PAEDIATRIC ANAESTHESIA REVIEW

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This article outlines the essential principles of safe paediatric anaesthesia covering the basics of anatomy, physiology and pharmacology emphasising the differences which exist between adults and children. It assesses how principles used in adult anaesthesia may be adapted to paediatric anaesthesia and includes suggested techniques, monitoring methods, regimens for fluid management and new advances in paediatric pain management. It is divided into three sections; physiology, pharmacology and practical considerations.

PHYSIOLOGY

One of the most important differences between paediatric and adult patients is oxygen consumption which, in infants may exceed 6 ml/kg/min, twice that of adults. There are physiological adaptations in paediatric cardiac and respiratory systems to meet this increased demand.

Cardiovascular. The cardiac index (defined as the cardiac output related to the body surface area to allow a comparison between different sizes of patients) is increased by 30-60 percent in neonates and infants to help meet the increased oxygen consumption. Fetal haemoglobin (which is present in fetal life and up to 3 months following birth) is not able to deliver oxygen to the tissues as efficiently as normal haemoglobin because the oxy-haemoglobin dissociation curve is shifted to the left causing oxygen to be released less readily. Neonates have a higher haemoglobin concentration (17 g/dl) and blood volume and this together with the increased cardiac output compensates for the decreased release of oxygen from haemoglobin in the tissues. Replacement of fetal haemoglobin with adult haemoglobin begins at 2-3 months of age and this period is known as physiological anaemia as haemoglobin concentrations may fall to 11 g/dl. Anaemia sufficient to jeopardise oxygen carrying capacity of the blood is possible if the haemoglobin concentration is less than 13 g/dl in the newborn and less than 10 g/dl in the infant under 6 months of age.

Neonatal myocardium has a large supply of mitochondria, nuclei and endoplasmic reticulum to support cell growth and protein synthesis but these are non-contractile tissues which render the myocardium stiff and non-compliant. This may impair filling of the left ventricle and limit the ability to increase the cardiac output by increasing stroke volume (Frank Starling mechanism). Stroke volume is therefore relatively fixed and the only way of increasing cardiac output is by increasing heart rate.

The sympathetic nervous system is not well developed predisposing the neonatal heart to bradycardia. Anatomical closure of the foramen ovale occurs between 3 months and one year of age. Arterial blood pressure increases with age.

Table 1 depicts many of these cardiovascular differences.

Age	Neonate	Infant	1yr	5yr	Adult
0_2 Consumption (ml/kg/min)	6	5	5	4	3
Systolic BP (mmHg)	65	90	95	95	120
Heart Rate (beats/min)	130	120	120	90	77
Blood Volume (ml/kg)	85	80	80	75	70
Haemoglobin (g/dl)	17	11	12	13	14

Respiratory. There are some special features peculiar to the paediatric airway. The head is relatively large with a prominent occiput, the neck is short and the tongue is large. The airway is prone to obstruction because of these differences. Infants and neonates breathe mainly through their nasal airway, although their nostrils are small and easily obstructed. The larynx is higher in the neck (more cephalad), being at the level of C3 in a premature infant and C4 in a child compared to C5-6 in the adult.

The epiglottis is large, floppy and U shaped. The trachea is short (approximately 4-9 cm) directed downward and posterior and the right main bronchus is less angled than the left. Right mainstem intubations are therefore more likely. The glottic opening (laryngeal opening) is more anterior and the narrowest part of the airway is at the cricoid ring. (In the adult airway the narrowest point is the vocal cords). The diameter of the trachea in the newborn is 4-5mm. Since the resistance to airflow through a tube is directly related to the tube length and inversely related to the fourth power of the radius of the tube, tracheal oedema of just 1mm can dramatically increase resistance to breathing.

The size of the endotracheal tube is critical, as one that is too large will exert pressure on the internal surface of the cricoid cartilage resulting in oedema which could lead to airway obstruction when the tube is removed. An uncuffed endotracheal tube which has an air leak around it when positive pressure is applied to it should be used in children under 10 years of age. An uncuffed tube provides a larger internal diameter compared with a cuffed tube. In general the internal diameter of endotracheal tube related to age is as follows:

Premature	2.5 - 3.0 mm
Neonate to 6 months	3.0 - 3.5 mm
6 months - 1 year	3.5 - 4.0 mm
1 - 2 years	4.0 - 5.0 mm
> 2 years Use the formula	$4 + \frac{\text{Age}}{4}$

Because of the higher position of the larynx and the shape of the epiglottis intubation may be easier in infants and young children using a straight bladed laryngoscope to elevate the epiglottis rather than a curved Mackintosh blade in the vallecula. Although the length of the trachea varies, in most infants up to one year of age, if the 10cm mark of the endotracheal tube is at the alveolar ridge (gums), the tip of the tube is just above the carina. With older children an easy formula of

$\frac{\text{Age}}{2} + 12$ will provide a guide to which mark should be at the lips. After intubation the tube should be secured carefully to the maxilla rather than the mandible which is mobile and the position of the tube checked by auscultation and capnography if this is available.

Alveolar minute ventilation is increased to meet the increased oxygen demands. Carbon dioxide production is also increased in neonates but a normal $PaCO_2$ level (blood CO_2 level) is maintained by the increased alveolar ventilation. Tidal volume is similar for adults and children on a ml/kg basis, so that the increased alveolar ventilation is achieved by an increase in respiratory rate. All of these factors give the lungs less reserve of oxygen so that a well oxygenated infant with upper airway obstruction can become cyanotic in a matter of seconds. Control of ventilation is immature in neonates and responses to hypoxic conditions are unpredictable, sometimes resulting in periods of apnoea. Ex-premature babies are at risk of apnoea following general anaesthesia up to 52 weeks gestational age and should be closely observed for 24 hours post operatively.

Infants have relatively soft chest walls compared with the more rigid chest wall of older children and adults. This results in intercostal and sternal recession in small children with airway obstruction. The diaphragm is responsible for most of the ventilation in this group and anything tending to decrease its efficiency, such as a distended abdomen, may cause respiratory problems for the infant.

Renal system and fluid balance. The neonatal kidney is characterised by a decrease in glomerular filtration rate, sodium excretion and concentrating ability. These values slowly approach those of the adult by 12 months of age. Consequently, the infant cannot handle a large water load and may be unable to excrete electrolytes.

The extracellular fluid volume (ECF) is equivalent to about 40% of the body weight in neonates as opposed to 20% in adults. This difference has disappeared by the age of two years. The increased metabolic rate of infants results in a faster turnover of extracellular fluid. An interruption of the normal fluid intake can therefore rapidly lead to dehydration and careful attention to intra-operative fluids is mandatory. Fluid requirements can be considered as **maintenance fluids and replacement fluids.**

Maintenance fluid requirements are calculated on an hourly basis depending on the body weight. A suitable way of working this out is as follows: 4 ml/kg for the first 10 kg, adding 2 ml/kg for the second 10 kg and 1 ml/kg for each kg over 20kg.

Example of maintenance fluid calculation:

8kg child
8kg X 4mls/kg = **32mls/hour maintenance**

12kg child (is 10kg + 2kg)
10kg X 4mls/kg = 40mls/hr
+2kg X 2mls/kg = 4mls/hr
Total = 40 + 4 = **44mls/hour maintenance**

25kg child (is 10kg + 10kg + 5kg)
10kg X 4mls/kg = 40mls/hr
+10kg X 2mls/kg = 20mls/hr
+ 5kg X 1ml/kg = 5mls/hr
Total = 40+20+5= **65mls/hr maintenance**

The maintenance fluid replaces the fluid that the child would normally have been drinking. After most minor or moderate surgery children will return to drinking fairly quickly and make up any deficit. However after major surgery or when there are pre-existing fluid deficits intravenous maintenance fluids will be required. A regimen with 30% of the fluid as normal saline and 70% as dextrose 5% is suitable for this purpose. Alternatively 4% glucose in 0.18% saline may be used.

Replacement fluids. Patients undergoing surgery may also need intravenous fluid to replace abnormal losses of fluid from bleeding or "third space" loss and any pre-existing deficits. "Third space" loss refers to fluid which is lost from the circulation during surgery. Some of this fluid forms oedema in the area of the operation, some may be lost into the bowel and there may also be losses from evaporation. In general the more major the surgery the more replacement fluid will be required. These losses are commonly replaced by balanced salt solutions such as Hartmanns solution. Colloid solutions are sometimes used when losses are heavy.

Body surface surgery (eg a hernia), or surgery involving a distal extremity will result in only minor fluid losses and replacement fluids will only be needed in the event of significant blood loss. Abdominal or chest surgery will have much greater requirements for fluids and possibly blood. In general abdominal surgery will need extra fluid to replace these third space losses at around 10mls/kg/hour for each hour of surgery.

Pre-existing deficit. Patients who are already fluid depleted preoperatively need replacement in a volume proportional to the degree of dehydration estimated on the basis of the history and clinical signs: Dry skin and mucus membranes represents a 5% deficit. Cool peripheries and loss of skin elasticity, depressed fontanelles and eyeballs and oliguria represents a 10% deficit. A hypotensive moribund patient, unresponsive to pain represents a 15% deficit. The volume required to replace this deficit is calculated as the percent deficit times 10mls/kg. Whenever possible fluid deficits should be corrected prior to surgery, though time is always limited with emergency or urgent surgery. If venous access is impossible fluids can be administered via the intra-osseous route (Update in Anaesthesia Number 5, page 17).

Replacement of blood. Blood volume varies according to age (Table 1). In general blood replacement is required when the haematocrit drops below 25% (around a Hb of 8g/dl) or when the estimated blood loss exceeds 20% of the calculated blood volume. Lesser degrees of blood loss can be replaced by colloid, such as gelatin, dextran or albumin or crystalloid solutions. If crystalloid is used then a volume of three times the estimated blood loss should be given, usually in the form of lactated Ringers (Hartmanns solution) or 0.9% saline. Try to warm iv fluids for children in theatre if they are receiving replacement fluids.

Calculation of blood loss is best done by collecting and measuring suction blood during the procedure. Swabs may be weighed on a simple pair of kitchen type scales. If the weight of the dry swabs is subtracted from the total weight then the extra grams can be taken to indicate the number of mls of blood on the swab. The swabs should be weighed before they dry, because of inaccuracies due to evaporation.

Temperature regulation. Maintenance of body temperature may be a major problem even in warm countries. Neonates and infants have a large surface area to volume ratio and therefore a greater area for heat loss, especially from the head. There is an increased metabolic rate but insufficient body fat for insulation and heat is lost more rapidly. Infants

less than three months of age do not shiver and rely primarily on non-shivering thermogenesis to generate heat. The heat is produced in the brown fat and occurs only in infants. The fat is located primarily around the scapula, in the mediastinum and around the adrenal glands and kidneys. It is important to maintain a warm environment to minimise heat loss. For the very small neonate, operating room temperatures must be increased much to the dismay of the surgeon in heavy operating room scrub suits! In addition to warming the environment, heat loss may be reduced by wrapping the limbs and head in wool or foil, placing the child in a heating blanket, warming and humidification of inspired gases and warming of intravenous fluids. Very occasionally, in a hot theatre environment, children may become too hot, particularly if they were pyrexial preoperatively. Atropine or ether anaesthesia may increase this tendancy. The temperature can be measured in theatre using a simple thermometer.

PHARMACOLOGY

Changing factors during development determine the response of the paediatric patient to various drugs. These include those affecting pharmacokinetics (absorption, distribution and elimination) and those affecting pharmacodynamics (the effect of the drug on the body).

Inhalational agents. Both induction and emergence from anaesthesia are more rapid in children than in adults. This is probably because of a smaller lung functional residual capacity per unit body weight and a greater tissue blood flow, especially to the vessel rich group (brain, heart, liver and kidney). The vessel rich group in adults is 10 percent of body weight versus 22 percent in neonates.

Anaesthetic potency has traditionally been measured by the minimal alveolar concentration (MAC) required to prevent response to a surgical incision. The anaesthetic requirements of paediatric patients vary according to age. In general the MAC of inhalational agents are greatest in the young and decrease with age. However neonates require lower concentrations of volatile anaesthetics than infants. For example the MAC in preterm neonates for halothane is 0.87 percent compared to 1.20 in older infants. MAC decreases to 0.9 by 3 years of age and then progressively declines with age reaching 0.76 in adults. There are slight increases at the time of puberty. The reasons for this apparently greater anaesthetic requirement in infants are unclear, but may reflect interaction of many factors such as residual elevated progesterone and/or endorphin levels as well as an immature central nervous system. Thus, there is nearly a 30 percent greater anaesthetic requirement for infants to obtain the same depth of anaesthesia. It should be emphasised that there is a smaller margin of safety between adequate anaesthesia and severe cardiovascular depression for the infant and child compared to the adult. This is because the cardiac output in infants is largely dependent on heart rate. Some of the myocardial depression of volatile anaesthetics can be offset by the administration of vagolytic agents such as atropine.

Nitrous Oxide is used as a carrier gas to supplement more potent inhalational agents. It is virtually odourless and makes the introduction of more pungent agents more acceptable. As it is relatively insoluble it rapidly achieves equilibrium with alveolar concentration leading to rapid induction and recovery. In the recovery period rapid diffusion into the alveoli may reduce alveolar concentrations of oxygen (diffusion hypoxia) and high concentrations of oxygen should be given for 5 - 10 minutes following its administration. Because it is very diffusible it rapidly equilibrates with gas filled body cavities and should be avoided in such conditions as pneumothorax.

Brief Review of Halothane. Halothane is a halogenated hydrocarbon. The carbon-fluoride bonds are responsible for its non-flammable and non-explosive nature. During preparation it is mixed with thymol as a preservative and is stored in amber colored bottles to retard spontaneous oxidative decomposition. It has a MAC of 0.76 and vapor pressure of 243mmHg. Circulatory effects include dose dependent reductions in blood pressure and cardiac output often associated with reductions in heart rate. It is non-pungent and therefore allows for a smooth inhalational induction. Halothane causes an increased respiratory rate and decreased tidal volume which results a rise in $PaCO_2$. Halothane increases the susceptibly of the heart to the arrhythmic effects of adrenaline (epinephrine) injected by the surgeon. Although children are less likely that adults to exhibit this effect, doses of adrenaline should be kept under 10mcg/kg when using halothane.

Around 20% of halothane is metabolised by oxidative metabolism in the liver. Rarely hepatic dysfunction (sometimes known as "halothane hepatitis") is diagnosed when other causes of hepatic impairment have been excluded. Certain factors increase susceptibility, including repeated exposures to halothane and obesity. Extremely rarely, severe and occasionally fatal liver damage may occur. However, in patients with liver problems, halothane has undoubtedly been wrongly incriminated in many patients when a more detailed investigation would have cleared the anaesthetic from any blame. The mechanism of hepatic dysfunction in unknown but several theories exists, including metabolic, hepatic oxygen deprivation and immunological.

Enflurane is less useful as an induction agent as it may cause breath holding, coughing and laryngospasm. It may cause cardiovascular and respiratory depression and should be avoided in epileptic patients especially when controlled ventilation is used as it lowers the threshold for seizures.

Isoflurane has a pungent odour and induction is characterised by breath holding, coughing and laryngeal irritation. It is more useful for maintenance of anaesthesia and causes ventilatory and cardiovascular depression similar to halothane.

Sevoflurane is a recently introduced inhalational agent which has the advantage of a pleasant non-irritating odour and a low blood/gas solubility coefficient. Consequently induction is both rapid and smooth and it is an ideal agent for inhalational induction but is considerably more expensive than halothane.

Ether has a high blood gas solubility ratio and a pungent odour. Consequently inhalational induction takes a long time and may be associated with respiratory irritation. It causes minimal respiratory and cardiovascular depression and is therefore extremely safe. It is flammable in air and explosive in oxygen.

Intravenous Anaesthetics. An immature blood brain barrier and decreased ability to metabolise drugs may increase the neonate's sensitivity to barbiturates and opioids. Lower doses may be required to produce the desired pharmacological effects. Children less than 6 months old are susceptible to the respiratory depressant effect of opioids and when used, the infant's breathing should be monitored. On the other hand, older, healthy children require higher doses of thiopentone to achieve intravenous induction of anaesthesia (5-7 mg/kg in children versus 3-5 mg/kg in adults).

Propofol is a new intravenous anaesthetic agent that is being used in paediatric anaesthesia. It is dissolved in a soyabean emulsion and is associated with rapid recovery and reduced nausea and is therefore popular for daycase anaesthesia. Induction of anaesthesia may be associated with pain on injection which can be prevented by mixing lignocaine with the propofol. Induction doses of 2-5 mg/kg may be associated with apnoea, a reduction in arterial blood pressure and cardiac output, similar to thiopentone. As always, with use of such drugs, cardiac and respiratory function need to be monitored. Propofol is safe for patients with acute intermittent porphyria and does not trigger malignant hyperthermia.

Ketamine is a phencyclidine derivative that is widely used in paediatric anaesthesia. An induction dose of 1-2mg/kg produces dissociative anaesthesia characterised by open eyes and nystagmus. Muscle tone is preserved but not sufficiently to maintain laryngeal reflexes. Blood pressure is maintained due to sympathetic stimulation and it is the agent of choice in shocked patients. It does not produce significant depression of ventilation, upper airway tone is well maintained and it causes bronchodilation and is recommended for asthmatics. It causes a rise in intra-ocular and intracranial pressure. Hallucinations may occur in the recovery period but these can be minimized by the administration of benzodiazepines and the provision of a quiet recovery environment. It causes salivation in children, and should be used in combination with an antisialogogue such as atropine 0.02mg/kg. It can also be given intramuscularly in a dose of 5-10mg/kg. (See also Update No4 for a full review of ketamine.)

Muscle Relaxants. Neonates and infants are more sensitive than adults to non-depolarising muscle relaxants. Initial doses, however are similar in both age groups because the increased extracellular fluid volume and volume of distribution in younger patients means that less drug actually reaches the neuromuscular junction. This increased sensitivity

combined with decreased glomerular filtration rate and hepatic clearance can result in prolonged duration of muscle relaxants in neonates. The dose of neostigmine per kg required for antagonism of non-depolarising muscle relaxants is similar in children to adults. A combination of either atropine 0.02mg/kg or glycopyrrolate 0.01mg/kg with neostigmine 0.05mg/kg is suitable.

Neonates and infants require more suxamethonium on a body weight basis to produce comparable degrees of skeletal muscle paralysis, 2 mg/kg for infants versus 1 mg/kg for adults to obtain acceptable conditions for intubation. Again, this change in drug requirement reflects dilutional effects of the increased extra cellular fluid volume and volume of distribution of younger patients. When suxamethonium is contraindicated, one of the newer non-depolarising agents, rocuronium, allows intubation almost as rapidly.

Table of drug doses

Thiopentone	5-6mg/kg standard induction dose
Suxamethonium	1-2mg/kg (2mg/kg in infants)
Atropine	0.02mg/kg
Ketamine	1-2mg/kg IV 3-5mg/kg IM "sedation" 8-10mg/kg IM anaesthetic dose 8mg/kg rectally
Curare	0.5 mg/kg
Atracurium	0.5 mg/kg
Pancuronium	0.1 mg/kg
Vecuronium	0.1 mg/kg
Neostigmine	0.05mg/kg

PRACTICAL CONSIDERATIONS

Preoperative Assessment. Every patient should be visited by the anaesthetist prior to surgery, preferably in the presence of the parents in order to obtain a history, perform a physical examination and evaluate laboratory data in addition to estimating the patient's response to hospitalisation. Parental anxiety and fears concerning surgery and anaesthesia are very real and may be transmitted to the patient. To prepare the child psychologically for elective surgery, educational booklets and a clear explanation are useful. Parents are informed of what to expect, possible risks and the anaesthetic plan. If a parent wishes to accompany the child to the induction room they should be warned in advance what to expect and arrangements made for someone to escort them from the room once induction of anaesthesia has occurred.

Fasting. Safe anaesthesia depends on the patient being fasted. However, numerous studies have shown that the traditional prolonged period without clear liquids prior to anaesthesia is unnecessary. Fasting periods can safely be shortened in normal infants and children who feed frequently during the day. A baby who is used to feeding every two hours will come to surgery less distressed and better hydrated if he or she has been allowed to have clear liquids closer to the time of surgery. Most hospitals have developed more liberal fasting guidelines along the following lines:

Newborn to 12 months:
No formula or breast milk 4 hours before surgery
Clear liquids up to 2 hours before surgery

Over 1 year:
No formula, milk or solid food 6 hours before surgery
Clear liquids up to 2 hours before surgery

(A clear fluid is defined as a fluid through which print can be seen. Remember breast milk is not a clear fluid.)

Common conditions relevant to anaesthesia
What is the anaesthetist to do if the parents tell you the child "has a cold" (upper respiratory tract infection)? Children, especially those having ENT type procedures such as ear tubes or tonsillectomy, often have clear rhinorrhea (nasal discharge) and procedures should not be cancelled on this basis alone. Purulent rhinorrhea, productive cough and fever indicate the cold is a more systemic problem and elective surgery is better postponed for one to two weeks. Ask the parents how the child with a cold has been acting. Is he or she eating and playing normally or is it associated with general malaise and fatigue? These are the cases best postponed. Performing an anaesthetic in the presence of a systemic upper respiratory tract infection may result in laryngospasm and ventilatory problems with hypoxia, all easily avoided if the procedure is simply postponed until the child is well.

Asthma is a common disorder (3-5% of the population) resulting in airway hyperreactivity in

response to a variety of stimuli. Active bronchial asthma is usually characterised by reversible narrowing of airways resulting in audible wheezing on auscultation of the chest. Obstruction of airflow leads to changes in lung volumes, chest wall mechanics, and altered distribution of ventilation and perfusion resulting in hypoxemia and hypercarbia. Pulmonary function tests show the ratio of FEV1:FVC is less than 80 percent.

The sympathetic nervous system plays a major role in maintaining normal bronchial tone and treatment often includes beta-adrenergic agonists, theophylline, anticholinergics, glucocorticoids (in severe cases) and cromoglycate. Beta-adrenergic agents are usually given in the form of inhalers or nebulisers producing bronchodilatation by activation of beta-2 receptors thus avoiding the undesirable beta-1 cardiac effects.

Theophylline and aminophylline produce bronchodilation by inhibiting phosphodiesterase, the enzyme that breaks down cyclic AMP. Anticholinergics produce bronchodilation through their antimuscarinic action and also dry up airway secretions. Glucocorticoids (steroids) have anti-inflammatory effects as well as membrane stabilization and are used in severe cases. Beclomethasone is used as an inhaled steroid and produces fewer systemic side effects.

Management of anaesthesia for the asthmatic patient includes preoperative assessment to determine the severity of the asthma. Elective cases are best avoided in the presence of active wheezing. The goal during induction and maintenance of anaesthesia in the asthmatic is to avoid unnecessary stimulation of the non-anaesthetised airway which may result in bronchospasm. Regional anaesthesia is a good choice as any manipulation of the airway is avoided but is often not practical in children. If general anaesthesia is needed, a smooth induction and emergence is the goal, using drugs such as the volatile anaesthetics, non-histamine releasing opioids or ketamine to establish a depth of anaesthesia that will depress hyperreactivity of the airway. Ketamine is the only intravenous agent with bronchodilating properties.

Intraoperative wheezing should be treated by deepening the anaesthetic and by using inhaled beta-2 agonists by aerosol (salbutamol / terbutaline). Severe bronchospasm can be treated with intravenous aminophylline using a 6mg/kg loading dose followed by 0.5-0.9mg/kg/hour by infusion. Cardiac dysrhythmias during aminophylline need to be carefully monitored. With refractory bronchospasm, adrenaline may be required - in this situation halothane should be turned off. Hydrocortisone (3mg/kg 6 hourly) may also prove useful but acts slowly producing an effect after about 2 hours.

Epilepsy. Seizures represent abnormal synchronisation of electrical activity of the brain and may be localised or generalised. Grand mal seizures are most common and are characterised by loss of consciousness followed by clonic/tonic motor activity. The condition is usually controlled with daily doses of anticonvulsants including phenytoin, phenobarbitone, carbamazepine and valproic acid.

Preoperatively, the anaesthetist needs to determine how active the disease is, i.e., is it well controlled on medications and when was the last seizure? Adverse side effects of the medications can be determined clinically (ataxia, dizziness, confusion and sedation). Anticonvulsants should be ideally continued pre and post operatively to maintain therapeutic levels. Fortunately, most have a prolonged half-life so missing one or two doses is not critical.

Anaesthetic agents which may provoke epilepsy include ketamine, enflurane and methohexitone. Phenytoin and carbamazepine may increase the dose requirements for non-depolarising muscle relaxants due to hepatic microsomal enzyme induction.

Sickle Cell Disease is an inherited disorder resulting from the formation of abnormal haemoglobin (HbS). HbS differs from normal adult haemoglobin (HbA) in the substitution of valine for glutamic acid at the sixth position of the beta chain of haemoglobin. HbS has lower affinity for oxygen as well as decreased solubility. Upon deoxygenating, HbS polymerizes, causing the cells to take on a sickle shape and obstruct vessels.

Painful vaso-occlusive crises result which are thought to be due to micro infarcts in various tissues resulting in joint pain, chest pain and abdominal pain. Aplastic crises can produce profound anemia when red cell production is exhausted. The red cell survival is only 10-20 days compared to the 120

days of a normal red cell, resulting in chronic anaemia. The diagnosis is confirmed with haemoglobin electrophoresis. Update in Anaesthesia No. 4 contains a full discussion of Sickle Cell disease.

Optimal preoperative preparation includes hydration, control of infections and ensuring an acceptable haemoglobin concentration. Preoperative simple or exchange transfusion may be necessary to achieve a haemoglobin concentration of 10g/dl or greater with 40-50% of normal HbA present.

Intraoperative problems that might promote sickling should be avoided including dehydration, hypothermia, hypoxaemia, hypotension and acidosis. An inspired oxygen tension of 50 percent is desirable, if possible. Many clinicians also avoid the use of tourniquets as these may enhance sickling distal to the tourniquet. The same principles apply in the postoperative period. Supplemental oxygen, optimal pain control, pulmonary physiotherapy, hydration and early ambulation are all desirable.

Pre-medication should be prescribed according to the needs of the patient. Providing that a good rapport has been established with the child and parents most children do not require pre-medication. Sedatives should be reserved for those who are unduly anxious. Oral midazolam 0.75mg/kg administered 30 minutes prior to induction is very suitable. When prepared from the parenteral form the bitter taste can be reduced by adding a teaspoonful of paracetamol elixir. Other commonly prescribed pre-medications are oral trimeprazine 3mg/kg and diazepam 0.25mg/kg. Intramuscular pre-medications are traumatic for children and should be avoided whenever possible

Atropine or glycopyrrolate can be administered orally (or intramuscularly) preoperatively or given iv on induction of anaesthesia. Certain anaesthetic drugs, particularly suxamethonium and halothane may cause vagally induced bradycardia. This effect is more prominent in infants under three months of age. A vagolytic dose of atropine (0.03 mg/kg) provides complete protection against vagal cardiac slowing or other cardiac arrhythmias in infants under 6 months of age. These seemingly large doses are well tolerated by infants. In general, if atropine is needed, many anaesthetists prefer to give it intravenously in the operating room. As depth of anaesthesia is often judged by changes in heart rate, the resultant tachycardia from atropine may make it more difficult for the anaesthetist. Flushing of the face, delirium, restlessness and agitation may occasionally occur in the recovery room following atropine or scopolamine (hyoscine).

A recent advance is EMLA (a Eutectic Mixture of Local Anaesthetic) prepared with prilocaine and lignocaine as an emulsion in a white cream. It produces skin anaesthesia after it has been in place for one hour under an occlusive dressing and has proved useful for painless venous puncture even in very young children. Systemic absorption of the drug is well below toxic levels even after extensive application of the cream. However, methaemoglobinaemia may be produced by the metabolism of prilocaine in the young infant or the older infant after repeated application or where it has been placed on broken skin. Another local anaesthetic cream has recently been introduced based on amethocaine (Ametop).

Basic Anaesthetic Techniques

The induction room. There are advantages in anaesthetising children in a dedicated induction room outside the operating theatre away from distracting sights and sounds. Anxiety may be reduced if a parent accompanies the child. Anaesthesia can frequently be induced with the child sitting on the parent's lap. When induction is over the child can then be transferred to the table and the parents escorted from the room by a nurse.

Equipment checks. Since children can deteriorate rapidly during anaesthesia it is especially important to check that all drugs and apparatus are ready prior to induction. In particular there should be two laryngoscopes, suction apparatus, a range of endotracheal tubes and masks. The Rendell-Baker mask is designed to fit closely around the face to minimise the dead space although some anaesthetists prefer to use a clear mask which allows the child's colour to be checked during induction. Atropine and suxamethonium should be instantly available in case unexpected laryngospasm or other airway problems develop causing hypoxia and bradycardia.

Induction of anaesthesia is generally by intravenous or inhalational methods. Since the introduction of topical local anaesthetic preparations intravenous induction has increased in popularity.

In the absence of suitable veins induction can

generally be achieved rapidly using one of the potent inhalational agents. Nitrous oxide may be added to oxygen as the carrier gas to speed induction but the proportion of oxygen must be kept at >30% to reduce the possibility of hypoxia. The application of a face mask may be unacceptable to the patient in which case the anaesthetic can be gradually introduced via the cupped hand of the anaesthetist held initially away from the patients face.

An inhalational induction of anaesthesia is usually very easy to perform with halothane which is not irritating to the airway. The induction is started with 70% nitrous oxide (if available) and 30% oxygen for a few breaths. The volatile anaesthetic is then gradually introduced, increasing a half percent with every three breaths. More rapid increases should be avoided as coughing or even laryngospasm may develop. A calm voice is helpful from the anaesthetist. Once anaesthesia is obtained, an intravenous cannula or needle may be inserted and drugs can be administered as needed for the surgery. Muscle relaxants are often used to facilitate intubation. If laryngospasm occurs before an intravenous catheter is placed, positive airway pressure should first be used in an attempt to cure the spasm. If this is not successful and hypoxia develops, suxamethonium administered sub-lingually 2mg/kg or intramuscularly 4mg/kg (preceeded by atropine if possible to prevent bradycardia) should be used.

Once anaesthesia has been induced veins usually become more prominent and an indwelling intravenous cannula should be inserted as soon as possible. In babies and children less than six months intubation is advisable due to the difficulty of maintaining an airway. Because of the problems of absorption atelectasis, falling functional residual capacity and hypercapnia it is common practice to ventilate all children under 20kg for anything but very short procedures. The laryngeal mask airway is now manufactured in paediatric sizes and provides an alternative form of airway management but they are not suitable for controlled ventilation in small children because of the danger of gastric dilatation.

Muscle relaxants are often used to facilitate intubation. If suxamethonium is selected atropine must be drawn up ready to administer in case of bradycardia. If a second dose of suxamethonium is required it should always be preceded by atropine (0.02mg/kg) since bradycardia is common with repeat administrations.

It is important to flush an indwelling intravenous cannula with saline following the administration of any drug to prevent any residue in the dead space of the cannula being inadvertently injected when the cannula is next used.

Occasionally the anaesthetist is confronted by an unruly and hysterical child who will not co-operate with either of the above methods of induction. While an IM injection of ketamine (3-5 mg/kg) is possible, it is often easier and less traumatic to gown up the parent and bring them to the induction or operating room with you to be present with the child until an inhalational induction is performed. However, there must be sufficient staff to allow someone to escort the parent out of the operating room after anaesthesia is induced. If intramuscular ketamine is the only option, secretions in the airway can be kept to a minimum if glycopyrolate (0.01mg/kg) is added to the injection. Alternatively atropine may be given after anaesthesia develops.

Anaesthesia Breathing Systems

Many anaesthesia ventilators designed for adults cannot reliably provide the low tidal volumes and rapid respiratory rates required for infants and small children. Unintentional delivery of large tidal volumes to a small child can generate large airway pressures and cause barotrauma (damage to the lungs due to excessive inspiratory pressure).

Spirometers are less accurate at small volumes and delivered tidal volumes may be reduced when adult anaesthesia breathing systems are used due to compression of the gas in long breathing tubes with high compliance. Dedicated paediatric anaesthesia tubing is usually shorter and stiffer and the smaller tidal volumes can be better delivered manually with a 500ml or 1000ml breathing bag.

The efficiency of breathing circuits is measured by the fresh gas flow required to eliminate CO_2 rebreathing. Mapleson circuits are lightweight, and inexpensive. The Mapleson A circuit (Magill circuit) is very efficient during spontaneous ventilation if fresh gas flow is equal to the patients minute ventilation. It is inefficient during controlled ventilation and requires a high gas flow to prevent rebreathing. The Mapleson D is more efficient than the A system with controlled ventilation requiring

a fresh gas flow of 1 to 2 times minute ventilation. The Bain circuit is a co-axial Mapleson D system.

The Ayres T-Piece (Mapleson E) functions in a similar way to the Mapleson D circuit, but because there are no valves and very little resistance to breathing it has proved very suitable for children under 20kg. The version most commonly used is the Jackson-Rees modification which has an open bag attached to the expiratory limb (classified as a Mapleson F system). Fresh gas flows of 2-3 times minute volume should be used to prevent rebreathing during spontaneous ventilation, with a minimum flow of 3 litres/min. During controlled ventilation the litres of fresh gas required per minute can be calculated by giving 1000 ml + 100 mls/kg. The minimum flow should be 3 litres/min. (A full discussion of breathing systems can be found in Update No. 7.)

In general circle systems are bulky with increased resistance making them less suitable for spontaneously breathing children.

Drawover systems have slightly increased respiratory resistance compared with standard continuous flow apparatus. There are 2 ways of using drawover apparatus for small children.

The systems can be converted to continuous flow by connecting a continuous flow of oxygen to the upstream side of the vaporiser. A T piece can then be connected in the normal fashion. Ensure that there are no leaks.

There are differences in the performance of the different drawover vaporisers when supplied with a continuous flow of gas. In this mode, the Oxford Miniature Vaporiser (OMV) requires 4 - 6 litres / minute of fresh gas flow to work efficiently. The EMO requires 8 - 10 litres /minute flow to perform predictably. Lower flows should not be used with this technique.

An alternative technique when using the OMV is to make a paediatric drawover circuit using a AMBU Paedivalve and small AMBU inflating bag. The child's respiration should be supported or controlled throughout, but this vaporiser has been reported to work well at small tidal and minute volumes.

Monitoring techniques for paediatric patients should be similar to those of adults undergoing comparable types of surgery. Standard monitoring includes close observation by the anaesthetist, precordial or oesophageal stethoscope and blood pressure. Where facilities allow the presence of more advanced monitors increases the safety of anaesthesia. These include non-invasive blood pressure, pulse oximetry, temperature, end tidal CO_2 and ECG, all of which should be placed on induction of anaesthesia . There is no doubt that the best monitor available is the pulse oximeter which was discussed in detail in the 5th edition of Update in Anaesthesia.

The stethoscope (precordial or oesophageal) is a most valuable monitoring device and should be used continually in all paediatric patients. It is inexpensive, reliable, does not require any external source of power or maintenance. It provides information on the cardiovascular system (heart rate and rhythm, intensity of heart sounds) and respiratory system (respiratory rate, the presence of secretions, pulmonary oedema and bronchospasm). It also gives instant warning of ventilator disconnection.

Blood pressure measurement requires the correct size of the cuff. A cuff that is too large will give artificially low readings and one that is too small will give readings that are falsely high.

In seriously ill children who are undergoing more extensive surgery with potential for fluid losses, blood pressure should be closely monitored. The central venous pressure may be assessed to help determine the blood volume status. Hourly, urinary output with a Foley catheter is also useful and should exceed 0.5 ml/kg/hr. Hypoglycemia occurs frequently in seriously ill children or very young infants and should be treated with 1-3 ml/kg of a 20% glucose solution intravenously over 5 minutes. Excessive glucose replacement should be avoided as an osmotic diuresis resulting in dehydration may result from hyperglycemia.

All monitors as well as a reliable intravenous infusion should be secured in position before the commencement of surgery after which access to the patient may be difficult.

A Common Intra-operative Problem

Bradycardia in paediatrics often means hypoxia and restoring adequate ventilation and oxygenation may be all that is needed to restore heart rate. Bradycardia from vagal influence, as seen in eye

muscle surgery, can be treated by asking the surgeon to relieve tension on the eye muscle and giving intravenous atropine. Bradycardia resulting from increased intracranial pressure is treated with hyperventilation, diuretics and surgical release of the pressure.

Basic Postoperative Care

Infants and children generally recover faster than adults from anaesthesia and surgery. The immediate postoperative care is as critical as the intra-operative care and the child should be taken to a recovery area with trained staff. The anaesthetist should report to the recovery room personnel any intra-operative problems that occurred. The airway should be maintained to assure adequacy of ventilation and oxygenation and any unexpected findings reported to the anaesthetist. Vital signs should be taken frequently in the first hour and pain treated. The child may return to the ward when the observations are stable, he is fully conscious and his pain is controlled.

Occasionally croup or subglottic oedema after endotracheal anaesthesia manifests itself in the first few hours after extubation. Mild croup results in a hoarse cough, more severe croup may cause labored respiration, sternal recession, anxiety and inadequate ventilation. Mild cases will resolve over time and may only require extra observation and possibly some humidified oxygen. Nebulised adrenaline (5mg) by facemask is used in more severe cases. It is the vasoconstrictor effect of the adrenaline that relieves the oedema but the effect may be short lived. The patient should be monitored very closely as it may recur after the treatment and may require a second dose. Steroids may or may not be useful and a single, large dose of i.v. dexamethasone (4mg for infants, 8mg for children) can be used. If the above treatment is ineffective, preparations should be made for reintubation using a smaller endotracheal tube. This complication may be prevented by using the correct size of endotracheal tube at induction of anaesthesia.

Post operative pain management

Methods of treating postoperative pain in children include the use of systemic analgesics and local anaesthetic agents. The systemic analgesics can be divided into non-opioids and opioids. This area was discussed more fully in Update No 7.

1. Non-opioid analgesics (for mild or moderate pain)

a) paracetamol (acetaminophen) 15mg/kg 6 hourly

b) NSAIDS - this group of drugs has become extremely popular for treating post operative pain in children as they are effective with few side effects and produce an opioid sparing action. They should be avoided in patients with coagulopathy (because of a tendency to prolong postoperative bleeding), nephropathy, gastropathy and asthma. Diclofenac 1-3mg/kg per day in divided doses is widely used. It is also available as a suppository. NB: Aspirin should not be used for children under 12 years because of the association with Reye's syndrome.

2. Opioids (for severe pain)

Opioids may be administered by IM, IV or oral routes. Children are sensitive to opioids and doses should be reduced accordingly. They should not be given to children <5kg.

Suggested doses intramuscularly:

Morphine: 0.1-0.2mg/kg 4 hourly (may be given subcutaneously also)

Pethidine: 1 - 1.5mg/kg 4 hourly

Slow IV administration avoids the need for painful intramuscular injections, but the child should be closely observed whilst this is given.

Codeine is also a useful drug and may be given orally or intramuscularly in a dose of 0.5-1mg/kg 6 hourly. Codeine should not be given intravenously.

Local anaesthetic techniques

Local wound infiltration with bupivacaine 0.25% at the conclusion of surgery is very effective and is extremely simple and safe. It reduces the need for additional measures. Other regional blocks are used in specific situations eg intercostal blocks following thoracotomy, ilio-inguinal and ilio-hypogastric nerve blocks following hernia repair and orchiopexy, dorsal nerve blocks of the penis or caudal blocks following circumcision. Caudal anaesthesia is described on page 14.

Unusual diseases in paediatrics

Pyloric stenosis. Hypertrophy of the muscle of the pyloric sphincter causes obstruction leading to persistent vomiting. It occurs in about one in every 500 live births and usually manifests itself around 2-6 weeks of age. Persistent vomiting results in loss

of hydrogen ions with compensatory attempts the kidney to maintain a normal pH by exchanging potassium for hydrogen. It is the "hypo" disease with the result being a dehydrated infant with hypokalaemia, hyponatraemia, hypochloraemia and metabolic alkalosis. It is not a surgical emergency and the infant should first be rehydrated with intravenous fluid therapy including sodium chloride with potassium supplements for 24-48 hours.

When the infant presents for surgery with normal electrolyte values, the likelihood for aspiration is still high and the stomach should be emptied with a nasogastric tube before induction. Anaesthesia should be induced using a rapid sequence pattern with atropine, thiopentone, suxamethonium and cricoid pressure until the position of the endotracheal tube is confirmed. Postoperative respiratory depression is common in these patients, possibly as a result of CSF alkalosis and the use of opioids should be avoided. The postoperative pain is easily treated with paracetamol and infiltration of local anaesthetic at the time of surgery. The infants are usually happy to feed 3 - 6 hours after the surgical procedure.

Epiglottitis. Symptoms of epiglottitis include an acute onset of difficulty in swallowing, high fever and inspiratory stridor in 2-6 year old children. Children suffering from epiglottitis typically remain upright and dribble saliva. It is an emergency and treatment includes antibiotics and intubation of the trachea until the swelling has subsided with medical therapy. Any attempt to visualise the epiglottis should not be undertaken until the child is in the operating room with appropriate airway equipment for endotracheal intubation and instrumentation for tracheostomy. (It goes without saying that personnel capable of using these instruments need to be present!) Induction and maintenance of anaesthesia for intubation of the trachea is with halothane in oxygen. Muscle relaxants are avoided as skeletal muscle relaxation may result in total upper airway obstruction. Use an endotracheal tube half a size smaller than calculated and have a variety of sizes available, including a stylet. The swelling usually improves in one to two days after appropriate antibiotic therapy. Extubation of the trachea is performed in the operating room after direct laryngoscopy confirms reduction of swelling of the epiglottis. The presence of a leak around the endotracheal tube is used as a sign that swelling has resolved enough for the child to breathe on their own without the presence of an endotracheal tube.

Down's Syndrome (trisomy 21) occurs in about 0.15 % of live births. The condition is associated with mental retardation, congenital cardiac anomalies (atrial and ventricular septal defects), duodenal atresia, hypotonia, small mouth, subglottic stenosis, hypoplastic mandible and protruding tongue. Patency of the upper airway may be difficult to maintain after onset of unconsciousness for the above reasons but intubation is usually not difficult. Manipulation of the neck during intubation should be done cautiously as 10% of these patients have associated asymptomatic atlanto-axial instability.

Prematurity. Six percent of infants in the United States of America are born prematurely, before 37 weeks gestational age. During the last 3 months of gestation, organs are still developing, both structurally and developmentally. When an infant is born prior to term, these organs are asked to function fully when they may not be ready. Preterm infants are less able to maintain body temperature, suck, swallow, eat and even maintain ventilation adequately. As a result, birth asphyxia predisposes them to central nervous system damage, retinopathy of prematurity, intraventricular haemorrhage, respiratory distress syndrome, bronchopulmonary dysplasia, anaemia, apnoea, patent ductus arteriosis and necrotizing enterocolitis.

Anaesthesia for premature infants is often difficult because they may have multisystem disease and respond poorly to anaesthesia. It is important to gather as much information as possible prior to anaesthesia; birth history, ICU problems, laboratory data, radiological findings, state of hydration and nutrition and clotting status. It is advisable to have a second anaesthetist in the operating room to help. The operating room needs to be warm, 35-37 degrees centigrade and an infrared heater, if available, should be placed over the operating room table. Fluids are warmed and heating blankets may also be used. Oxygen requirements should be dictated by the neonate's needs. Using 100 percent oxygen to a neonate who does not need it only predisposes that baby to development of retinopathy of prematurity.

Conclusion

It has not been possible to cover all aspects of paediatric anaesthesia in a single article but it is hoped that this overview of the main principles will prove useful for those called upon to anaesthetise paediatric patients. More detailed accounts of particular techniques and the management of specific paediatric problems will appear in future editions.

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