

Equipment in paediatric anaesthesia

Graham Bell* and Rachel Homer

*Correspondence Email: gebell@btinternet.com

AIRWAY ADJUNCTS

Oropharyngeal ("Guedel") airways

These are universally popular in children as they are easy to use and fast to insert. They can be used to supplement airway manoeuvres such as jaw-thrust and chin lift during resuscitation, induction, and emergence from anaesthesia. The airway should only be inserted when the child is deeply anaesthetised. If the child is too light the airway will not be tolerated, potentially leading to coughing, gagging, expulsion of the airway, or laryngospasm.

Oropharyngeal airways in children are best inserted correctly oriented. You should take care to avoid damage to the delicate soft palate in young children, and to the posterior pharyngeal wall if a relatively large airway is used. They are less likely to cause trauma on insertion than a nasopharyngeal airway.

Nasopharyngeal airways

These are particularly useful in children with a tendency towards upper airway obstruction or a reduced level of consciousness. They are better tolerated than an oropharyngeal airway. To insert:

- Lubricate with gel to minimise trauma to the turbinates
- Avoid local anaesthetic preparations because these can alter pharyngeal muscle tone and impair airway patency
- Insert gently along the floor of the nose
- Take care not to exert too much pressure at the post nasal space where the adenoids may be damaged.

Nasopharyngeal airways are usually used during recovery rather than during anaesthesia. A common indication is for the child at risk of upper airway obstruction after cleft palate repair. To prevent damage to the suture line during insertion, railroad the airway over a smaller nasogastric tube (confirm that this is in the stomach first), or allow the surgeon to insert the nasopharyngeal airway under direct vision.

Facemasks

A plastic facemask with an inflatable cuff/rim gives a better seal on the face, and is less frightening to the child than the traditional black rubber facemask. The correct size of facemask is one that reaches from the cleft of the chin

SUMMARY

Differences in anatomy and physiology between children and adults mean that much of the equipment needed to anaesthetise children needs to be specially adapted.



Figure 1. Oropharyngeal airways come in a range of sizes suitable for premature neonates up to adults. To find the correct size, hold with the flange in line with the middle of the incisors. The tip should just reach the angle of the child's jaw

Graham Bell

Consultant in Paediatric Anaesthesia

Rachel Homer

Fellow in Paediatric Anaesthesia
Royal Hospital for Sick Children,
Glasgow

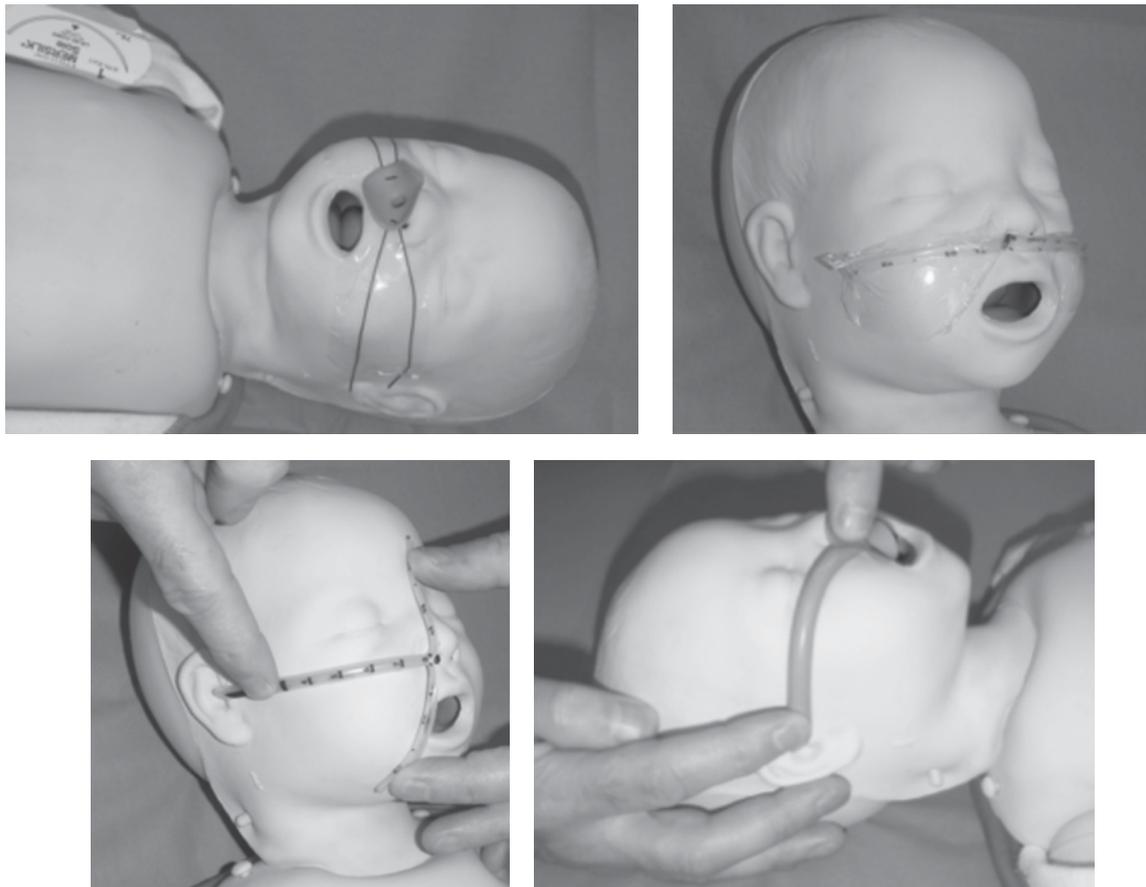


Figure 2. The correct diameter of the nasopharyngeal airway is the same as the size of the endotracheal tube for that child (see Table 2). Estimate the length by the distance from the nostril to the tragus of the ear as show. An uncuffed endotracheal tube makes a satisfactory nasopharyngeal airway. Either attach a standard connector (to stop the tube from advancing and becoming 'lost' in the nose); or split the tube to facilitate secure taping as shown. Sutures may be tied around the tube to secure the airway as shown.

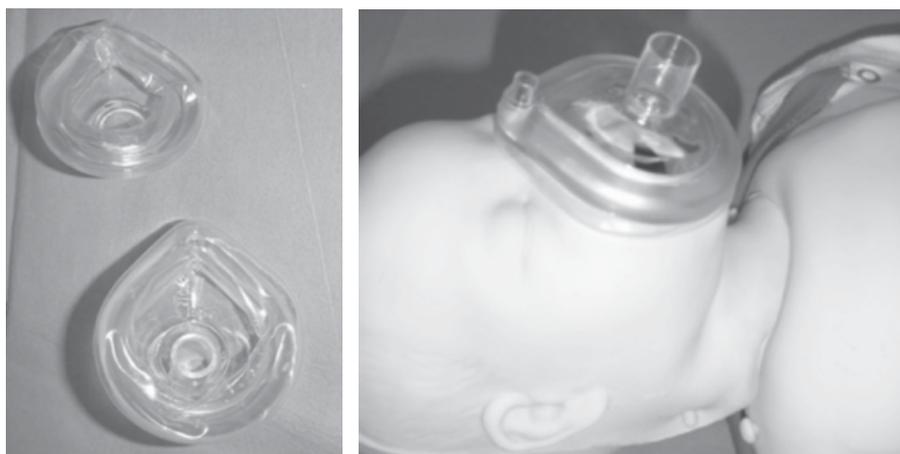


Figure 3. Clear plastic facemasks

to the bridge of the nose, but does not cover the eyes. For small babies, round masks are available, or turn a shaped mask 'upside down' for an acceptable seal.

Laryngeal mask airways (LMAs)

The LMA is the most widely available example of a supraglottic airway device. They are suitable to use during maintenance

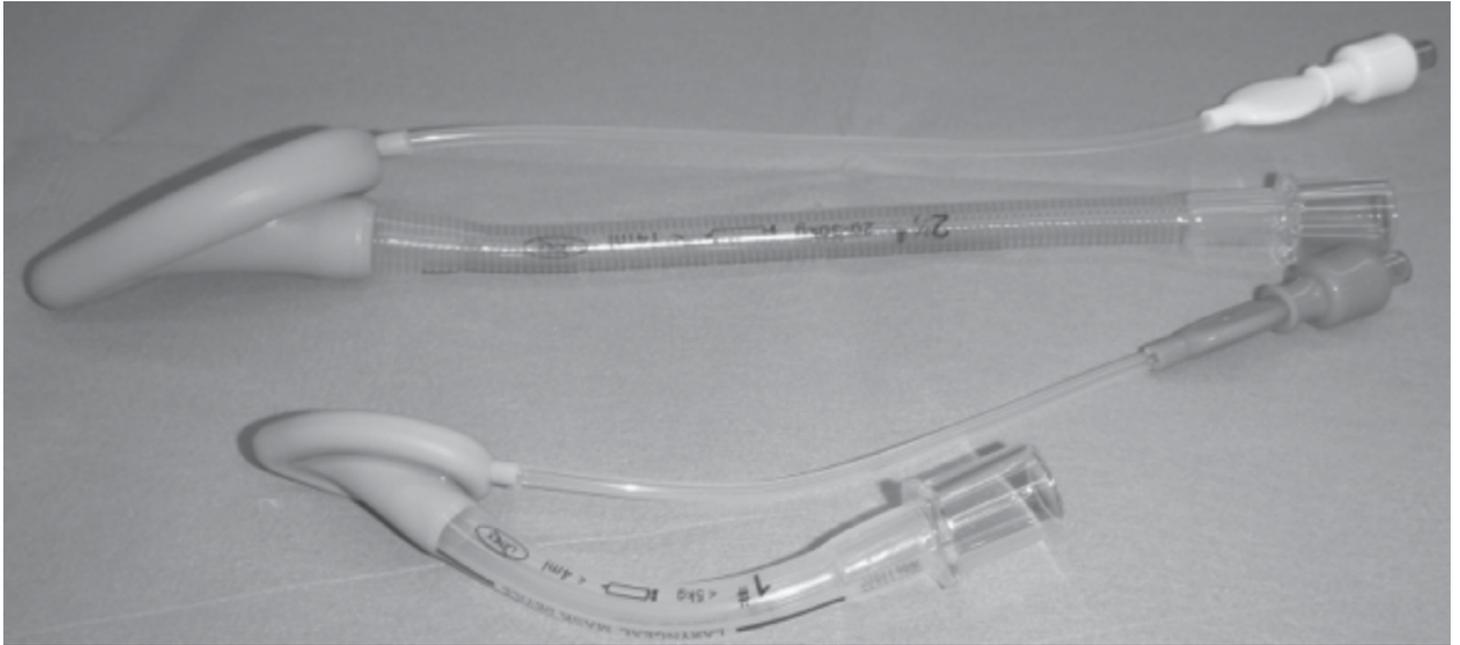


Figure 4. LMAs are available in a range of sizes appropriate for babies up to adults. They may be either single-use or designed for repeat resterilisation. Rigid versus flexible stems can be easier to insert but more frequently displaced by heavy drapes or when close to the surgical field

of anaesthesia in cases which you would otherwise manage by holding a facemask (low aspiration risk), to free the anaesthetist's hands for other tasks.

The size 1 LMA is less useful for routine anaesthesia because:

- It is designed for children <5kg in whom intubation and ventilation are generally preferred
- It tends to dislodge, in which case it occludes rather than maintains the airway
- Coughing and laryngospasm on insertion are more common with smaller LMAs.

It may still be useful to rescue a difficult airway, even in a small baby (see Difficult airway article, page 116).

Table 1. Manufacturers' guide to LMA sizes

Weight (kg)	LMA size	Maximum cuff volume (mls)
<5	1	4
5-10	1 ½	7
10-20	2	10
20-30	2 ½	14
30-50	3	20

In adults it is common to mechanically ventilate the lungs through the LMA. In children there is a higher risk of gastric insufflation, so this is not widely practiced.

Serious airway damage from the LMA cuff has not been reported, but be aware that the cuff pressure exceeds that of a tracheal tube. Capillary perfusion pressure in children is lower than in adults, thus the potential for injury is probably greater, even if the cuff is not inflated above the recommended maximum volume (see Table 1). Be even more cautious in longer procedures, as lingual oedema has been reported after LMAs have been in for a long time.

Avoid overinflation of the LMA cuff:

- Lower cuff pressures tend to give a better seal
- There is less risk of pressure injury to tissues.

Opinions vary as to when to remove the LMA in children. The choice is either deeply anaesthetized ("asleep") or fully awake; between these extremes, you risk precipitating laryngospasm. Some suggest that the best time to remove the LMA is when the pharyngeal reflexes return and the child spits the airway out.

Use in difficult intubation – see article page 116

The intubating LMA is not made below a size 3, therefore is not suitable for young children.

Laryngoscopes

The epiglottis is long and U-shaped in infants and small children. This is advantageous when breast-feeding but requires a different approach for intubation. A curved blade placed in the vallecula will not provide a reliable view of the glottis. Straight blades designed to lift the epiglottis along with the soft tissues at the base of the tongue give an easier view.

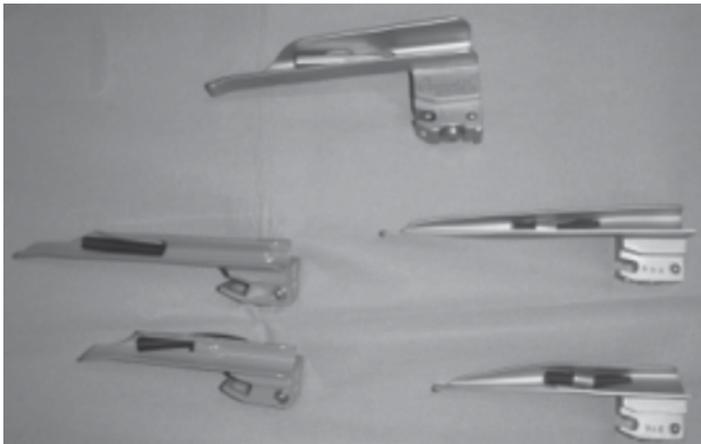


Figure 5. The most popular straight blades are [left to right] the Miller, the Robertshaw and the Oxford [top in (a)]. Many paediatric anaesthetists use a MacIntosh (size 3) curved blade in all children over 1 year old. Others prefer a straight blade until 5 years old. No one design has been shown to be truly superior.

The international standards organization has a size mark for laryngoscopes from 5 (largest) to 000 (smallest – too small even for tiny premature babies). A size 1 blade is the correct size for a normal term baby, and a size 0 for premature neonates who weigh less than 3kg.

It is possible to intubate with a laryngoscope that is slightly too big, and rarely possible with one too small. MacIntosh considered smaller sizes of his original (size 3) blade unnecessary, as the distal portion of the size 3 blade is straight and therefore suitable for smaller children. He was correct!

Many disposable laryngoscope blades exist. Some are of high quality but this cannot be assumed, for example some have

broken during clinically realistic force tests. Manufacturers label these blades Miller, Robertshaw etc., but they are often not exact copies of the blades whose name they bear. Both laryngoscopic view and illumination may vary.

Endotracheal Tubes (ETT)

The black marks used for guidance during laryngoscopy vary widely between manufacturers and between tube types. Some are meant to indicate the appropriate position at the cords. Others simply make the tip easier to see. The only reliable advice that can be given on ETT markings is to ignore everything except the actual distance markings in centimetres.

A 3.5mm uncuffed ETT is suitable for the normal term neonate. Use the formulae below to guide ETT selection in older patients (Table 2). There should be a small leak around the ETT to avoid excessive pressure on delicate mucosa. If ventilation is compromised, the leak is too large. The nose will accommodate the same size ETT as the larynx prior to puberty.

A neonate's trachea may be less than 4cm in length. The ETT should sit at least 1cm above the carina, which is anteriorly inclined and more symmetrical than in adults. Small flexion/extension movements may cause accidental endobronchial intubation or extubation respectively. You must be meticulous in placing and securing the ETT.

Some children receiving intensive care benefit from a cuffed tracheal tube. Most paediatric anaesthetists prefer uncuffed tubes for routine anaesthesia in children up to 8 – 10 years old.

Reasons to choose an uncuffed tube:

- Larger internal diameter tube can be used
- Confusing tube markings and long cuff shoulders have led to frequent endobronchial intubation with traditional cuffed tubes. The microcuff tube® avoids these problems
- Overinflation of endotracheal tube cuffs risks the potential but rare complication of tracheal stenosis

Reasons to choose a cuffed tube:

- Fewer intubation attempts with different sized tubes
- Reduced leak – more important in ICU, also in anaesthesia as better paediatric circle systems are developed and use of low flow anaesthesia in children increases

There is no good evidence that either cuffed or non-cuffed tracheal tubes are better.

BREATHING SYSTEMS

Semi-open (see article on drawover anaesthesia, p23)

Semi-closed

The T-piece is the most popular system for anaesthetising small children in UK with many advantages:

- Lightweight
- Compact
- The bag is easily visible whilst observing the patient
- Simple to use for spontaneous or controlled ventilation
- No valves
- Low internal resistance
- Low compression volume (i.e. the operator has a good 'feel' for the lung compliance).

Jackson-Reece modified the system by adding an open-ended bag. This bag has several advantages:

- Respiratory monitor during spontaneous ventilation
- Easy to convert to manual controlled ventilation
- Easy to apply PEEP.

In skilled hands the T-piece is the best system for resuscitation. The application of CPAP / PEEP splints the upper airway open and so improves the efficacy and ease of ventilation.



Figure 6. T piece attached to oxygen cylinder. The same connection will fit the outlet of an oxygen concentrator. Alternatively, the T piece's green tubing connects directly to an anaesthetic machine's common gas outlet. A T piece requires gas flow.

However, in less skilled hands, the T-piece may result in

- Inadequate ventilation (requires practice to use)
- Gastric insufflation
- High peak inflation pressures
- Inadvertent barotrauma.

It is customary to use adult breathing systems in children > 20 – 30kg. To prevent hypercarbia during controlled ventilation, the fresh gas flow in ml can be predicted by the formula $(1000 + (200 \times \text{kg}))$ (minimum of at least 3 l/minute), which is approximately 1.5x the minute volume. During spontaneous breathing in young children, there is no end expiratory pause and the system becomes less efficient; twice the fresh gas flow required for controlled ventilation should be used (i.e. about 3 x the minute volume).



Figure 7. Humphrey ADE. Newer versions are, in fact, AE systems; there is no option for a Mapleson D. The E system (lever down) is a T-piece; it has no bag and no valve and is used for controlled ventilation (fresh-gas flow as for the T-piece, above). The A system (lever up) has the configuration of a parallel Lack circuit. This is ideal for children breathing spontaneously because of the low resistance of both the smooth inner bore of the tubing and the expiratory valve. A flow rate of 3 l/minute is sufficient for most children before adolescence.

Closed

Early circle systems imposed a high work of breathing due to the resistance of one-way valves. This is much less of a problem with modern circles but other issues remain:

- A leak around the tracheal tube means that low flows cannot be used efficiently (solve by using cuffed tracheal tubes)
- The volume of the breathing system is large compared with minute volume, giving longer equilibration times than in adults
- The tubing has a significant compression volume, which may alter the characteristics of ventilation during positive pressure ventilation. Avoid by using stiffer tubes and smaller bellows
- Paediatric circle systems do not maintain the temperature or humidity of inspired gases adequately.

IV ACCESS

Administering fluids

Standard blood and fluid administration sets are suitable for children. A burette should be used for small children (<10kg) so that the volume of fluid can be measured accurately and to avoid giving excessive volumes of fluid.

In-line fluid warmers are of great benefit, but they add considerable deadspace into the system, and require electricity, and costly single-use disposables. Water baths are not commonly used to warm IV fluids because contamination with *Pseudomonas* species can cause serious infection. Fluids may be stored in a warming cabinet or other warm place prior to administration. Some anaesthetists place the sealed bag of IV fluid on top of the monitor as this becomes warm during use. This is only partially effective, but makes use of a readily available source of heat!

Peripheral cannulae and flushing

Young children more commonly have a patent foramen ovale. This means that bubbles administered IV may embolise to the systemic circulation rather than the lung. Remove all air bubbles from the fluid administration system. It is difficult to give guidelines about the amount of air that poses a danger because speed of injection is as important as volume. Deaths have occurred after as little as 0.5ml.kg⁻¹ injected rapidly.

The 'dead-space' of injection ports and cannulae can be significant. For example, neonates have been paralysed by the quantity of suxamethonium present when the hub of the cannula was flushed post-operatively. Anaesthetists must flush the cannula carefully with saline after injecting drugs,

particularly if an IV extension has been used. Avoid flushing with heparinised saline in neonates. Heparinised saline contains 10 iu.ml⁻¹ of heparin; 10ml given to a 3kg neonate is 33 iu.kg⁻¹ and this could easily affect clotting.

Central venous catheters

These are smaller versions of adult catheters, with up to 4 lumens.

Sites for central venous access

Femoral venous access is more popular in children than adults. The tip of the catheter is the most likely place for thrombus formation, so choose the length of the catheter so that the tip does not lie at the junction of the renal veins with the inferior vena cava (IVC). Either short lines (catheter tip in the iliac vein or lower IVC) or long lines (tip just below the diaphragm) are appropriate. Central venous pressure monitored from the latter position is as accurate as from the superior vena cava (SVC). Confirm the position of longer femoral lines on X-ray if available, because the line may pass into the contra-lateral femoral vein, the renal vein or the epidural venous plexus. In children <2 years old, the J-portion of J wires may exceed the dimensions of the central vein which will make the wire difficult to thread.

The umbilical vessels are easily accessible during the first 24 hours of life (and less easily so for a further 3 days). Placing the tip of an umbilical venous catheter in the correct position is easier if you adapt the catheter tip to be a unipolar electrode and monitor the ECG signal until you obtain a characteristic atrial ECG. Umbilical arterial lines have been linked with the development of necrotising enterocolitis, although this is not proven. Umbilical venous catheters are particularly prone to thrombosis, which may lead to portal hypertension. They should be replaced as soon as alternative access is practical.

Peripherally inserted central catheters (PICC lines)

These are available as small as 27g and provide access for drugs or parenteral nutrition. Smaller lines cannot be used for pressure monitoring or sampling. Hypertonic drugs (e.g. thiopentone) or drug precipitates (e.g. thiopentone/ suxamethonium) are likely to block these lines. Flush all medicines in immediately after administration.

Intra-osseous needles

There are discussed in a separate article (see page 242)

DEFIBRILLATORS

There are no specific defibrillators designed for children. Many standard defibrillators have paediatric paddles similar to those shown in Figure 8: the adult paddle slides off the smaller paediatric paddle. Paddles must be positioned as far apart as possible to reduce the chances of arcing. Use gel pads (not

shown) to reduce impedance between paddle and patient as for adults. Self-adhesive pads may be available (see Figure 8).

The appropriate size of paddle is the largest pad that will fit the child's chest, as this will reduce both transthoracic impedance and the potential for chest burns. These pads are often labelled with a recommended weight range for standard hospital controlled dose defibrillators, or with an age range for automatic external defibrillators (AEDs).

The appropriate energy levels for children are different from those for adults (see Paediatric Resuscitation p264). 'Advisory' defibrillators and AEDs prompt the user down adult Advanced Life Support (ALS) algorithms and so are not recommended in infants < 1 year old, although they have been used successfully in young children when there has been no alternative. Paediatric pads, if used on an AED, will automatically deliver a lower energy, which varies between defibrillator models. Adult

pads on an AED will deliver up to 360J.

There is evidence that biphasic waveforms are more effective for the treatment of ventricular fibrillation. Advantages seen in adult practice include

- Less time needed to charge
- Improved first shock success rate (90% compared with 60%)
- Less myocardial injury
- Decreased incidence of skin burns
- Increased battery life of the defibrillator.

Current paediatric recommendations are to select the same energy ($4J.kg^{-1}$ in cardiac arrest) for a monophasic or biphasic defibrillator (see resuscitation articles p267 and 270.)

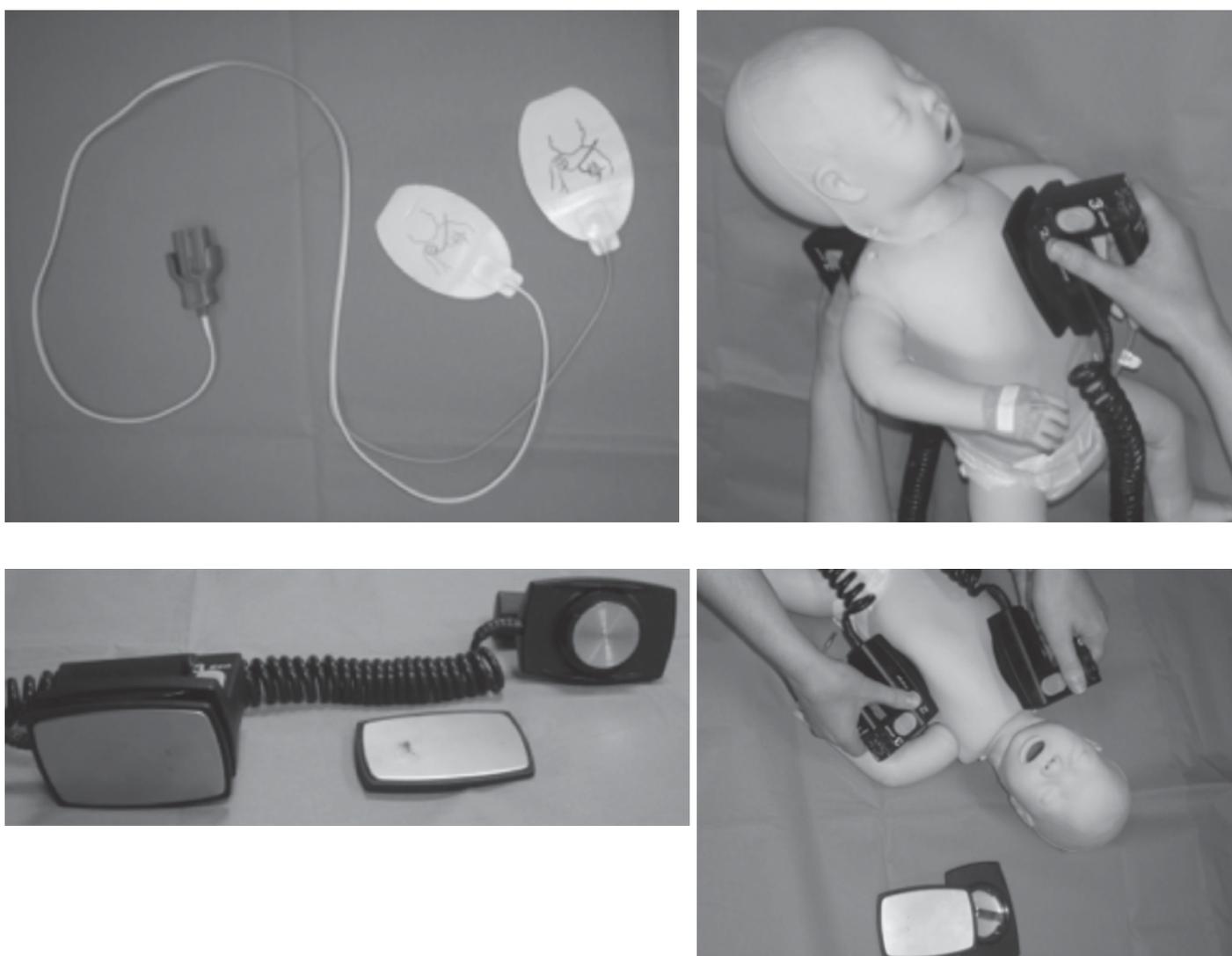


Figure 8. Paediatric defibrillator pads and paddle positions.

TEMPERATURE CONTROL

Good temperature control is vital in paediatric anaesthesia (see basic sciences article p4). You must monitor temperature during active warming.

Warming methods include:

- **Forced air heating blankets** e.g. the Bair Hugger. These devices deliver warm air up to 43°C for active warming. They can also blow room temperature air to cool patients who are pyrexial
- **Simple warming blankets** reduce conductive losses to the table and are cheap and effective although not as efficient
- **Overhead radiant heaters** are also cheap and effective. Pay strict attention to the safe minimum height of radiant heater above the patient. Patient signs of systemic overheating will be late. Local overheating presents as burns. Radiant heaters increase insensible water loss in neonates
- Prevent heat loss by **insulation** when active heating is impractical or unavailable. Almost any insulating material may be used e.g. clean blanket or clothing, cotton wool, tinfoil or bubble wrap
- **Raised operating theatre temperature** for babies or small children. You will need to compromise between the thermo neutral temperature for the anaesthetised patient (34°C for premature neonates, 33°C for term neonates reducing through childhood to 30°C at adolescence) and a comfortable working temperature for staff (up to 25°C). One solution is to have the temperature relatively high during induction of anaesthesia, and then reduce it once the patient is draped and use a forced air warmer if available to maintain a 'microclimate' during surgery
- In theory **circle systems** warm and humidify inspired gases. In practice these effects are small. Some circle systems have additional heaters to aid gas warming. HME (heat moisture exchange) filters help
- **Heated humidifiers** may be added to any breathing circuit, and will help warm the patient by warming airway gases. Monitor gas temperature at the patient end to avoid airway burns
- **Warm fluids** – as above.

MONITORING

Standard monitors for a child are the same as for an adult. It is acceptable to complete the attachment of patient monitors after induction of anaesthesia to prevent a child becoming distressed as long as there is no compromise to safety.

Oesophageal or precordial stethoscope

This low-technology device offers continuous, immediate information on breath and heart sounds without the lag times associated with oximetry and capnography.

Pulse oximeter

Oximetry probes need to be matched to the size of the patient. Too large a probe will give a poor reading due to light scatter and easily falls off. When you choose the site carefully, you can use adult sized probes for younger children e.g. an adult ear probe can be attached to a digit. These ear probes have spring closures, which may produce sufficient pressure to cause ischaemia in a child's finger. Wrap-around probes are available and may be used on digits, or in small babies wrapped around a foot or hand. They have no risk of pressure necrosis but do produce heat. Burns have occurred in children with low peripheral perfusion e.g. during cardiopulmonary bypass.

The absorption spectra of foetal and adult haemoglobin are similar, and at 660nm and 910nm in a basic pulse oximeter the device is accurate in detecting desaturation of foetal haemoglobin.

Problems and pitfalls

- Pulse oximeters are poor indicators of hyperoxia due to the shape of the oxyhaemoglobin dissociation curve. Whilst the pathogenesis of retinopathy of prematurity is multifactorial, it is important to avoid hyperoxia in at risk babies (particularly premature neonates)
- Pulse oximeters may be inaccurate in the presence of certain pigments: methylene blue gives a falsely low reading. Bilirubin does not affect pulse oximetry
- Potential inaccuracies in children with congenital heart disease: the oximeter derives arterial saturation by subtracting the 'fixed absorbance' part of the signal. In tricuspid regurgitation, the monitor may detect a pulsatile venous component of the signal, and display the venous saturation
- In infants with a physiological shunt through a patent ductus arteriosus, the pulse saturation will vary between the right arm (pre-ductal) and other limbs (post-ductal). The pre-ductal blood supplies the cerebral circulation, so measure saturation on the right arm as a minimum.

Phone app based pulse oximeters are appearing on the market. All necessary hardware is incorporated into the finger probe with a connection to a mobile phone where the phone app provides the software and display. Some of the probes now have FDA approval, but experience of their use is limited at present.

Apnoea monitors

These are frequently requested by paediatric anaesthetists to monitor babies <6 months old after anaesthesia. They are designed to alarm after 15 or 20 seconds of apnoea. They detect breathing in one of two ways:

- By changes in impedance measured through ECG electrodes on the chest
- By a change in pressure detected by a sealed mattress or a small sensor on the abdomen as shown in Figure 8 (abdominal excursions move a fine foil strip in the monitor) (More common).

Apnoea monitors are cheap and non-invasive but have some disadvantages:

- Prone to false positive alarms, and to interference from mobile phones
- Will not detect airway obstruction, because movement of the chest and abdomen still occurs
- Cardiac pulsation may trigger the monitor, even if the child is apnoeic.

These monitors should be used as an adjunct to high dependency nursing care, not a substitute for it.

Electrocardiography (ECG)

As children do not usually have ischaemic heart disease, the ECG is used mainly as a heart rate and rhythm monitor and rarely to detect ischaemia. At birth, the right ventricle is as thick as the left. This manifests as right axis deviation and right ventricular hypertrophy on the ECG (dominant R wave in V1, deep S wave V5 & V6, inverted T wave V1-4). With growth, the left ventricle becomes larger than the right. By age



Figure 10. An apnoea monitor for a baby

2-5 years, the axis is within the adult range. T wave inversion reverses by 10 years old when the ECG becomes similar to that of an adult.

Lead II is usually the best choice in all ages as the prominent P wave aids rhythm recognition. A common error is that large T waves may be read as QRS complexes by the monitor causing double counting of the rate.

Blood pressure measurement

Non-invasive blood pressure measurement

All non-invasive blood pressure machines that measure from a cuff are automated oscillotonometers. The most important considerations are the width and length of the bladder used in the cuff (see Table 3).

Table 3. Determining the appropriate size of a blood pressure cuff. If the cuff is too small, the reading will be artificially high; the reverse is true if the cuff is too big. Common Error: generally, oscillotonometers over-read lower pressures, i.e. they over-read values within the normal neonatal range.

BP cuff bladder width	Should cover approximately 2/3 of the upper arm	Neonate 3cm Baby 5cm Small child 6cm Large child 9cm
BP cuff bladder length	Minimum 40% of the circumference of the upper limb; $\geq 80\%$ is ideal	

The machine settings for adult, paediatric or neonatal modes usually control only the maximum inflation pressure. This is to avoid excessive pressure and the risk of bruising or trauma in babies or small children if exposed to the values in a hypertensive adult.

Direct arterial blood pressure measurement has the same principles as in adults. If using an umbilical arterial catheter in neonates, which is relatively long and thin, inspect the trace for signs of overdamping.

Safety point: take care with manual flushing. Meticulously avoid bubbles, and note that a brisk 1ml flush in a neonate is sufficient to push bubbles or thrombus from the radial artery back as far as the vertebral artery.

Peripheral nerve stimulators

Peripheral nerve stimulators may be used in children for monitoring neuromuscular blockade, or localization of peripheral nerve. The response of the paediatric neuromuscular junction to neuromuscular blockade is similar to that of

adults. In neonates, the immature junction is sensitive to non-depolarising muscle relaxants, with reduced prejunctional reserves of acetylcholine.

CO₂ monitoring/end-tidal agent monitoring/oxygen monitor

End-tidal gas measurements are unreliable in babies. The tidal volume is small compared with equipment dead space volume, fresh gas flow, and leak around the endotracheal tube. Small tidal volume and rapid respiratory rate confound the monitor's real-time analysis.

You should still obtain some CO₂ tracing if you are careful to minimise equipment deadspace, but with a large and variable A-a gradient.

CONCLUSION

Consideration of the anatomical and physiological differences between paediatric and adult patients makes it easier to select the correct equipment to anaesthetise all patients safely. Availability of the appropriate equipment may be the more difficult problem.