose molecule for PET scan, while MIBG scans (for neuroblastoma or pheochromocytoma) usually take place within 24 h of injection. The scan itself is similar to a CT or MRI scan, and takes approximately 30–60 min. The scans are performed in areas not always equipped for anesthesia.

Review Questions

1. A 3 year old girl is being managed in ICU after an intracerebral hemorrhage. She is intubated and ventilated and you are going to take her to MRI for scanning. Describe the precautions you would take to prevent burns to the child in the scanner. Describe the other precautions you would take while the patient is having the scan.
2. A 2 year old child is going to have a gastroscopy to investigate possible reflux. What are the advantages and disadvantages of the different ways to manage the airway in this child for this procedure?

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Central Venous and Arterial Access for Children

28

Neil Chambers and Yu-Ping Chen

This chapter focuses on advanced vascular access techniques in children, and assumes that the reader is familiar with these techniques in adults. The intraosseous route is recommended for emergency resuscitation if peripheral IV access cannot be obtained, and both of these routes are discussed elsewhere in this book.

28.1 Central Venous Access in Children

Central venous access is challenging in children compared to adults because of their small-sized central veins, proximity to major structures and variation in their anatomical position. The success rate is lower and there are more complications compared to adults. Anesthesia or sedation is usually required for their insertion in children.

Ultrasound guidance and careful positioning of the child and equipment are important for insertion. The ultrasound probe, syringe and needle are held stabilized against the child's body and equipment is positioned so there is no need to move or look away from the child or ultrasound screen. The child's vein is small, superficial, mobile and easily collapsed by the needle so aspiration of blood is sometimes only seen when the needle is withdrawn. Arterial puncture is difficult to detect, especially in infants with cyanotic heart disease. Pressure transduction is the best technique to distinguish between vein and artery.

The risk of local complications with central venous catheter (CVC) insertion is higher in children than adults, primarily due to the proximity of structures. Central venous anatomy may vary, especially in children with congenital heart

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disease who are more likely to have a left-sided superior vena cava. Children, like adults, are at risk of infection while their CVC is in situ. The smallest diameter catheter with the minimum number of ports required reduces the risk of infection, as well as thrombosis of the vein. Although antimicrobial-impregnated catheters are sometimes recommended for adults, there is no firm evidence to support their use in children. Antibiotic prophylaxis is not needed at the time of insertion. Routine central catheter replacement is not generally recommended for children in critical care.

28.1.1 Position of the Catheter Tip

Correct positioning of the catheter tip reduces the risk of perforation of the vein wall or cardiac chamber, migration into other veins, and thrombosis or thrombophlebitis from the drugs being infused. The optimal position is in the lower third of the superior vena cava (SVC) or at the SVC-right atrium junction, but above the pericardial sac. The ideal tip position on fluoroscopy or chest X-ray is debated, however current best practice is to place the tip no more than two vertebral bodies below the carina (this position allows for the parallax error of the X-ray beam (Fig. 28.1). Technologies using ECG or ultrasound to confirm the correct tip placement are either not available in pediatric sizes or are not adequately validated.

All catheter tips should be positioned parallel to the vein wall to minimize the risk of perforation and thrombophlebitis. Catheters inserted on the right side are naturally more parallel to the SVC wall but catheters inserted on the left side need to be carefully positioned in the inferior third of the SVC to be parallel and not sticking into the wall of the SVC (Fig. 28.2).

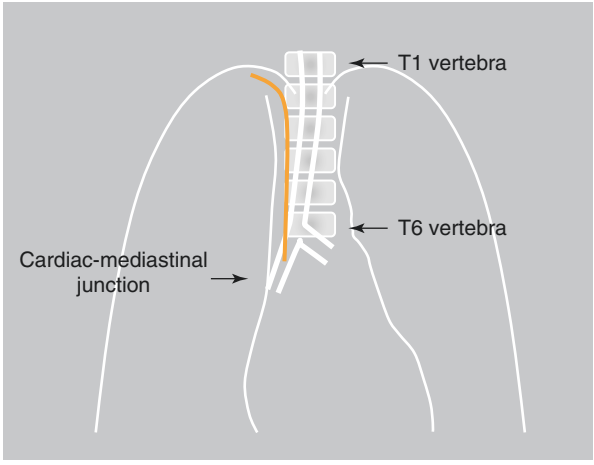

Fig. 28.1 Desired tip position on chest X-ray for central catheters in children is 1–2 vertebral bodies below the carina

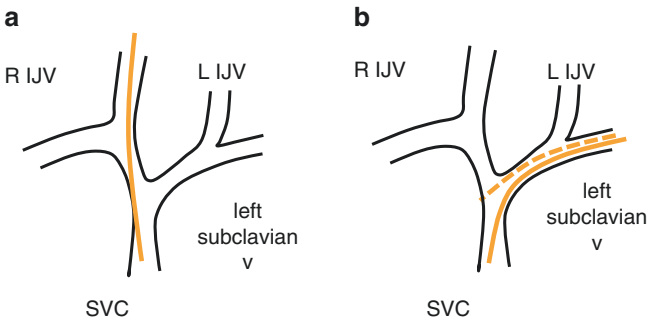

Fig. 28.2 (**a**) The distal part of right-sided catheters is usually parallel to the SVC wall. (**b**) The distal part of *left*-sided catheters can push against the vein wall and perforate the SVC (dashed line). Advancing the catheter so the tip is in the correct distal position ensures the distal part of the catheter is parallel to the SVC wall (solid line)

28.2 Internal Jugular Vein CVC

The internal jugular vein (IJV) is often used in children for CVC insertion because it has the lowest risk of complications. The vein is more variably sized, smaller and closer to the carotid artery in children compared to adults. Its position relative to the carotid artery may vary—it is most commonly antero-lateral and partly overlapping the carotid artery. The amount of overlap may increase when the head is rotated to the side. It is completely lateral to the carotid artery in less than a quarter of children, and occasionally it is even medial to the carotid. It is usually at a depth of less than 1 cm, and is only about 5 mm in diameter in infants.

28.2.1 Technique

A shoulder roll extends the child's neck and allows better access. The head is turned slightly so the needle will be clear of the chin. A head-down tilt usually has minimal effect on the size of the IJV in infants but reduces the risk of venous air embolism. Maneuvers to increase the diameter of the vein are not usually required. Simulated valsalva is probably the most effective. When it is combined with liver pressure and head-down tilt, the vein size increases about 65%. The effect of these maneuvers can be observed on ultrasound to assess any benefit.

Most commonly, a high approach to the IJV is used with the needle insertion lateral to the carotid pulsation at the level of the cricoid. The advancing needle can compress the vein, and blood is often aspirated only as it is being withdrawn. After entering the vein with the needle, the guide wire is passed gently to avoid perforating the vein. The J-tip of the wire has a curve larger than the vein diameter of infants and will either traumatize the vein or not advance into the vein. To overcome this problem,

the stiffer, straight end of the wire may be inserted, or a short soft straight wire followed by a catheter long enough to act as a conduit into a larger, distal part of the vein for the J-wire. The length of the catheter inserted depends on the size of the child—4–5 cm for a right IJV insertion in a neonate, a little longer when inserted on the left side. The smallest 2-lumen catheter currently available is 4F and 5 cm long.

Tip
The length of catheter to insert (in cm) for the right IJV (high approach) equals one tenth of the child's height.

The external jugular vein is an unreliable route for central access because it has valves and an angled course that usually prevents a guidewire or catheter advancing. It can be useful however, for peripheral venous access.

28.3 Subclavian Vein CVC

Subclavian vein catheters have a higher risk of pneumothorax and arterial puncture during insertion. However, they are popular postoperatively because they are more comfortable and better tolerated by awake children, and less likely to kink with head movement. They may be preferable in trauma cases when urgent access is required but the neck needs to remain in a neutral position or is in a cervical collar. Subclavian insertion is also easier than IJV insertion using local anesthesia in the older, awake child. Although they are associated with a lower infection rate, they have a higher thrombosis and occlusion rate compared to internal jugular catheters.

28.3.1 Technique

The right subclavian approach may be preferable to avoid injury to the thoracic duct on the left. For insertion, the child is positioned with the head in a neutral position. The landmark-based infraclavicular approach is similar to adults with needle insertion at the midclavicular point where the clavicle bends sharply, aiming the needle medially and slightly cephalad towards the contralateral shoulder or sternal notch. Inserting the needle too far laterally increases the risk of pneumothorax. The guidewire should be relatively straight after insertion to avoid kinking when dilating the vein. Tips to achieve this include a slight laterally and inferiorly placed skin puncture with minimal skin traction and then advancing needle behind clavicle in a consistent direction. Real-time ultrasound guidance assists successful cannulation in less time, and reduces the risk of inadvertent subclavian artery puncture and pneumothorax. With the supraclavicular approach, the subclavian vein is accessed more medially where it joins the internal jugular vein to form the brachiocephalic vein. This approach was less popular in the past due to the greater risk of pneumothorax,

however real-time ultrasound may reduce the risk of such complications and increase the safety of this approach.

Keypoint
Subclavian catheters have several advantages over IJV catheters in children. The IJV route, however, is most commonly used in children to reduce the risks of arterial puncture and pneumothorax.

28.4 Femoral Venous and Arterial Catheters

The femoral vein and artery are frequently used when cannulation attempts elsewhere have failed, particularly in infants. It has a low risk of complications at the time of insertion and is a good choice for the occasional operator needing good IV access urgently. A roll is placed under the hips to bring the leg into a neutral position and the leg externally rotated. The needle is inserted 1–2 cm below the inguinal ligament, using ultrasound guidance. A normal length IV cannula is not suitable because patient movement shifts it out of the vessel, and various types of longer catheters are available. The catheter size should be 20G or smaller in the femoral vein and 4F in babies. Venous thrombosis is more common in young infants, especially if large diameter catheters are used. Femoral venous catheter tips should terminate in the inferior vena cava. They do not accurately measure central venous pressure, although trends in the recorded value can be useful. Migration of the catheter tip into the spinal venous plexus is a concern, and a lateral abdominal X-ray is taken to exclude this (the catheter tip should be anterior to the vertebral bodies). Transient venous congestion of the leg occasionally occurs, and requires close observation and sometimes exchange for a smaller catheter or removal of the catheter. Femoral arterial catheters can cause limb and intestinal ischemia—limb ischemia develops in 25% of neonates if a 20G cannula is used.

Note
Femoral lines have few complications at insertion, however thrombosis and limb ischemia are concerns in neonates and infants.

28.5 Umbilical Catheters

Catheters inserted into the umbilical vein or artery are usually inserted by pediatricians using a cut down technique. The vessels can be cannulated in the first 3–5 days of life, but are constricted and thrombosed after that time. Umbilical artery catheters may cause emboli to the legs, intestinal ischemia and renal artery thrombosis, but

overall are very safe. The tip of umbilical artery catheters is kept below the level of the renal arteries to minimize complications.

28.6 Longer-Term Central Venous Access Devices (CVAD)

Central venous devices in children provide secure access and protect vessels from thrombophlebitis caused by antibiotics and other irritant therapies. CVAD's include Peripherally Inserted Central Catheters (PICC lines), short central lines inserted into the jugular or subclavian vein and tunneled under the skin, and surgically inserted long lines (Infusaport, Broviac, Hickman and others) (Table 28.1). They all have in common a catheter tip in a central position in the inferior third of superior vena cava or at the cavo-atrial junction.

28.6.1 PICC Lines

PICC lines are inserted in a peripheral vein but the tip is positioned in a large, central vein less likely to be affected by irritant IV agents. They are often used in children to avoid multiple, traumatic peripheral IV insertions, but this compassionate indication needs to be balanced with the higher likelihood of complications in children as well as the probable need for general anesthesia. They are suitable for infants and children who need antibiotics or parenteral nutrition (TPN) for 2 weeks or longer, and are also used in some preterm neonates for TPN and drugs. Another advantage of PICC lines is they facilitate discharge from hospital by allowing IV therapy at home. Oncology patients usually require longer-term lines such as the Infusaport, or tunneled cuffed CVADs such as the Broviac® or Hickman® line**.**

PICC lines are usually inserted in the arm. The basilic vein on the medial side of the upper arm is one of the best sites for insertion in children (Figs. 28.3 and 28.4). Insertion in the middle third of the upper arm allows the child to freely move their elbow and improves the function and patency of the PICC line. The catheter tip is

Table 28.1 Types of central venous access devices and their typical duration of use, problems and advantages

CVAD	Comment
Non-tunneled IJV or Subclavian CVC	Short term device, infection risk after 1 week suitable for 1 week of treatment
Tunneled, uncuffed CVAD (e.g. IJV or subclavian	Medium term device, infection risk after 2 weeks
PICC	Medium term device, suitable for 4–8 weeks of therapy. Large proportion fail before end of therapy
Tunneled, cuffed CVAD (e.g. Broviac, Hickman)	Long term device, suitable for several months of therapy; often used in oncology children. Low failure rate
Infusaport	Long term device, implanted, lowest risk of infection, may remain in situ many years. Often used in oncology children or children requiring long term IV access (e.g. hemophilia)

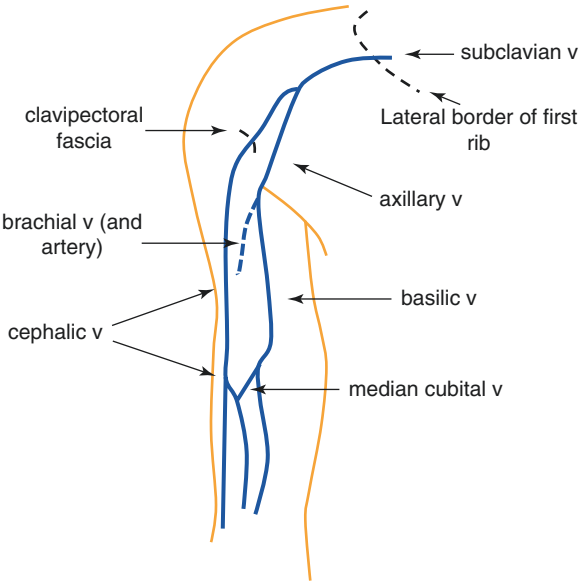

Fig. 28.3 Schematic of veins in right arm. The basilic vein in the medial side of the upper arm is one of the best veins to use as it has the most direct route into the axillary vein and thorax. The cephalic vein is commonly used but the catheter may catch at the clavipectoral fascia or at the valve where it joins the axillary vein. The pair of brachial veins beside the brachial artery can be accessed but with the risk of arterial puncture

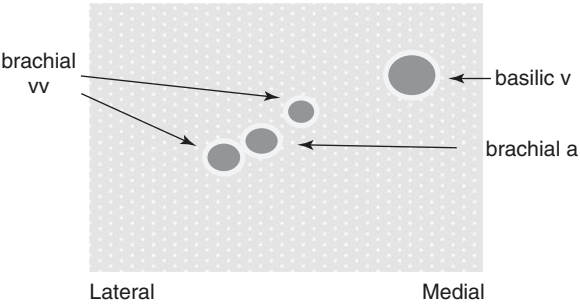

Fig. 28.4 Schematic ultrasound image of anterior mid-upper arm showing basilic vein clear of other vessels, and brachial veins adjacent to the brachial artery

also most likely to advance to a central location when inserted in the basilic vein due to its more direct route to the axillary vein. Although almost any vein can be used for insertion, there are problems with some insertion points: the cubital fossa is commonly used, but elbow movement is restricted and damages the catheter. Similarly, insertion in the distal forearm or leg exposes the catheter to movement and environmental contamination.

28.6.1.1 Technique

In young children, PICC lines are usually inserted under sedation or general anesthesia and positioned using fluoroscopy. The smallest diameter catheter should be used to reduce the risk of subclavian or axillary vein thrombosis (3F in children, and 2F in neonates). The vein chosen should be at least three times the diameter of the catheter. The very fine 2F catheter is too small for fluid boluses or blood products, and may rupture with injection pressure. It is not suitable for intraoperative use and routine blood sampling.

The required length of the catheter is measured either externally on the surface of the child or more accurately by positioning a measured guide wire under fluoroscopy. The catheter is cut to length before insertion. Some PICC catheters include a 'stiffening' wire within the catheter to aid catheter manipulation and visibility during fluoroscopy. This wire must not be cut or damaged when shortening the catheter: there have been many reports of embolization of the cut wire. Insertion using fluoroscopy allows accurate positioning of the tip. If fluoroscopy is not available, a predetermined length catheter is inserted and its position checked with a chest X-ray. If this is done once the child is awake, repositioning of the catheter may not be possible.

The commonest problem during insertion is difficulty advancing the catheter. Changing the arm position, applying traction to the arm, or removing the stiffening wire and flushing with saline while advancing the catheter may help to advance the catheter. If the catheter is stopping at the clavipectoral fascia, applying infraclavicular pressure may be useful, but it may indicate vein stenosis from a previous PICC or spasm of the vein. Some proceduralists negotiate difficult, tortuous venous anatomy with guide wires under fluoroscopic control, then railroad the catheter over the wire.

The tip of the PICC should be in lower third of the SVC or at the junction of the SVC and right atrium. Catheters not in this position are more likely to cause venous thrombosis or infection, occlude earlier and are less likely to function for the length of time needed. If the catheter cannot be placed in this position, the risk of accepting a more peripheral position is balanced against the risks repeating the insertion. The position of the tip changes with arm movement—the catheter tip moves inferiorly (distally) another 1–2 cm when the arm is brought from an abducted position down to the side of the body with the elbow fixed.

Note
The tip location affects the rate of complications. Catheter tips that are not correctly located are more likely to fail and increase morbidity.

28.6.2 Complications of CVADs

Although early complications related to insertion are uncommon, later complications and problems are very common (Table 28.2). These include accidental removal, thrombosis, occlusion and leakage around the insertion site. A fibrin sheath often forms within the lumen of the catheter and prevents aspiration of blood samples while still allowing flushing. This sheath may contribute to occlusion or thrombosis of the catheter. Thrombolysis of clotted, blocked catheters appears safe and effective at restoring catheter patency. The consequence of these complications is some catheters, particularly in younger children, do not remain in place for the planned duration of treatment and may need replacing.

Complications are more common if the catheter tip is not central—4% if central, 28% if not and includes an eight times increased risk of thrombosis. Thrombosis of

Table 28.2 Complications preventing completion of the planned duration of treatment

Complications of CVADs
Thrombosis of catheter or central vein
Accidental removal
Leakage
Inability to aspirate blood
Occlusion
Perforation of heart/pericardial tamponade
Infection
Fracture of catheter, embolism or knotting
Thrombophlebitis at insertion site

the subclavian vein occurs in about 4% of children with a PICC line, but is symptomatic in only about one third of cases. Thrombosis is reduced by using a small diameter PICC, which keeps the catheter-to-vein diameter ratio small. Line infection depends on patient factors such as age, illness type and severity; and catheter factors such as insertion site, type of catheter type, urgency of placement, tunneling and tip position.

A structured central line service, usually nurse-led, decreases complications and re-insertion rates. A coordinated approach includes selecting the most appropriate CVAD for each child, overseeing the care of the line, managing complications, and involvement in the timing of removal or replacement. These are some of the simple but important interventions that ensure the most appropriate line is placed in a timely fashion that achieves the patient's therapeutic and management goals.

28.7 Arterial Lines

Arterial line insertion may be technically difficult in infants and small children. Transillumination can be helpful in neonates, and real-time ultrasound improves the success rate in children of any age. The catheter inserted is often relatively large compared to the artery in neonates, and distal ischemia is a major concern. The radial, brachial and femoral arteries are the most commonly used sites. The ulnar artery is generally not recommended in children. The brachial artery can be used in neonates bigger than about 2 kg, but it is used only if more distal arteries can't be cannulated as there is poor collateral circulation and an increased risk of ischemia. Brachial arterial lines are best placed using a short cannula to avoid obstructing collateral vessels. A 22G cannula is most commonly used in babies and children, but some prefer a 24 g cannula for all sites in newborns. Securing and splinting of arterial lines need to provide secure fixation and protection and allow visual inspection of distal perfusion and skin at insertion point.

28.8 Cutdowns

Venous or arterial cutdowns can be used as a last resort by those skilled at the technique. They should not be used for routine insertion.

Review Question

1. A 3 year old child has osteomyelitis of the tibia and IV antibiotics for at least 2 weeks. It is difficult to obtain peripheral IV access in the child. You are asked to help with IV access. Discuss the options for treatment and access in this child.

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The Child at Risk: Child Protection and the Anesthetist

29

Craig Sims and Dana Weber

Anesthetists may encounter children who have been physically or sexually abused. There are ethical and legal obligations to protect the child in this circumstance. The safety of the child is paramount and overrides all other considerations. Surgeons, nurses and all other health workers have the same legal obligation to report suspected child abuse. They should have training in child protection and be aware of the arrangements for child protection in their own hospitals. Although doctors have obligations to maintain patient confidentiality, the legal obligations to report suspected child abuse over ride confidentiality considerations. Modern societies have specific legislation dealing with these obligations, such as the 2004 Children's Act in the United Kingdom and state-based legislation in Australia. New Zealand does not yet have legislation for mandatory reporting of suspected child abuse.

29.1 Detection of Abuse

The anesthetist may be the first person to notice the signs of child abuse, either as part of the preoperative assessment or in theater. Alternatively, the anesthetist may be present when the surgeon or nursing staff notice signs, and rarely a child may disclose abuse to the anesthetist. Anesthetists involved in resuscitation or intensive care may also notice signs of abuse (Table 29.1).

Certain characteristics of the child's parents and social circumstances increase the risk of child abuse, and these are listed in Table 29.2. However, suspicion is usually raised due to the child's type of injury, a discrepancy between the injury and the explanation of how it occurred, or the type of injury relative to the child's age. There is also often a delay in seeking treatment. Traumatic injuries in young children not

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Table 29.1 Situations when the anesthetist may encounter possible child abuse

Situations when the anesthetist may be involved with suspected child abuse
Notices signs at preoperative assessment or in theater
Is present when surgeon or nursing staff discover signs
A child needs resuscitation or intensive care management with head injury or other injury without adequate explanation
A child may disclose abuse to anesthetist
Provides anesthesia for forensic examination of a child who is suspected of having been abused

Table 29.2 Risk factors for child abuse

Risk factor
Poor social circumstances, social isolation, poverty, child neglect
Parental alcohol or drug abuse
History of family violence or previous abuse
Single parent, stepfather living with child

Table 29.3 Clinical signs that may indicate child abuse, depending on the child's age and history of how the injury occurred

Signs of abuse
Significant bruising, especially in children too young to walk
Fractures in children too young to walk, rib fractures, multiple fractures or long bone fractures in young children
Cigarette burns or bite marks
Subdural hematoma and retinal hemorrhages in infants
Injuries in inaccessible places such as neck, ear, hands, feet and buttocks
Intra-oral trauma, damage to frenulum, especially in children too young to walk
Genital or anal trauma
Trauma without adequate reason for its occurrence
Multiple injuries of different ages
Delayed presentation

yet walking are unusual and are considered suspicious. For example, a fractured arm in a school aged child could quite plausibly be due to an accident, but a mid-shaft fracture of the humerus in a child aged less than 3 years is highly suggestive of abuse. Similarly, fractured ribs are very unusual in children in the absence of major trauma or an underlying bone abnormality.

Bruising is common in all children and so is less specific of abuse, but widespread bruising in a child too young to walk, or in unusual places on the body would support other evidence of abuse. Infants are at risk of abuse from often young, overtired and inexperienced parents who cannot deal with the baby's crying. 'Shaken baby syndrome' has long been recognized and consists of subdural hematoma, retinal hemorrhages and encephalopathy. Other injuries that strongly suggest abuse are listed in Table 29.3.

Keypoint
Child abuse is suspected by considering the age of the child, the type of injuries, the reported mechanism of injury and the social circumstances of the child. Any one sign by itself is rarely diagnostic.

29.2 Obligations of Health Care Workers

Health care workers, including anesthetists, are obliged to report their suspicions of child abuse (Table 29.4). Pediatricians are the group of doctors most commonly involved in suspected child abuse and are likely to have the most experience. It is therefore useful for the anesthetist to discuss any concerns with the Duty Pediatrician in a hospital. Alternatively, every children's hospital has a child protection unit from which advice can be obtained. Social Services can also be approached directly or by the pediatrician. The child may need to stay in hospital for his or her protection.

Consent needs to be obtained from the parent or guardian for anything more than a visual inspection of suspected injuries. Consent for surgery and anesthesia does not give consent for examination in relation to suspected child abuse. Parents (and the child if he or she is old enough and it is appropriate) should always be informed of the suspicions, except in rare cases where this is not in the best interest of the child. Consent for further examinations would usually be obtained by the pediatrician. If the parent or guardian is not available or refuses consent, then medical administration is contacted and legal advice sought. In cases of child sexual abuse, pediatricians with specific expertise in child sexual abuse and forensic examination are required. Colposcopy, photography and forensic sampling under anesthesia may be carried out in these cases.

Table 29.4 Obligations of the anesthetist when caring for children

Obligations of the anesthetist
Act in the best interests of child
Be aware of the child's rights to protection
Respect the child's right to confidentiality
Contact experienced pediatrician, social worker or Social Services if child abuse is suspected
Be aware of local child protection mechanisms
Be aware of parent's rights.

Review Question

1. A 4 year old boy weighing 15 kg presents for day surgery repair of a left inguinal hernia for which you plan general anesthesia and a caudal block. He is well and has no significant past history. When you position him for the caudal block, you notice some bruises on his legs and buttocks.
   (a) What pattern of bruising would be suspicious in this child?
   (b) List the clinical features that would arouse suspicion that physical child abuse has occurred
   (c) What should the anesthetist do if they suspect child abuse has taken place?

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Pediatric Intensive Care

30

Daniel Alexander

30.1 Recognition of the Seriously Ill Child

History, examination and judicious investigation will direct assessment of the pediatric patient. This process is easier for the anesthetist familiar with physiology in the young. However, there are several clear indicators of the critically ill infant. These are alertness and interaction, breathing, circulation and fluid balance over the preceding 24 h. Seriously ill children look tired or weak, do not resist examination or procedures such as IV insertion and are often pale or dusky. They are likely to be tachypneic, tachycardic and with signs of respiratory failure, cardiac failure, or both. The critically ill infant may also have a previously unrecognized congenital disorder. These and other conditions that should be considered in a critically unwell infant are listed in Table 30.1.

It is always wise to listen to the parent or caregivers who know their child best and are often able to detect changes from normal for their child. They can be of particular help with children who have complicated histories. 'Red flags' in the history include apnea, bilious vomiting (intestinal obstruction), seizures, intermittent abdominal pain and leg drawing (intussusception), rash (meningococcemia) and episodes of color change. Examination should assess the overall appearance of the child, vital signs including blood pressure (normal values Table 30.2), the adequacy and effectiveness of breathing, and the adequacy of cardiac output. Perfusion of the peripheries is especially helpful in assessing circulation, as blood pressure is maintained until late in illness.

Tip

There is little to lose by resuscitating a child whom in hindsight didn't need it, but there is much to be lost in a delay.

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Table 30.1 Conditions to always consider in the critically ill infant

Diagnoses to consider in the critically ill child
Sepsis (Group B Streptococcus, Meningococcus, UTI, Meningitis)
Duct dependent congenital cardiac lesions (Coarctation, HLHS)
Gut obstruction (volvulus, malrotation, intussusception)
Metabolic disorders
Non-accidental injury

HLHS Hypoplastic Left Heart Syndrome

Table 30.2 Normal ranges for heart rate and respiratory rate

Age	Heart rate (beats/min)	Respiratory rate (breaths/min)
<30 days	110–170	30–60
6 months	100–160	30–40
1 year	100–150	30–40
2 years	95–140	25–30
4 years	90–130	25–30
6 years	80–120	20–25
8 years	80–120	20–25
10 years	80–110	15–20
12 years+	60–100	15–20

Expected systolic blood pressure = 80 + (age in years × 2) mmHg

A child who looks critically unwell (hypoxic, mottled, grey, poorly perfused, drowsy), is bradycardic and relatively hypoventilating has already reached the point of decompensation and is about to arrest. If ever there is doubt about the need to mask ventilate in this situation, the answer is a resounding "Yes!". If ever there is doubt about the need to perform chest compressions, the answer will most likely be "Yes", (and it probably needed to be started a couple of minutes earlier).

Keypoint: Detecting the Seriously Ill Child
Alertness and interaction
Breathing: rate, effort and saturation
Circulation: heart rate and perfusion
Relative hypoventilation and bradycardia can be ominous
Fluid balance

30.2 Recognition of the Deteriorating Child

Early recognition of the deteriorating child followed by prompt and effective action can minimize events such as cardiac arrest, and may reduce the level of intervention required to stabilize the child. The evidence base for recognition and response

systems for the deteriorating child is still developing. Changes in the child's observations often occur 8–96 h before events such as cardiorespiratory arrest or unplanned admission to intensive care. Several tools have been developed to recognize the deteriorating child, most of which plot physiological observations in a graphical form to display trends. Graphical documentation is recommended because changes over time are easier to recognize.

The most important method to detect a child who is deteriorating is regular measurement, documentation and review analysis of observations. Standard observations include respiratory rate, oxygen saturation, heart rate, blood pressure, temperature and level of consciousness. The importance of monitoring blood pressure is often overlooked in institutions unfamiliar with dealing with critically unwell children. Other observations (such as seizure activity or BSL) may also be relevant for particular children.

Failure to respond to therapy may also indicate relative deterioration despite unchanged physiological parameters. For example, a child with severe upper airway obstruction who does not respond to multiple epinephrine (adrenaline) nebulizations and steroids may require intensification of management.

30.3 Intervention and Stabilization Before Transfer

After recognizing the child who is seriously ill or deteriorating, treatment is begun or increased to avoid cardio-respiratory arrest and to facilitate recovery. Most pediatric health care systems operate within a centralized model, with advice available from on call pediatric intensivists in specialized centers. Whilst anesthetists are well equipped to treat seriously ill children, early consultation with these centers ensures the appropriate interventions and transfer of patients. Management may be influenced by geographical and logistical considerations. For example, a child with acute severe asthma in an isolated rural hospital may be more safely managed locally with intravenous steroids, aminophylline and continuous salbutamol inhalation than with intubation, ventilation and transfer by aeromedical retrieval.

Several problems commonly occur during transfer to pediatric intensive care units. These problems are hypoventilation, hypoxemia, hypotension, hypoglycemia, hypothermia, unrecognized seizures, and lack of attention to cerebral perfusion pressure. Every patient needs at least one well-secured peripheral intravenous, intraosseous or central access. If transfer is expected to take some time, a second access site should be considered.

If the patient is ventilated, the endotracheal tube needs to be the correct size and well placed. If possible an X-ray should be taken after any intubation to ensure optimal position (neither endobronchial nor too high that may risk dislodgement). On chest x-ray the tip of the ETT should sit in the mid trachea, below the clavicular heads and well clear of the carina. The endotracheal tube needs to be of a size that there is not an excessive leak and ventilation can be assured. A cuffed ETT is preferable in most situations and highly desirable if high inspiratory pressures are anticipated. Cuffed ETT are routinely used in most critical care areas. They have the

Keypoint
Common problems during transfer to PICU are hypoventilation, hypoxemia, hypotension, hypoglycemia, hypothermia, unrecognized seizures, and inadequate cerebral perfusion pressure.

benefits of not needing to 'up-size' the ETT because of an excessive and unmanageable leak, and protection from airway soiling. Nasal ETTs are less mobile than oral tubes and are preferred by many units. Prolonged nasal intubation in adults may cause sinusitis, but this is not a problem in children. However, a secure, well placed oral ETT is perfectly acceptable and more straightforward to insert (See Chap. 18 Dental Anesthesia, Sect. 18.1).

30.4 Specific Conditions

30.4.1 Croup

Tracheolaryngobronchitis (croup) is a viral infection causing inflammation and narrowing of the upper airway. It is usually caused by parainfluenza (type 1 and 2) although other viruses such as rhinovirus, influenza A and B, adenovirus, and respiratory syncytial virus can produce a similar clinical picture. Young children have small upper airways and so are more at risk of respiratory obstruction than older children. Croup is a common reason for admission to pediatric intensive care. Often there is a history of a prodromal illness and 'seal-bark' cough. Stridor is high pitched and initially inspiratory, but as obstruction worsens it becomes biphasic and at rest. Stridor is absent when the obstruction and respiratory distress worsen. Cyanosis in air is seen just before respiratory arrest. Using supplemental oxygen to treat a child who has upper airway obstruction removes desaturation and cyanosis as markers of deterioration. For this reason, supplemental oxygen is given with caution and in an area of high acuity.

Croup is diagnosed after other conditions have been excluded. A differential diagnosis includes epiglottitis, bacterial tracheitis, angioedema, foreign body and retropharyngeal abscess. At times croup will present with an element of reactive lower airway disease ('Crasthma' or 'wheezy croup'). It is difficult to determine if a child has croup or epiglottitis. Children with croup have a hoarse voice (laryngo), cough (bronchitis) and are not systemically unwell despite having viremia and a high fever. Children with epiglottitis are septic and don't cough (Table 30.3).

Some children who present with croup have underlying tracheal stenosis from previous neonatal intubation. These children should be identified beforehand because they can be problematic in medical management and at intubation due to their already narrowed trachea. They may have a history of symptoms even before the episode of croup.

Treatment for mild croup is with oral steroid, and hospital admission may not be required. Oral steroids are effective in less than 1 h. Severe croup with signs of

Table 30.3 Comparison between signs and symptoms of croup and epiglottitis

Croup	Epiglottitis
Common illness of childhood	Rare
Viral etiology	Bacterial etiology
Hoarse voice	Sit forward and drool
Cough	No cough
Not systemically unwell	Septic and look unwell
Fever	Fever
Vocal cords usually easily visualized	May be very difficult to visualize cords

Table 30.4 Steps in treatment of child with croup causing upper airway obstruction

Treatment of severe croup
Oxygen (being aware that may mask signs of deterioration)
Nebulized epinephrine (adrenaline) 1% 0.05 mL/kg made to 4 mL with 0.9% saline or 0.5 mL/kg 1:1000 neat (max 6 mL)
Dexamethasone 0.6 mg/kg (max 12 mg) iv, IM or oral or prednisolone 4 mg/kg oral stat then 1 mg/kg 8 hourly or budesonide (nebule) 2 mg stat
Intubation if threatened airway; worsening sternal recession, restlessness, cyanosis in air or a silent chest

Table 30.5 Indicators used to decide if child with croup requires intubation

Signs indicating intubation needed in child with croup
Worsening respiratory distress—accessory muscle use, sternal recession, tracheal tug, intercostal recession
Child restless or tiring
Cyanosis while breathing air

Note that ABG's are not used

airway obstruction is treated with steroids, observation in an appropriate environment and nebulized epinephrine (adrenaline) for acute obstruction while waiting for the steroids to take effect (Table 30.4). Intubation is required in children with impending total airway obstruction, worsening sternal recession, restlessness, cyanosis in air or a silent chest (Table 30.5). Intubation is required in less than 0.5% of all children presenting with croup. An arterial blood gas sample is not indicated as it will distress the child and worsen the condition. The decision to intubate is based on clinical signs.

Most children with croup are straightforward to intubate. The vocal cords are readily seen, and the problem is with selecting an ETT that is small enough to pass through the cricoid ring with overlying edematous mucosa, but large enough to permit easy suctioning and reduce the risk of occlusion from secretions. Inhalational anesthesia in a controlled environment is preferable. If there is a suggestion of an alternate diagnosis such as epiglottitis, then consider the presence of a clinician able to provide a surgical airway in the advent of can't intubate, can't-oxygenate situation. Selection of the uncuffed ETT size is generally two half-sizes smaller than an age appropriate size (for example a 2 year old child who

would normally require a 4.5 mm ETT would be intubated with a 3.5 mmID ETT). Croup is an unusual situation nowadays in that an UNcuffed ETT is desirable. Longer than usual uncuffed 'croup tubes' are available for older children needing intubation.

Note
Acute upper airway obstruction in children:
Croup; epiglottitis, retropharyngeal abscess; bacterial tracheitis, angioedema, foreign body.

The majority of children with croup who require intubation have lower respiratory parenchyma disease (bronchitis) with reduced lung compliance and significant secretions. Despite this, the majority are easily managed with an uncuffed ETT.

30.4.2 Epiglottitis

Epiglottitis is a bacterial infection that causes the epiglottis and adjacent larynx to swell and occlude the airway. It is rare since the introduction of the highly efficacious Hemophilus influenza B vaccination program. It now usually occurs only in the unvaccinated or as consequence of a Group A streptococcus infection, and rarely in the immunocompromised such as post-varicella, oncology children and those on immunomodulation therapies. It may also be caused by burns and chemical ingestion. It is vital to recognize epiglottitis as it can cause a 'can't-intubate, can't-oxygenate' scenario. Epiglottitis should be considered as a diagnosis in children with acute upper airway obstruction.

Children with epiglottitis have a short history of fever and sore throat and are unwell and septic. They have a low-pitched biphasic stridor and sit forward in a 'tripod' position, refusing to swallow. They don't cough and there is no preceding viral prodromal illness. Once identified, children with epiglottitis should be managed as having a precarious airway with the potential for sudden obstruction. They should be allowed to keep sitting up in their position of comfort, as lying down may result in total obstruction. Interventions are minimized as distressing the child may trigger obstruction.

Definitive control of the airway is obtained in an optimal environment with gaseous induction, maintenance of spontaneous ventilation and ENT presence. These children can be very difficult to intubate. The epiglottis is easily seen, but it is cherry red, swollen and may completely obscure the glottic opening. It can be very difficult to know where to pass the ETT, and sometimes the only clue is seeing a few bubbles under the epiglottis as the child exhales. Laryngeal pressure may help obtaining a view of the cords, and sometimes the ETT just has to be passed up and behind the epiglottis blindly, gently trying to feel where the glottic opening is. An ETT 0.5 mm smaller than usual is used. Once intubation has occurred, the epiglottis is swabbed, blood cultures taken and appropriate antibiotics such as a third-generation cephalosporin begun.

30.4.3 Bronchiolitis

Bronchiolitis represents inflammation of the distal respiratory tract. It is commonly cause by respiratory syncytial virus (RSV) though can be caused by other viruses (rhinovirus, influenza, parainfluenza). Occasionally no virus is isolated. Bronchiolitis results in a large number of PICU admissions each year. Most children with bronchiolitis have a mild illness and are nursed at home or in a hospital ward. Older children with these viruses have a milder illness. Small children are at increased risk because of the small diameter of their airways. Infants less than 3 months, former preterm infants and children with co-morbidities such as chronic lung disease or cardiac lesions are the most likely to require admission and escalation to respiratory support.

Infants with bronchiolitis present with increasing respiratory difficulty. They have a preceding viral illness followed by tachypnea, cough and poor feeding. Examination reveals features of respiratory distress and fine lung crepitations. About 20% of infants present with apneas alone, but develop lung crepitations over the next 12 h.

Management is supportive, with oxygen and fluids. Oral feeds are deferred during periods of respiratory distress, and often antibiotics are commenced after a limited septic screen. Nasopharyngeal aspirates are often sent to confirm RSV status, although this is not universal practice and is probably most useful only for cohorting purposes. The respiratory stimulant caffeine may have a place in the management in those who present primarily with apneas. A clinical trial of bronchodilators or steroids may be justified if there is a strong family history of atopy, though the evidence for this approach is conflicting. Respiratory support is given if clinically warranted. This support starts with high flow humidified oxygen, then non-invasive respiratory support such as nasal CPAP, followed by intubation and ventilation. The criteria for intubation and ventilation are broadly similar to those for croup.

30.4.4 Acute Severe Asthma

Asthma is common and can occasionally become life-threatening if not managed appropriately. With aggressive early medical management, it is rare for an asthmatic child to require ventilatory support. All efforts should be made to avoid ventilation as it is carries risks of hemodynamic changes at induction and then complications from positive pressure ventilation.

Keypoint
Ventilation of the child with acute severe asthma carries risks of hemodynamic changes at induction and then complications from positive pressure ventilation.

Most children with exacerbations of asthma have a prior history of asthma or a family history of atopy. Often a trigger for the exacerbation is identified—either allergens or viral. Children with a mild exacerbation will respond to bronchodilator therapy given through a spacer device and a short course of oral steroids. Children with a severe exacerbation who are hypoxic should have salbutamol delivered as a nebulization with oxygen (8 L/min) and IV steroids. Bronchodilators are escalated according to clinical necessity (Table 30.6). Frequent salbutamol nebulizations are escalated to continuous nebulizations if required, then to intravenous salbutamol therapy. Intravenous aminophylline and magnesium also have a role in treatment of severe asthma though there is conflicting evidence. In general, any child requiring more than four hourly salbutamol treatments should be an inpatient in a hospital and anyone requiring hourly bronchodilator therapy should be considered for intensive care management.

In critical situations, it should be remembered that epinephrine (adrenaline) is a potent bronchodilator. Intramuscular or subcutaneous epinephrine (0.01 mL/kg 1:1000 epinephrine) at a time of crisis may be life-saving and grant extra time to prepare for emergency airway management.

Intubation should be contemplated only with extreme respiratory fatigue and respiratory failure as it is carries significant risk. Cardiovascular decompensation at induction is predictable and should be pre-empted with aggressive fluid resuscitation before induction and resuscitation drugs available. Ketamine is the drug of choice for induction because of its bronchodilator properties and relative cardiovascular stability. After intubation, high inspiratory pressures are required to achieve adequate tidal volumes. Goals for ventilation are tidal volumes of approximately 8 mL/kg with an expiratory time long enough to avoid air

Table 30.6 Escalating management of severe asthma

Treatment	Details
Oxygen	Subnasal, Hudson or non-rebreather mask to maintain $SaO_2 > 96\%$
Salbutamol	Nebulized 5 mg made to 4 mL with 0.9% saline 20 min × 3 doses
Ipratropium	Nebulized 250 μg given with salbutamol × 3 in first hour then 6 hourly
Steroids	IV hydrocortisone 4 mg/kg 6 hourly
	Intensify (or decrease treatment) sequentially as required
Hourly Salbutamol	Give hourly salbutamol as above
Half Hourly Salbutamol	Give half hourly as above
Continuous Salbutamol	Continuous nebulized undiluted 0.5% salbutamol delivered with oxygen 8 L/min
Aminophylline (will require dedicated line)	Load with 10 mg/kg over 1 h, if not on regular Then consider continuing 6 mg/kg every 6 h intravenously if effective
Intravenous Salbutamol (will require dedicated line)	Add salbutamol infusion 0.5–10 μg/kg/min (Salbutamol 3 mg/kg in 50 mL 5% dextrose, 1 mL/h = 1 μg/kg/min, consider loading 5 μg/kg/min for 1 h if not received significant inhaled therapy beforehand)
Magnesium sulfate	0.2 mL/kg 50% magnesium sulfate over 1 h (beware hypotension)
Mechanical ventilation	Fluid bolus, ketamine induction, muscle relaxant

trapping. Normocapnea is not essential initially. After intubation, aggressive bronchodilator therapy is continued. Although nebulized salbutamol can be delivered to an intubated child with an adaptor, IV therapy is better at this stage. The management of acute severe asthma is also covered in Chap. 8, Crisis Management, Sect. 8.4.

30.4.5 Meningococcal Sepsis

Neisseria meningitidis exists in 13 serogroups with 6 serotypes associated with disease (A, B, C, W, X and Y). Historically A, B and C accounted for most disease burden internationally, although the pattern of distribution has changed dramatically with the introduction of immunization programs for five serotypes (A, B, C, W and Y). The organism is carried in the nasopharynx in 5–10% of most populations, and becomes invasive opportunistically. The incubation period is from 2 to 10 days with the prodromal illness often of a flu-like illness. Septic shock due to Neisseria meningitidis can be a devastating disease if not appreciated early and treated aggressively. Mortality from meningococcal septic shock is as high as 40%.

The classical presentation is in a previously healthy child who becomes unwell and septic with a non-blanching rash. Unfortunately, other presentations are common. Many children are not unwell in the early phases of the disease and may be too young to express myalgia or headache to their parents. Up to 25% of children do not have a rash on presentation, or if the rash is present, it may be polymorphic or blanching. To compound this, children are able to maintain blood pressure by increasing systemic vascular resistance and heart rate (having a relatively fixed stroke volume). Because of this and despite being unwell, they lack hemodynamic compromise until late, and then decompensate quickly with bradycardia, hypotension and arrest. Examination of an unwell child includes inspection for a rash and thorough and repeated examination for adequacy of circulation. Tachycardia, hypotension, poor capillary refill time, evidence of peripheral vasoconstriction (cold hands and feet) and end organ insufficiency (tachypnea, oliguria, raised lactate) should prompt vigorous resuscitation. It cannot be overstated that a robust blood pressure in isolation is not a reassuring observation. Any shocked child is given supplemental oxygen and the adequacy of breathing assessed. Intravenous (or intraosseous) access needs to be achieved without delay.

Keypoint
Sick children can maintain a normal blood pressure until late, then decompensate quickly with bradycardia, hypotension and arrest. There is a high risk of cardiovascular collapse when inducing anesthesia to intubate a child.

The diagnosis is confirmed with blood cultures or a positive PCR (polymerase chain reaction). Lumbar puncture is contraindicated because the patient may have disseminated intravascular coagulation (DIC). Antibiotics are given urgently and although blood cultures are preferably taken beforehand, treatment is not delayed for this reason. If there is a delay in obtaining vascular access, intramuscular antibiotics is an alternative option.

Rapid resuscitation with 20 mL/kg 0.9% saline is followed by an assessment of response. Fluid challenges are repeated as clinically indicated. When 40–60 mL/kg of fluid has been given, other management strategies should be considered as well. Albumin 4%, inotropes (dopamine, norepinephrine or epinephrine) and mechanical ventilation maybe indicated, usually in consultation with intensive care. Hypoglycemia, hypocalcemia and coagulopathy often occur in meningococcemia and must be corrected early. Contact tracing and public health measures will need addressing on confirmation of the diagnosis.

Note
The importance of vigorous fluid resuscitation in the face of meningococcal septic cannot be overstated. Aggressive resuscitation and reassessment of cardiovascular adequacy is the key to a good outcome, with many children requiring 80–120 mL/kg of fluid resuscitation in the first hour of arrival to PICU.

30.4.6 Status Epilepticus

Seizures may result from many processes including febrile convulsions, idiopathic seizure disorder, ingestion, changes to anti-epileptic medications, metabolic disturbances, trauma and CNS infection (Table 30.7). Brief seizures are generally well tolerated in the absence of cardiovascular or metabolic compromise, but if protracted they cause metabolic and permanent brain changes (encephalomalacia). Seizures of any cause should be quickly controlled, hypoxia and hypoglycemia avoided and cerebral perfusion (blood pressure) optimized. After approximately 40 min, the seizures should be terminated by induction and intubation with thiopentone or propofol (Fig. 30.1).

Many children with epilepsy or recurrent febrile convulsions have an action plan and may have received treatment by parents or paramedics on the way to hospital. This treatment commonly includes rectal diazepam, intranasal or buccal midazolam or clonazepam. On occasion families are supplied paraldehyde that is administered rectally at the onset of seizures. All of these should be taken into account when assessing the child.

Once intubated effort must be made to ensure the patient stays free of seizures. This can be achieved by loading with additional anticonvulsants (a second agent—phenytoin, phenobarbitone and levetiracetam) or midazolam infusion. Occasionally a thiopentone

Table 30.7 The commonest causes of status epilepticus in children

Common causes of status epilepticus in children
Idiopathic (epilepsy)
Febrile convulsion
Tumour
Trauma
Infection (meningitis, encephalitis)
Metabolic (hypoglycaemia, hyponatremia, hypocalcaemia)

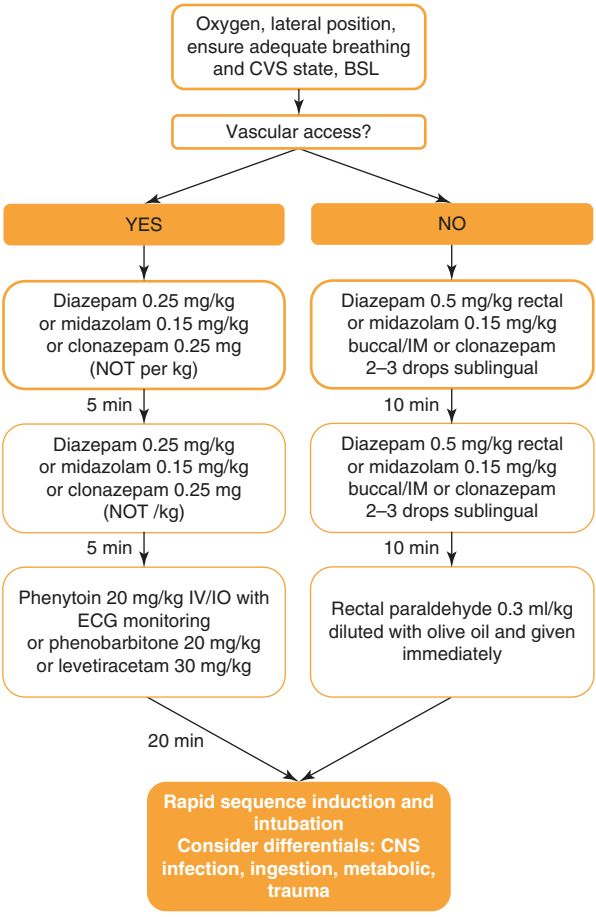

Fig. 30.1 Emergency management of seizures in a child

infusion is required, but this requires central access and often leads to an inotropic requirement. If possible, ongoing muscle relaxation should be avoided to ensure recurrent seizures are detectable. If the clinical condition requires ongoing paralysis or there are concerns about ongoing seizures, then an EEG monitoring should be used.

30.4.7 Diabetic Ketoacidosis (DKA)

DKA is characterized by the triad of hyperglycemia (blood glucose >11 mmol/L), metabolic acidosis (venous pH < 7.3 or bicarbonate <15 mmol/L) and increased total body ketone concentration. This triad of metabolic derangement is caused by insulin deficiency and the effects of counter-regulatory hormones. This may happen in a newly diagnosed diabetic, a known diabetic with an inter-current illness or (most commonly) a known diabetic with missed insulin doses.

First presentation of diabetes may be heralded by a history of polydipsia, polyuria and unexplained weight loss. Early recognition may avoid development of the acidosis. With progression, nausea, vomiting and abdominal pains are common. Lethargy, drowsiness, an acute confusional state or loss of consciousness can occur. Occasionally there is a family history of diabetes or other autoimmune endocrinopathy. Dehydration is usually present with deep, rapid breathing (Kussmaul). Lethargy, drowsiness or altered consciousness can be present with more established ketoacidosis. A venous blood gas will show metabolic acidosis with respiratory compensation, hyperglycemia and ketonemia.

Initial management should follow the lines of all unwell patients—ensure adequacy of airway, oxygen supplementation and 10 mL/kg 0.9% saline if there is evidence of circulatory insufficiency. Insulin is begun after fluid resuscitation and diagnosis.

The goals of therapy in DKA are:

- The correct of dehydration. The degree of dehydration is usually overestimated as there is a coexisting catabolic state with wasting. Rehydration after the initial fluid resuscitation is done slowly, and usually over a 24–48 h period to avoid cerebral edema. Normal saline (0.9%) is used initially to account for maintenance and deficit, and a dextrose-containing solution used as serum blood sugar levels normalize.
- To correct acidosis, reverse ketosis and restore normal blood glucose level. Insulin is started usually as an infusion at 0.1 Unit/kg/h (maximum 5 Unit/h), although intermittent subcutaneous insulin is an option.
- To avoid hypokalemia as metabolic acidosis resolves. Although there is hyperkalemia initially, there is underlying potassium depletion and hypokalemia will develop as the acidosis is corrected. Potassium will need to be supplemented and the levels monitored. Cardiac monitoring is required if the child is receiving >0.4 mmol/kg/h of potassium).
- To avoid complications of therapy. Cerebral edema is a recognized cause of death. Neurological observation should be conducted frequently in the rehydration phase of a child managed for DKA. Hypoglycemia or hypokalemia are risks of initial therapy. To adequately monitor for these complications may require nursing in a high acuity area with a dedicated access point for frequent blood gas analysis.

Review Questions

1. You are called to the emergency department to assist in the assessment and resuscitation of an unwell 2 year old boy. He has had a fever for 24 h and has become increasingly lethargic. This morning he has developed a non-blanching rash. On examination he is pale, poorly perfused and is disinterested in his surrounds. His heart rate is 195 bpm and blood pressure 120/50 mmHg with an appropriate size cuff. A lactate obtained by an arterial stab before your arrival is 8 mmol/L. The resident has not been able to obtain intravenous access.
   (a) Discuss your approach to this situation, in particular outlining priorities of management.
   (b) Comment on the blood pressure measurement.
2. The ward resident asks you to attend to a 4 year old child currently an inpatient on the pediatric ward. She had been admitted to the ward earlier in the evening with a 2 day history of a barking cough and a 6 h history of increasing stridor. She was admitted with a diagnosis of croup and was given a dose of oral steroids before admission to the ward 8 h ago. She has become increasingly agitated with a biphasic stridor. She is working hard to breathe. Her oxygen saturation before oxygen therapy was 92%, but now is fully saturated with a Hudson mask at 6 L/min.
   (a) Outline your approach to management of this child's airway issues.
   (b) Comment on the use of oxygen therapy in this child.
3. You have intubated a child for ongoing ICU care. Where is the best position for the tip of the ETT— not too high and not too low, but where? What is the best method to ensure correct depth of the ETT?

Further Reading

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A Selection of Clinical Scenarios

31

Dana Weber and Craig Sims

This chapter contains several hypothetical clinical situations that are discussed in detail to show some management options and why one option might be better than others. It will also be useful for readers preparing for the short answer question section of the exams. Although the questions are answered in an exam style, the answers are longer than would be expected in the usual short-answer format, and not every detail would be needed to score well in an exam.

31.1 An 8 Month Old, 10 kg Infant Presents for Laparotomy After a Failed Attempt at Reducing an Intussusception with a Barium Enema

(i) **Describe and justify your perioperative fluid management**

These infants are often unwell and hypovolemic from vomiting, bowel losses and rectal bleeding, and may be septicemic. Hypotension at induction is a concern, and I would ensure the infant has received 10–30 mL/kg of 0.9% saline or Hartmanns (CSL) fluid during resuscitation before induction. The response to every bolus would be assessed to guide further fluid resuscitation. 5–10 mL/kg fluid boluses could be given over 15–30 min using an infusion pump if available or by manually infusing using a three-way tap and 10 mL syringe as a 'piston-pump' (see Chap. 5, Sect. 5.4.4).

During anesthesia and surgery, any blood or fluid loss would be replaced with isotonic fluid such as Hartmanns. Ongoing maintenance fluid for a laparotomy is around 10 mL/kg/h, and this would be given in addition to any losses. Fluid status would be assessed by monitoring heart rate, BP, urine output, the

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plethysmographic or arterial trace variation with ventilation and arterial blood gases to monitor the pH, bicarbonate and lactate concentrations. The hemoglobin level would also be regularly measured, and the decision to transfuse dependent on (i) hemoglobin concentration, (ii) the likelihood of further blood loss during surgery, and (iii) the infant's cardiovascular stability. This infant does not need any glucose intraoperatively because gluconeogenesis is effective in an infant of this age and surgical stress is likely to trigger a hyperglycemic response.

Post operatively, the infant will have no oral intake. The basic maintenance rate for IV fluids for this infant is 4 mL/kg/h, or 40 mL/h. Although there is likely to be an increase in ADH secretion and fluid retention postoperatively, there will also be extravascular space losses into the peritoneal cavity, and possibly blood loss. It would therefore be reasonable to increase the maintenance rate to 50 mL/h to allow for this and frequently assess fluid status based on observations, urine output and peripheral perfusion. The infant will need glucose postoperatively while fasting. A suitable fluid needs to be a salt-rich isotonic fluid containing glucose, such as 5% dextrose with saline 0.9%. Hypotonic fluids such as 2.5% dextrose with 0.45% saline may cause hyponatremia and should be avoided in this clinical scenario. Daily measurement of plasma electrolytes will be needed while the infant is on IV fluids.

(ii) **At the completion of surgery, the hemoglobin is measured at 70 g/L. Would you transfuse this infant?**

This is a low hemoglobin, and around the 'transfusion trigger' for children of 70–80 g/L. If the infant was previously well without cardiorespiratory disease, has stable blood pressure, pulse, respiratory rate and perfusion with urine output 10 mL/h and no ongoing blood loss, transfusion can be avoided. The Hb needs to be measured regularly to ensure it is not falling.

(iii) **In what circumstances would it be reasonable to provide continuous epidural analgesia for postoperative pain relief in this child?**

Epidural analgesia would be reasonable if the infant does not appear septic and has stable observations. The anesthetist must be trained and skilled at epidural insertion in smaller infants and postoperative ward staff must be trained and familiar with the management of epidurals in infants.

31.1.1 Further Commentary

Part (i) of the question asks only about perioperative fluid management. In an exam, no marks would be scored for mentioning induction technique. If it had been asked however, induction would include the fluid boluses discussed above, a modified rapid sequence induction, and a technique to prevent hypotension at induction. Such a technique might be fentanyl 1–2 μg/kg, allowing time for this to take effect to reduce the induction dose of propofol to about 2 mg/kg, or using ketamine 1–2 mg/kg for induction.

See Chap. 15 Sect. 15.11 about intussusception, and Chap. 5 Sects. 5.3 and 5.4 about IV fluids.

31.2 A Girl Who Has Just Turned 9 Years Old and Weighs 26 kg Is Scheduled for Laparoscopic Appendicectomy. She Has a 36-h History of Abdominal Pain and Nausea, and Has an IV Line In Situ

(i) **Describe your induction technique, including airway management.**

This child is at risk of aspiration and will need a modified rapid sequence induction and endotracheal intubation. The formula for cuffed ETT size suggests 3.5 + 9/4 = 5.75 mmID ETT. I would choose to use a 5.5 mmID ETT, since rounding up to a size 6 mm ETT may result in the cuff catching at the cricoid ring.

Induction technique: Ensure preparation of equipment and drugs and confirm there is a skilled assistant who is familiar with the application of cricoid pressure in children. If there is concern the child is dehydrated or hypovolemic, a 10 mL/kg bolus of Hartmanns would be given before induction.

I would use a modified rapid sequence induction with preoxygenation, fentanyl 0.5–1 μg/kg and propofol 4–5 mg/kg, followed by rocuronium 0.6 mg/kg, application of cricoid pressure and gentle mask ventilation with a high concentration of sevoflurane (4–6%) while monitoring blood pressure. After 2–3 min, or guided by a nerve stimulator assessing paralysis, intubation would be performed with the cuff of the ETT passed just beyond the vocal cords. After checking for $ETCO_2$ and bilateral air entry, the assistant can release cricoid pressure.

(ii) **During intubation, there is a good view of the vocal cords, but a 5.5 mmID and then a 5.0 cuffed ETT will not pass beyond the vocal cords. What will you do?**

The first step would be to ensure the vocal cords are relaxed either clinically or by using a nerve stimulator to confirm muscle relaxation peripherally. Next I would choose a 5.0 UNcuffed ETT. A 4.5 mm cuffed ETT could be used instead, but the internal diameter is small and resistance high in a child of this age. All intubation attempts would be performed gently to avoid airway trauma. Dexamethasone 8–12 mg would be given to reduce the likelihood of airway edema and stridor after extubation, and an ENT review arranged postop. If an ETT even smaller then 5 uncuffed or 4.5 cuffed were needed for intubation, then edema causing critical airway narrowing and obstruction would become a concern, and keeping the child intubated postop until an urgent ENT review would probably be best.

(iii) **Intubation was achieved with a 5.0 mmID uncuffed ETT and surgery was uneventful. A mildly inflamed, non-perforated appendix was removed. How will you ensure the child is comfortable postop?**

A multimodal approach to analgesia would be appropriate, with intraoperative analgesia including morphine 4–5 mg (0.1–0.2 mg/kg), IV paracetamol 390 mg (15 mg/kg), parecoxib 15 mg (0.6 mg/kg) and local anesthetic infiltration to the laparoscope port sites with 8.5 mL of ropivacaine 0.75% (2.5 mg/kg

maximum dose). Ondansetron 4 mg would reduce postoperative nausea and vomiting. The child is likely to tolerate oral fluids soon after surgery, and oral analgesia could be used. Oral paracetamol and ibuprofen could be given regularly, and oral oxycodone 2–4 mg 6 hourly as required. Isotonic IV fluids would be continued until the child is drinking adequate amounts.

31.2.1 Further Commentary

There are many possible ways of anesthetizing this child for this procedure, but the question has asked for the technique I would use. The answer needs to reflect the reasons for the method chosen. A modified rapid sequence induction (RSI) was used for this child. The classic RSI is an adult technique that cannot be brought across and used in children. It includes a predetermined dose of induction agent immediately followed by suxamethonium and then apnea until intubation. It includes the risks of hypoxia, awareness, and a hurried, traumatic intubation. Important factors leading to aspiration are insufficient anesthesia, coughing, and straining during induction or intubation. The hurried nature of RSI does not ensure the absence of these factors.

Gentle mask ventilation is safe during cricoid pressure, does not inflate the stomach and prevents apnea and hypoxia. Because mask ventilation is performed before intubation, there is no need to obtain a rapid paralysis, and a standard dose of rocuronium can be used. Children also benefit from a faster onset of relaxants. Over-pressuring with a high concentration of sevoflurane enhances muscle relaxation and prevents awareness (because the brain concentration of sevoflurane will be lower than the inspired concentration over the short time of induction). Monitoring of relaxation to determine the time of intubation is optimal, but it may not always be possible to apply the monitor before induction, and it is difficult to apply once the assistant is busy performing cricoid pressure.

Cricoid pressure was used for this child. There has been debate about the effectiveness of cricoid pressure, particularly since it can make intubation more difficult. Although some have abandoned its use, it is still a common part of anesthesia and reasonable to persist with at this stage. However, it should be lessened or removed if there is mask ventilation is difficult or of intubation is difficult.

Sometimes the bulky, low pressure high volume cuff of the ETT gets held up at the cricoid ring during intubation, and one size smaller than expected needs to be used. In this child however, a 5.0 tube won't pass either. This is the correct size ETT for a 6 or 7 year old, and it is unusual that it won't pass in a 9 year old. A cautious approach to intubation is needed to avoid severe stridor and upper airway obstruction after surgery. Dexamethasone is given to reduce edema at the cricoid, and this is particularly important in young children who already have a small airway diameter. A small concern about dexamethasone for the scenario patient is the concurrent appendicitis and any possible immunosuppression it might cause.

See also Chap. 1, Sect. 1.6.3 about rapid sequence induction, Chap. 4 Sect. 4.7.1 about cuffed endotracheal tubes, and Chap. 9 Sect. 9.3 about analgesics.

31.3 A 12 Year Old Girl Is Admitted for a Diagnostic Gastroscopy

(i) **Describe your anesthetic technique for this child.**

After preoperative assessment and obtaining informed consent from the parent and assent from the girl, induction would be performed in an area with suitable equipment, monitoring and skilled assistance.

After either inhalational or IV induction, anesthesia would be maintained with bolus doses of propofol containing alfentanil 25 μg/mL. Dosing would be adequate to provide unconsciousness, immobility, and to suppress upper airway reflexes while avoiding excessive amounts causing apnea. Equipment to support respiration would be immediately available.

(ii) **On arrival in theater, she is anxious and upset. She tells you she doesn't want the procedure anymore. Her mother is present in theater and insists you go ahead with the anesthetic. How would you proceed in this scenario?**

She is having an elective procedure which could be rescheduled if required, though this has implications for the family's and health care facility's time and use of resources. Although she might be less anxious on another day, simply rescheduling may not improve the situation next time.

She is younger than the legal age to consent or withhold consent, and the parent is able to decide for her at this age. Although she is an older child at 12 years of age, she is unlikely to be Gillick-competent because of her extreme anxiety affecting her reasoning—any long-term desire of hers to have the procedure and obtain a diagnosis of her condition is overwhelmed by her acute anxiety and short-term desire to avoid anesthesia and the procedure. She is too old to restrain, and to do so would be extremely upsetting for her, her mother and all staff present.

The first step would be a discussion with her about the reasons for her anxiety. At this age, children often fear awareness, death or pain. Discussion with her and her mother about her fears may be enough for her to regain her confidence and cooperation. Nevertheless, induction of anesthesia is a stressful time for any person, and she may also benefit from premedication such as oral midazolam 0.5 mg/kg to a maximum of 15 mg given 30 min before induction.

If these steps weren't successful, rescheduling of the gastroscopy could be considered after discussion with the proceduralist about its urgency. The child could be taught coping skills by a psychologist in the interim. A premed given in a planned manner at the next admission, before her anxiety has escalated, may also be more effective.

See also Chap. 1, Sect. 1.4 about consent and Gillick competency, and Chap. 27, Sect. 27.6 about endoscopy.

31.4 A 2 Year Old Child Is Scheduled for Rigid Bronchoscopy and Possible Removal of an Inhaled Foreign Body

(i) **How is the diagnosis of an inhaled foreign body made in young children?**

History: The caregiver may witness the child choking on an object. There is usually a sudden onset of symptoms including cough, wheeze or stridor. If the foreign body is large and lodges high in the respiratory tract (larynx or trachea), the child may have sudden onset of choking, breathlessness, cyanosis or stridor. Some cases may be subtle with cough, persistent chest infections or wheeze and can be difficult to differentiate from other common pediatric respiratory conditions, such as croup, asthma and pneumonia.

Examination may be normal, but may reveal tachypnea, wheeze or absent breath sounds on the affected side, or in more severe cases, cyanosis or respiratory distress.

Investigations: A chest X-ray is often normal, as most foreign bodies are radiolucent. It may show atelectasis or consolidation from blockage of a bronchus. The expiratory chest X-ray classically shows hyperinflation of the affected side, due to the foreign body acting as a ball valve and trapping gas distally, but this is uncommon. CT scanning sometimes shows a foreign body but may also delay diagnosis. Sometimes bronchoscopy must be performed to exclude an inhaled foreign body.

(ii) **The child has a cough and quiet expiratory stridor, but has no respiratory distress and is otherwise well. SpO_2 breathing air is 97%. Outline your anesthesia technique and the rationale for it.**

I would begin by discussing the surgeon's planned technique for bronchoscopy, the plan for anesthesia, and how we will communicate about ventilation and the airway during the bronchoscopy. After ensuring there is skilled assistance and preferably a second anesthetist, an inhalational induction with sevoflurane in 100% oxygen would be performed. This allows a gradual onset of anesthesia, and allows the airway patency and the ability to gently assist ventilation to be assessed. Using 100% oxygen during induction preoxygenates the child.

After induction and insertion of an IV catheter, a bolus of propofol 1–2 mg/kg would be given to suppress laryngeal reflexes, direct laryngoscopy performed and the vocal cords and trachea sprayed with 2% lidocaine 3 mg/kg using an atomizer spray device. Fentanyl 0.5 μg/kg would be given incrementally (avoiding apnea) to supplement anesthesia. Mask anesthesia would then continue until bronchoscopy begins.

I would choose to use a pediatric T-piece circuit for this procedure because it is lightweight when attached to the bronchoscope and allows rapid changes in the inspired concentration of volatile agent. I can also assess lung compliance if there are problems with ventilation in this small child more readily with the T-piece than with a circle circuit.

When the surgeon is ready to begin bronchoscopy, the face mask would be removed, the bronchoscope inserted and the anesthetic circuit connected to the side arm of the ventilating bronchoscope. I would give 4–6% sevoflurane in 4–6 L/min of 100% oxygen during the procedure. Propofol boluses 1–2 mg/kg would be given to quickly deepen anesthesia if required. If the child was breathing spontaneously without coughing and remaining immobile, anesthesia would continue while monitoring the adequacy of ventilation and depth of anesthesia. If the child seemed inadequately anesthetized with either coughing, movement or breath-holding, anesthesia would be deepened with sevoflurane and propofol, and gentle ventilation.

When the surgeon removes the eyepiece of the bronchoscope, I would stop ventilation and temporarily turn off the sevoflurane to reduce theatre pollution.

If the procedure is difficult or prolonged, dexamethasone 0.5–0.6 mg/kg could be considered to reduce edema at the cricoid that might be caused by passage of the bronchoscope—this could be discussed with the ENT surgeon performing the procedure. IV fluids would be given because the child will not be able to drink until 60 min after the vocal cords were sprayed with lidocaine.

At the end of the procedure when the bronchoscope is removed, the facemask would be reapplied and the child placed in the left lateral position. I would give oxygen and remain with the child monitoring them until awake.

(iii) **List the possible causes of hypoxemia during rigid bronchoscopy**

The bronchoscope within a mainstem bronchus or beyond (only one lung being ventilated)

Anesthesia inadequate with coughing, bucking, abdominal-wall rigidity

Prolonged apnea or hypoventilation

The foreign body shifting to block a mainstem bronchus, the trachea or the larynx

Atelectasis of the lung

Measurement error

Equipment problems

31.4.1 Further Commentary

Some would use TIVA for these cases, and this is particularly useful for difficult, prolonged procedures during which the window of the bronchoscope is removed frequently and for prolonged periods. A small dose of fentanyl supplements propofol and volatile anesthesia, but the dose must be cautious to avoid apnea or hypoventilation. Some would use alfentanil instead. Some others would use remifentanil or ketamine with propofol.

See also Chap. 17 for discussion of alternatives during bronchoscopy—spontaneous or controlled ventilation, volatile or intravenous anesthesia.

31.5 You Are to Anesthetize a 3.5 kg Neonate for Laparotomy. Justify the Endotracheal Tube You Would Use for This Neonate

This neonate (first 30 days) weighs 3.5 kg and therefore likely to be near term, and not preterm.

I would use a size 3 mmID microcuff ETT with the cuff inflated at or below 20 cmH_2O. If it does not easily pass the subglottis, I would use a 3 mmID UNcuffed ETT.

This ETT was chosen because it has a high volume, low pressure cuff and there is evidence it is safe in this age group. Compared with an uncuffed ETT, there will be no leak, PEEP can be applied without difficulty and the $ETCO_2$ and tidal volumes can be measured more accurately. Lower fresh gas flow rates can be used and pollution with anesthetic gases leaking around the ETT is avoided. The size of the ETT is more likely to be correct at the first attempt compared to an uncuffed ETT, so there will be less tube changes and possible complications from the changes. The smaller internal diameter of the cuffed ETT will increase resistance compared to the larger uncuffed ETT for this age, but this would not be an issue because ventilation will be used during anesthesia.

The laparotomy will be associated with changes in abdominal tension and lung compliance, and a cuffed ETT may allow better control of ventilation with changes in compliance. The laparotomy may be associated with a regurgitation and aspiration risk, and the cuffed ETT might provide better protection than an uncuffed ETT.

You could write a paragraph justifying an uncuffed ETT if you chose that instead. See Chap. 4 Sect. 4.7.2 and Chap. 14 Sect. 14.9.4.

31.6 A 6 Year Old Boy with Duchenne Muscular Dystrophy (DMD) Presents for Emergency Open Reduction and Fixation of His Fractured Tibia. He Is Usually Well and Active, and Has Been Taking Oral Prednisolone for More Than 1 Year. He Last Ate 12 h Ago

(i) **What are the concerns for anesthesia for this boy?**

The anesthetic concerns are:

(i) Suxamethonium is contraindicated in DMD as it may cause rhabdomyolysis and hyperkalemic cardiac arrest.

(ii) There are many reports of volatile anesthetic agents triggering rhabdomyolysis in DMD.

(iii) He is taking long-term steroids for the management of his muscular dystrophy, and may need steroid cover.

(iv) He has a chronic medical condition, is likely to have a lot to do with hospitals, and may be wary and anxious of medical procedures.

(v) Emergency surgery is planned, and there is a risk of aspiration during anesthesia. However, the fasting duration is acceptable.

(ii) **Are there any investigations you would like to perform before anesthesia and surgery?**

Routine electrolytes and hemoglobin levels are unlikely to be helpful. The creatine kinase could be measured, but will be elevated and will not contribute to any decisions about anesthesia. Children with Duchenne muscular dystrophy can develop cardio-respiratory problems, but this child is active and young, and unlikely to have developed these problems yet.

(iii) **Outline your anesthetic technique for him**

Could use spinal or epidural anesthesia for this procedure—potential problems:

- Managing the child's anxiety while performing the block and during surgery,
- Dealing with inadequate analgesia from the block
- Possibility of hurriedly converting to general anesthesia during surgery
- Not accustomed with technique in children
- More familiar with general anesthesia, and would choose this but avoid volatile anesthetic agents and maintain anesthesia with propofol.

Technique would include:

- Prepare anesthetic machine by removing the vaporizer.
- Premedication with oral midazolam 0.3–0.5 mg/kg 30 min before induction, to reduce anxiety and facilitate IV insertion (since inhalational induction after a failed IV insertion is not possible).
- IV induction with propofol 4–5 mg/kg, depending on the effect of the premed on the child (premed will reduce the dose of propofol needed for induction).
- Size 2.5 LMA to avoid muscle relaxant.
- Maintain anesthesia with nitrous oxide in oxygen and propofol infusion starting at 15 mg/kg/h, reducing to 12–13 mg/kg/h after 15 min, then 11 mg/kg after another 15 min, and 10 mg/kg thereafter (Macfarlane regimen), depending on depth of anesthesia and response to surgery.
- BIS monitor because IV anesthesia has a greater risk of awareness; careful monitoring of clinical depth.
- Steroid cover with IV hydrocortisone will be needed for the surgical stress response. It would be appropriate to seek advice from pediatric endocrinology about this. In the interim, hydrocortisone 2.5 mg/kg (maximum 50 mg) would be given during surgery.
- Analgesia with morphine 0.1 mg/kg, IV paracetamol 15 mg/kg, and infiltration of the wounds with local anesthetic.
- Ondansetron IV and Hartmanns IV fluid
- Oral paracetamol and ibuprofen postoperatively
- Depending on extent of surgery, oral opioids (oxycodone 0.1 mg/kg) or IV PCA morphine.

(iv) **You have attempted to insert an IV cannula to induce anesthesia 3 times but have not succeeded. The child is upset and fearful. What will you do?**

It would be reasonable to ask another anesthetist for help with the IV

Nitrous oxide during attempted insertion

Give another oral premed, such as ketamine and try again when premed is effective

Induce anesthesia with IM ketamine 5 mg/kg

See Chap. 12 Sect. 12.2.3 about muscular dystrophy.

Further Reading

Simpson RS, Van K. Fatal rhabdomyolysis following volatile induction in a six year old boy with Duchenne muscular dystrophy. Anaesth Intensive Care. 2014;42(1):805–7.

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Glossary of Syndromes and Diseases

32

Charlotte Jorgensen

This glossary briefly outlines some conditions that may be encountered as part of a busy pediatric practice. The list is not complete, as other conditions are covered within the various chapters. For this reason, details about specific conditions are best accessed using the main index at the rear of the book.

Acyl CoA Dehydrogenase Deficiencies (Also Fatty Acid Oxidation Disorders) Mitochondrial enzyme defects affecting fatty acid metabolism with a buildup of toxic substances and over-utilization of peripheral glucose. Medium chain acyl-CoA dehydrogenase deficiency (MCADD), VLCADD and LCHCADD are the most problematic for anesthesia. Risk of hypoglycemia and metabolic crisis with high fat diet or poor oral intake. Avoid prolonged fasting, suxamethonium and propofol infusion. Consider 10% dextrose.

ADEM Acute disseminated encephalomyelitis. Frequently has a history of preceding infection or vaccination. Affects myelin and white matter leading to visual loss,

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	weakness, loss of coordination and altered consciousness associated with rapid onset fever. Single episode in contrast to MS, which is recurring.
Adrenogenital Syndrome	Inherited autosomal recessive disorder affecting cortisol production by the adrenal glands with a compensatory increase in pituitary secretion of adrenocorticotropin. The results are abnormal cortisol or aldosterone synthesis and an increase in androgen production causing ambiguous genitalia in female infants, precocious sexual development in males, premature closure of growth plates, glucose and electrolyte disorders and blood pressure changes.
Apert Syndrome	Autosomal dominant abnormality of first branchial arch causing premature closure of cranial sutures, midface hypoplasia, choanal atresia, cleft palate, fusion of cervical spine (mainly C5-C6) and syndactyly. May have associated cardiac and renal abnormalities as well as intellectual impairment due to megalocephaly, hypoplasia of white matter and agenesis of the corpus callosum. Obstructive sleep apnea is present in 50% and there may be an increased incidence of upper airway obstruction at induction, which is mostly overcome by routine maneuvers.
Arthrogryposis Multiplex Congenita	AMC is a physical diagnosis involving multiple joint contractures, possibly due to congenital myopathy before birth. Contractures may affect neck and mouth, and may affect respiratory function directly or by causing scoliosis.
Ataxia-Telangiectasia	Autosomal recessive disorder with progressive neurological impairment and early onset of cerebellar ataxia, telangiectasia and variable immune deficiency and predisposition to malignancy. Hypersensitive to medical radiation.

Beckwith-Wiedemann Syndrome Macroglossia, visceromegaly and hypoglycemia from insulin-like growth factor. Associated with omphalocele and diaphragmatic eventration in neonates. Increased risk of Wilms tumor and hepatoblastoma. Must receive glucose while fasting.

CHARGE Syndrome Syndrome consisting of coloboma of the eyes, heart defects, choanal atresia, developmental delay, intellectual impairment, genitourinary anomalies and ear anomalies. These children are frail with multiple abnormalities. Cardiac defects and poor respiratory reserve most problematic for anesthesia.

Chickenpox Varicella zoster virus is highly contagious and will spread via respiratory droplets or direct contact. Patients are infectious from 2 days before the rash appears until all blisters have crusted. Exposed patients should be isolated from 8 to 21 days after the exposure.

Chromosome 22q11.2 Deletion (DiGeorge) Syndrome The most common microdeletion (approximately 1:4000) causing phenotypically similar disorders including DiGeorge and Velocardiofacial syndromes with cardiac disease, hypoparathyroidism, immunodeficiency mainly related to T cell changes, autoimmune disease, intellectual impairment and psychiatric disorders including ADHD, anxiety and psychosis in adults. Facial abnormalities such as micrognathia and cleft palate may cause airway difficulties.

Cornelia De Lange Syndrome Rare genetic disorder with IUGR, short stature, moderate to severe intellectual disability, gastro-intestinal problems and malformations mainly affecting the upper limbs. Distinctive facial features include arched eyebrows which meet in

	the middle, low set ears and widely spaced teeth. May be associated with microcephaly, micrognathia, cleft palate, diaphragmatic hernia and cardiac abnormalities.
Cri-du-Chat Syndrome	Characterized by a high-pitched, cat-like cry. Micrognathia and abnormal larynx. Hypotonia, severe intellectual disability. Cardiac defects common.
Crouzon Syndrome	Inherited in an autosomal dominant pattern, although over half are new mutations. Abnormality of first branchial arch causing underdevelopment of the midface with craniosynostosis, exophthalmos, hypertelorism, hydrocephalus, Chiari type I malformation and hindbrain herniation. The upper cervical vertebrae may be fused occasionally. When the mandible size is normal and there are no neck issues, mask fit may be awkward but intubation is usually straightforward.
Cystic Hygroma	Congenital benign multiloculated lesion of lymphatics which can occur anywhere in the body, but typically occurs in the neck, where it may cause significant airway problems.
Dandy-Walker Malformation	Hypoplasia of the cerebellar vermis with expansion of the fourth ventricle and hydrocephalus. Causes raised intracranial pressure, intellectual impairment, developmental delay with signs of cerebellar dysfunction, and central respiratory disorders.
Di George Syndrome	See chromosome 22q11.2 deletion syndrome.
Fetal Alcohol Spectrum Disorder	A disorder caused by in-utero alcohol exposure. Diagnosis is complex. Features include abnormal facies, microcephaly, poor motor skills, intellectual disability, attention deficit and hyperactivity, regulation of affect, failure to thrive and cardiac defects.

Fragile X Syndrome
Chromosomal disorder causing progressive intellectual impairment and behavioral problems, with approximately one third having features of Autism Spectrum Disorder. Seizures in 5–15%.

Freeman-Sheldon Syndrome
A rare congenital contracture syndrome with myopathy affecting the facial, limb and respiratory muscles. Also called Whistling Face Syndrome. Features include microstomia, micrognathia, microglossia, hypertelorism and joint contractures particularly of the hands and feet. Anesthetic concerns include difficult airway due to small mouth and jaw, and postoperative respiratory complications. Although there have been case reports of MH in some children with Freeman Sheldon, there is no genetic link or association.

Galactosemia
Disorder of galactose metabolism. Type 1 most common and most severe. Untreated causes failure to thrive, hypoglycemia, hepatic failure, coagulopathy and seizures. May be associated with sepsis, developmental delay and development of cataracts. Types 2 and 3 are associated with less problems.

Glandular Fever (Infectious Mononucleosis)
Epstein-Barr virus infection common in teenagers. Incubation period is 30–50 days. Associated with fever, sore throat, lethargy, lymphadenopathy and splenomegaly, although 50% do not develop symptoms. May also have a rash, jaundice and abdominal pain from enlarged liver and spleen. May last for weeks to months. Infectious period may last months after the infection and some become carriers. No need to isolate patients. Spread is via saliva and respiratory droplets.

Glucose-6-Phosphate Dehydrogenase Deficiency
X-linked enzyme deficiency causing hemolysis after certain triggers. Most patients are asymptomatic with normal

or near-normal Hb. Some present with neonatal jaundice or hemolytic crisis in response to infection or oxidative agents.

Triggers include fava beans (broad beans), fava bean pollen, sulfonamides, nitrofurans, quinolones, antimalarials, aspirin, methylene blue and other drugs. Propofol, volatile agents and opioids are safe. A rare subgroup of children have chronic hemolysis in the absence of trigger agents, and paracetamol cannot be used in this subgroup.

Glycogen Storage Diseases

Disorders of glycogen metabolism and storage. Different types vary in severity and each require unique management.

Fasting causes hypoglycemia, and each patient will know their tolerable fasting time. Older children usually able to fast overnight. These children should be first on list, have blood glucose monitored, and receive 10% dextrose 4–5 mL/kg/h if any doubt about ability to fast.

Type 1. Glucose-6-phosphatase deficiency and unable to convert glycogen to glucose. Glycogen accumulates in liver, kidneys and small intestines. Associated with hypoglycemia, lactic acidosis and hyperuricemia.

Type 2. (Pompe's disease). Glycogen infiltration causes macroglossia and potential airway difficulty.

Type 3. Glycogen debranching enzyme deficiency. Associated with muscle weakness and cardiomyopathy.

Type 4. Branching enzyme deficiency causing formation of abnormal glycogen leading to cirrhosis of the liver and fibrosis of cardiac and skeletal muscle.

Goldenhar Syndrome

Also known as Facio-Auriculo-Vertebral sequence. A defect of the branchial arches leads to a small, asymmetrical mandibular hypoplasia, small

	or absent ear, and cervical spine abnormalities. May also have intellectual impairment and cardiac defects. Airway may be difficult due to asymmetrical mandibular hypoplasia and cervical fusion. As the severity of the jaw deformity increases, so does the difficulty in intubation. The difficulty is not affected by which side the deformity is on, and may worsen with age.
Hand Foot and Mouth Disease	Coxsackie virus infection, causing blisters on the hands, feet, in the mouth and nappy area. Generally mild and in children younger than 10 years. Most adults are immune from previous infection. Spread is via direct contact, respiratory droplets and feces. The blisters last 7–10 days are infectious until they all dry out, although the virus may be shed in the feces for a further 2 weeks.
Henoch Schonlein Purpura	Most common vasculitis in childhood. Unknown etiology but half have a history of recent upper respiratory tract infection. Associated with widespread purpura, arthralgia, abdominal pain and renal involvement.
Homocystinuria	Disorder of methionine metabolism. Most common type is associated with lens dislocation, thromboembolism events and osteoporosis. May have developmental delay. Risk of hypoglycemia with fasting. Avoid nitrous oxide.
Impetigo ('School Sores')	Staphylococcus aureus or pyogenes skin infection mainly of the face, hands and feet. Commonly affects children but can occur at any age. The open sores are highly contagious, spreading via direct contact or touched surfaces such as toys, clothes, towels etc. Typically clears up in 7–10 days with topical antibiotics and personal hygiene.
Kawasaki Disease	Second most common vasculitis in childhood. Unknown etiology. May cause cardiac and cerebral ischemia

	from aneurysm formation, despite early treatment with IV immunoglobulin.
Klippel-Feil Syndrome	Congenital condition characterized by short neck, low posterior hairline and restricted cervical spine movement secondary to fused vertebrae. May be associated with other anomalies. Airway may be difficult.
Lipidosis	Lysosomal storage disease. Includes Tay-Sachs, Leigh Syndrome, Gaucher, Niemann-Pick, Fabry and Krabbe disease. Associated with hepatomegaly and developmental delay. Avoid lactate containing fluids and large doses of propofol.
Measles	Viral illness with a red and slightly raised rash associated with mild to severe constitutional symptoms. Complications include pneumonia (20%) and encephalitis. Infectious period is 24 h before rash until 4 days afterwards. Usually lasts 10 days.
Methylmalonic acidemia (MMA)	One of the organic acidurias. Abnormal methylmalonic acid metabolism causes metabolic acidosis with or without hyperammonemia. Associated with encephalopathy, hypotonia, developmental delay, hepatomegaly, hypoglycemia, recurrent vomiting and dehydration. Avoid nitrous oxide and fasting. Some concerns about large doses of propofol.
Molluscum Contagiosum	Common viral skin infection causing small raised spots with a central dimple. Mainly affects children, as adults have been exposed previously. Most heal within months without treatment. Spread is by direct contact, pool water, bath toys and towels.
Mumps	Viral illness associated with fever and swollen salivary glands. May cause encephalitis and myocarditis. Spread is by respiratory droplets and infectious period is 7 days before onset of symptoms until 8 days afterwards. However,

	one in three are asymptomatic but still infectious.
Noonan Syndrome	Short stature, flattened midface, webbed neck and micrognathia, although the airway is usually not difficult. Mild intellectual disability, cardiac defects (particularly pulmonary stenosis) and coagulopathy.
Osteogenesis Imperfecta	Inherited abnormality in collagen production leading to extremely fragile bones. Multiple genetic causes forming five clinical subtypes. Type I is the mildest and commonest, and is non-deforming with blue sclera. Severe forms are associated with scoliosis, short stature, midface hypoplasia, pointed jaw and abnormally formed teeth. Care is required with intubation, positioning and use of tourniquets. Hyperthermia during anesthesia is common, but not associated with MH. Bisphosphonate therapy is the mainstay of fracture prevention.
Phenylketonuria	Disorder of metabolism of phenylalanine to tyrosine that causes irreversible brain damage unless managed with a diet low in phenylalanine. No specific anesthetic implications if asymptomatic and on correct diet.
Prader-Willi Syndrome	Abnormality of chromosome 15 causing hypotonia, hypogonadism, intellectual disability, erratic emotions and outbursts, short stature, hyperphagia and early morbid obesity. Sleep apnea, respiratory and cardiac problems secondary to morbid obesity. See www.pws.org.au.
Rett Syndrome	Severe neurodevelopmental disorder in females only. Onset after age 1 year with regression of language skills, loss of purposeful hand movements, hypotonia, autistic behavior, deceleration of head growth and seizures. May have associated cardio-respiratory abnormalities.

Reye's Syndrome Rare, acute encephalopathy and fatty degeneration of the liver (first described by Reye in Australia in 1963). Cause is unknown, but typically preceded by a viral infection. An association with aspirin when used to treat symptoms of a viral illness lead to avoidance of aspirin in children. Underlying fatty acid oxidation disorder increases the risk.

Roseola Very common mild viral illness associated with a fine, raised, red rash and high fever in children usually aged between 6 months and 3 years. Can be confused with measles or rubella. Infectious period is before symptoms start. Main complication is febrile convulsions.

Rubella (German measles) Viral illness associated with a distinctive red rash, lymphadenopathy and coryzal symptoms. Usually mild. Associated with high risk of miscarriage or congenital abnormalities if infected during first trimester of pregnancy. Infectious period is 7 days before rash appears until at least 4 days after rash.

Russell-Silver Syndrome (Silver-Russell Dwarfism) Growth retardation in utero and after birth combined with normal head circumference, triangular face and asymmetry of limbs, body or face. Other features may include micrognathia that may be severe enough to affect intubation, feeding problems, lack of subcutaneous fat, a propensity for hypoglycemia and developmental delay. Rare cases are associated with cardiac defects. See https://www.healthline.com/health/russell-silver-syndrome.

Sturge-Weber Syndrome Neurocutaneous angiomas ('portwine stains'), typically in the trigeminal distribution. Leptomeningeal angiomas may cause seizures, focal deficits, developmental delay and learning disorders. Angiomas in pharynx or larynx may cause obstruction and require

	treatment, or can be traumatized during airway instrumentation. Airway angiomas are more likely if multiple angiomas are present or in the 'beard area' of the face.
Tourette Syndrome	Involuntary motor and vocal tics, sometimes associated with obsessive-compulsive disorder or ADHD.
Treacher Collins Syndrome	Genetic dysmorphogenesis of the first and second branchial arches. Associated with downward slanting eyes, coloboma, micrognathia, cleft palate, macrostomia, hypoplastic zygoma and abnormalities of the ear with conductive hearing loss. May have very difficult airway, and despite the laryngopharynx having an abnormal funnel-shape, the LMA is often effective. The airway becomes more difficult with age.
Turner syndrome	Chromosomal XO, thus only affecting females. Associated with short stature, hypoplasia of cervical vertebrae, webbed neck, broad chest and gonadal dysgenesis. Cardiac abnormalities occur in a third, mainly bicuspid aortic valve and coarctation of the aorta. May also be associated with renal and endocrine abnormalities, midface hypoplasia, micrognathia and learning disabilities.
VACTER(L) Association	Vertebral anomalies, Anal atresia, Cardiac defects, Tracheo-Esophageal fistula, Renal and Limb anomalies. Anesthetic considerations mainly relate to the cardiac and tracheal abnormalities. Most commonly encountered in neonates for tracheo-esophageal fistula repair. See www.vacterl-association.org.uk.
Velocardiofacial Syndrome	See 22q11.2 deletion syndrome.
Whooping Cough (Pertussis)	Highly contagious bacterial respiratory infection caused by bordetella pertussis. In adolescents and adults, it causes coryzal symptoms followed by cough lasting up to 3 months. Can be life threatening in young children, elderly

	and immunocompromised patients. Complications include pneumonia, seizures and hypoxic cerebral ischemia secondary to coughing fits. Spread is via respiratory droplets. Infectious period is likely the first 3 weeks from symptoms starting.
Williams syndrome	Spontaneous deletion of 26–28 genes on chromosome 7. Characterized by developmental delay with well-developed verbal skills, highly sociable personality, hypercalcemia and elfin-like facies with wide mouth, full lips and small chin. Cardiac abnormalities are the major problem and include supravalvular aortic stenosis, pulmonary stenosis and coronary artery abnormalities making these children high risk for cardiac arrest during anesthesia, even when completely asymptomatic. See https://williams-syndrome.org/what-is-williams-syndrome.
Wiskott-Aldrich syndrome	Primarily affects males. Immune deficiency, microthrombocytopenia with or without bleeding abnormality, eczema, and increased risk of autoimmune disorders. Overlapping signs and symptoms and same genetic cause as X-linked thrombocytopenia and severe congenital neutropenia. See www.ghr.nlm.nih.gov/condition=wiskottaldrichsyndrome.

Short-Answer Questions from Past FANZCA and FRCA Examinations

33

Craig Sims

Listed below are the pediatric anesthesia short-answer questions that have been recently asked in the Australasian and UK Fellowship exams at the time of printing. The questions are listed in the chronological order in which they were set.

We gratefully acknowledge the assistance received in the preparation of this section from the Australian and New Zealand College of Anaesthetists. Questions are reproduced with permission from the Australian and New Zealand College of Anaesthetists, January 2019.

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Percentages shown in brackets indicate allocation of marks for that part of the question.

∗ Indicates the question was asked more than once during this time period.

33.1 FANZCA Short-Answer Questions 2014–2018

1. Outline the advantages and disadvantages of using the paediatric circle system and the Jackson-Rees modification of Ayre's T-piece (Mapleson F) for anaesthesia in a 15 kg child.∗
   - 23.3% and later 70.8% of candidates passed this question.

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2. An 8 week old baby is scheduled for an inguinal hernia repair on your list at a local general hospital tomorrow.
   (a) Outline the important issues when providing anaesthesia care for this baby. (70%)
   (b) Justify your decision to proceed with surgery at the local general hospital. (30%)

   - 45.8% of candidates passed this question.

3. A 3 year old child requires an adenotonsillectomy for obstructive sleep apnoea.

   - Outline and justify your peri-operative management plan.
   - 50.3% of candidates passed this question.

4. A 6-week-old term baby weighing 4.0 kg requires pyloromyotomy for pyloric stenosis.

   - How would you assess the baby's hydration status? (50%)
   - Detail and justify your resuscitation regimen. (50%)
   - 80% of candidates passed this question.

5. A 2-year-old boy scheduled for hypospadias repair is found to have a precordial murmur. Justify your decision to proceed.

   - 74.3% of candidates passed this question.

6. Describe the anatomy relevant to performing a caudal block in a 2-year-old male.

   - 40.5% of candidates passed this question.

7. Describe your assessment of a 4-year-old child who has been rescued from a house fire.

   - 24.9% of candidates passed this question.
   - *Editor's note: This question asks for* ***assessment****, not management*

33.2 FRCA Short-Answer Questions 2014–2018

(a) List the normal anatomical features of young children (<3 years old) which may adversely affect upper airway management. (35%)
(b) Which airway problems may occur due to these anatomical features? (30%)
(c) Outline how these problems are overcome in clinical practice. (35%).

65% of candidates passed this question.

Editor's note: The Examiner's report indicated a table with columns such as 'Anatomical feature', 'Problem' and 'Managed by' was an acceptable way to answer this question. A table is also a good way to answer questions about the advantages and disadvantages of something.

1. A 5 year-old child presenting for day case dental surgery under general anaesthesia is found to have a heart murmur that has not been documented previously.
   (a) What features of the history (5 marks) and examination (5 marks) might suggest that the child has a significant congenital heart disease (CHD)?
   (b) If the murmur is caused by an atrial septal defect (ASD) what ECG findings would you expect? (2 marks)
   (c) Which imaging modalities might be used in the assessment of the ASD (2 marks) and what specific additional information may be obtained? (2 marks)
   (d) List the current national guidelines regarding prophylaxis against infective endocarditis in children with CHD undergoing dental procedures. (4 marks)

   - 39.1% of candidates passed this question

2. A 5 year-old boy with Autistic Spectrum Disorder (ASD) is listed for dental extractions as a day case.
   (a) What constitutes ASD (1 mark) and what are the key clinical features? (6 marks)
   (b) List the important issues when providing anaesthesia for dental extractions in children. (6 marks)
   (c) Give the specific problems of providing anaesthesia for children with ASD and outline possible solutions. (7 marks)

   - 46.2% of candidates passed this question.
   - *Editor's note: 'part b' refers children in general, not just those with ASD.*

3. You are called to the Emergency Department to see a 2 year-old child who presents with a 4-h history of high temperature and drowsiness. On examination there is prolonged capillary refill time and a non-blanching rash. A presumptive diagnosis of meningococcal septicaemia is made.∗
   (a) What are the normal weight, pulse rate, mean arterial blood pressure and capillary refill time for a child of this age? (4 marks)
   (b) Define appropriate resuscitation goals for this child (2 marks) and outline the management in the first 15 min after presentation. (7 marks)
   (c) After 15 min, the child remains shocked and is unresponsive to fluid. What is the most likely pathophysiological derangement in this child's circulation (2 marks) and what are the important further treatment options? (5 marks)

   - 56.9% and later 64.2% of candidates passed this question
   - *Editor's note: Be careful not to answer part c in the answer of part b.*

4. You have anaesthetised a 5-year-old boy for manipulation of a forearm fracture. During the operation you notice that he has multiple bruises on his upper arms and body that you think may indicate child abuse.
   (a) Which other types of physical injury should raise concerns of abuse in a child of this age? (6 marks)
   (b) What timely actions must be taken as a result of your concerns? (7 marks)
   (c) List parental factors (5 marks) and features of a child's past medical history (2 marks) that are known to increase the risk of child abuse.

   - 44.7% of candidates passed this question

5. A 5-year-old child with Down's syndrome (trisomy 21) is scheduled for adenotonsillectomy.
   (a) List the cardiovascular (2 marks), airway/respiratory (5 marks) and neurological (3 marks) problems that are associated with this syndrome in children and are of relevance to the anaesthetist.
   (b) What are the potential problems during induction of anaesthesia and initial airway management in this patient? (6 marks)
   (c) What are the possible specific difficulties in the postoperative management of this child? (4 marks)

   - 62.1% of candidates passed this question

6. A 12-week-old male baby presents for a unilateral inguinal hernia repair. He was born at 30 weeks gestation (30/40).
   (a) What are the specific perioperative concerns in this baby? (11 marks)
   (b) What are the options for anaesthesia? (4 marks)
   (c) Discuss the advantages and disadvantages of general anaesthesia for this baby. (5 marks)

   - 28% of candidates passed this question.

7. A 5-year-old boy presents for a myringotomy and grommet insertion as a day case. During your pre-operative assessment you notice that he has a nasal discharge.*
   (a) List the features in the history (5 marks) and examination (6 marks) that would potentially cause an increased risk of airway complications?
   (b) Why would it be inappropriate to cancel the operation? (6 marks)
   (c) What social factors would prevent this child being treated as a day case? (3 marks)

   - 74% of candidates passed this question.

8. An 8 year old child is scheduled for an elective right femoral osteotomy due to impending dislocation of the hip. She has severe cerebral palsy.
   (a) What is cerebral palsy? (3 marks)
   (b) List typical clinical features of severe cerebral palsy, with their associated anaesthetic implications. Do this for the central nervous system (3 marks),

respiratory system (2 marks), musculoskeletal system (3 marks) and gastrointestinal system (2 marks).

(c) What are the expected problems in providing adequate postoperative analgesia in this patient? (2 marks)

(d) Outline a management plan to optimise analgesia in this patient. (5 marks)

- 78.8% of candidates passed this question

9. You are asked to assess a 15kg 4-year-old child who is scheduled for a strabismus (squint) correction as a day case procedure.

(a) List the anaesthetic considerations of this case, with regards to: age of the patient (4 marks), day case surgery (3 marks) and type of surgery. (4 marks)

(b) During the operation, the patient suddenly develops a profound bradycardia. What is your immediate management of this situation? (2 marks)

(c) What strategies would you employ to reduce postoperative nausea and vomiting (4 marks) and postoperative pain? (3 marks)

- 51.6% of candidates passed this question.

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C. Sims et al. (eds.), *A Guide to Pediatric Anesthesia*,
https://doi.org/10.1007/978-3-030-19246-4