Chapter

36 Anaesthesia for Radiology and Interventional Radiology in Children

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Radiology is a rapidly expanding service in paediatrics, often requiring general anaesthesia. Paediatric interventional radiology is a new speciality, and radiologists can perform an increasing number of procedures to facilitate treatment for some of the sickest patients in the hospital. Examples include tumour biopsy, embolisation of arteriovenous malformations, delivery of intra-arterial chemotherapy and insertion of tunnelled central lines for chemotherapy or long-term inotropic support for cardiac failure patients. The radiology suite is an 'unfriendly' environment for the anaesthetist, with access to the patient often limited by long distances and bulky X-ray equipment, and procedures may occasionally be performed with dimmed lights. Scrupulous attention must be paid to patient positioning, security of lines and tubes and maintenance of normothermia during long procedures. Constant vigilance with respect to both the patient's needs and the demands of the radiologist is required. Good communication and teamwork between the radiology team and anaesthetist are essential to ensure patient safety in this challenging but rewarding area of work. This chapter will describe anaesthesia for interventional radiology, including neuroradiology, computerised tomography (CT) and magnetic resonance imaging (MRI).

Vascular Access

Long-Term Vascular Access

This is one of the mainstays of the interventional radiologist. Children require long-term vascular access for the administration of chemotherapy, parenteral nutrition, inotropes or chemotherapy, or short-term access for courses of antibiotics or anti-viral or anti-fungal medication. A cuffed Hickman line or Portacath is inserted, depending on the treatment required and patient or parental preference. Lines are required for the duration of treatment and may remain in place for years unless they become infected.

It is important to assess children carefully preoperatively, as candidates for central access are rarely fit and healthy. Children with cardiomyopathy or severe pulmonary hypertension (right-ventricular pressure approaching systemic pressure) are at particular risk of cardiac arrest under anaesthesia. The risks and benefits of the procedure should be carefully considered, and a backup plan formulated in case of complications.

Anterior Mediastinal Mass

Children presenting with a haematological malignancy, neuroblastoma or intrathoracic germ cell tumour may have an anterior mediastinal mass (seen in up to 50% of children with non-Hodgkin's lymphoma). This may cause airway compression, superior vena cava (SVC) obstruction or vascular compression, which may result in cardiovascular collapse on induction of anaesthesia. Worrying symptoms and signs include stridor, wheeze, orthopnoea, facial swelling and history of cardiovascular collapse. Review of the preoperative chest X-ray and CT scan is essential to look for a widened mediastinum, compression of the great vessels, tracheal or mainstem bronchus or pericardial or pleural effusion (see Figures 36.1 and 36.2).

It may be preferable to start treatment and delay line insertion for a few days in children with a new diagnosis of lymphoma and severe respiratory symptoms to reduce the risk of anaesthesia. This requires close liaison with the oncologist, as treatment will shrink lymph nodes rapidly and may make diagnosis impossible.

For induction of anaesthesia, children with an anterior mediastinal mass should be placed in a position of comfort (often on the side), and spontaneous respiration should be maintained if possible. If a neuromuscular blocking drug is given and thoracic tone reduced, be prepared for distal

airway obstruction; this should be managed by application of continuous positive airway pressure (CPAP), repositioning or intubation with a long tracheal tube; some advocate the use of a rigid bronchoscope to regain airway patency. Vascular access should be placed in the lower limbs if the SVC is obstructed, and intravenous fluids and resuscitation drugs should be available in case of vascular compromise when the child is anaesthetised.

Tumour Lysis Syndrome

Children with lymphoma or high-count acute lymphocytic leukaemia (ALL) are at risk of tumour lysis syndrome 12–72 hours after starting chemotherapy due to massive release of intracellular metabolites. These children require hyperhydration and treatment with allopurinol or rasburicase to preserve renal function and prevent deposits of uric acid or calcium phosphate in renal tubules. The main chemotherapy drug used for lymphoma is dexamethasone, so children with a new diagnosis of lymphoma or leukaemia should not receive dexamethasone as an antiemetic, as this may inadvertently precipitate tumour lysis syndrome.

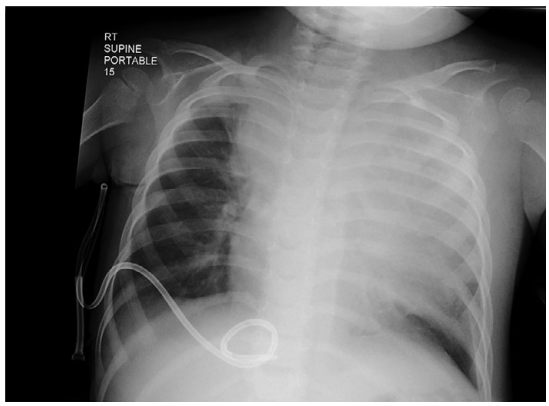

Figure 36.1 Chest X-ray of child with non-Hodgkin's lymphoma associated with a large anterior mediastinal mass.

For children requiring intermediate duration vascular access (six weeks to six months), a non-cuffed line such as a peripherally inserted central catheter (PICC) is inserted, usually via an antecubital fossa vein, or in infants and small children tunnelled over the chest wall and inserted into the internal jugular vein.

The other types of vascular access lines inserted in the radiology suite are dialysis catheters, either temporary (Vascath®) or long term (Permacath®). These are large-bore catheters, which are 'locked' with heparin 1,000 IU ml^{-1} to prevent line thrombosis and occlusion. The dead space of the line is always printed on the line, and this volume must be aspirated and discarded prior to use to prevent unintentional heparinisation of the patient.

Positive pressure ventilation is usually required in all tunnelled line insertions to decrease the risk of venous air embolism during central vein puncture. If a PICC line is required in older children, a spontaneous ventilation technique may be acceptable, as the line insertion utilises an arm vein only.

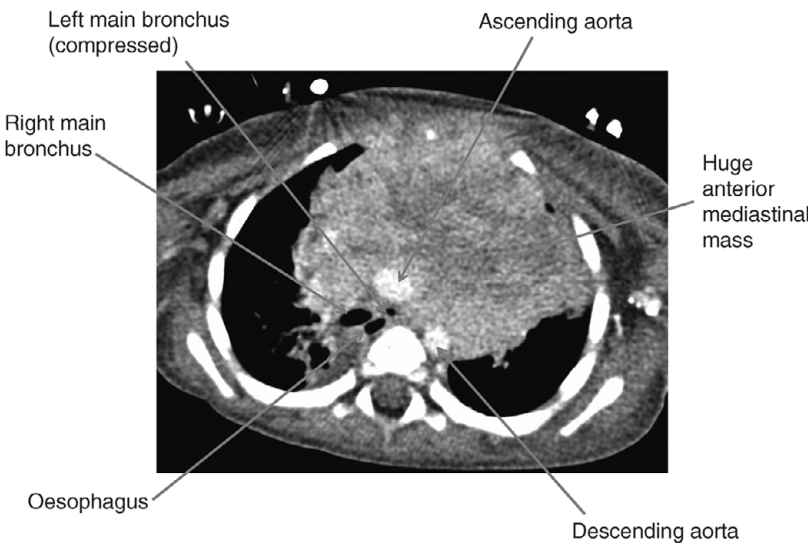

Figure 36.2 CT scan of child with non-Hodgkin's lymphoma associated with a large anterior mediastinal mass.

A platelet count above 50×10^9 l^{-1} and normal coagulation are required; children with a coagulopathy may require blood products to cover line insertion.

Portacaths and cuffed lines are removed under general anaesthesia, but non-cuffed lines may be removed on the ward. Children with acute myeloid leukaemia (AML), non-Hodgkin's lymphoma, Wilm's, neuroblastoma or bone tumours may have received intensive chemotherapy with anthracyclines (doxorubicin, daunorubicin or epirubicin). They are at risk for anthracycline-induced cardiomyopathy, which may be subclinical. These children require thorough preoperative assessment, and a recent echocardiogram should be reviewed.

Biopsy of Solid Organs or Tissues

Liver Biopsy

Diagnostic liver biopsy may be required to determine the nature of acute or chronic liver disease. A Tru-Cut biopsy needle is inserted into the liver under ultrasound guidance, and several core samples are taken using the same tract. The following precautions are taken to reduce the risk of bleeding:

- Platelet count must be at least 100×10^9 l^{-1}.
- Coagulation must be normal.
- A collagen gel foam plug is inserted in the biopsy tract at the time of the procedure.

The patient is usually positioned on their side with a bolster placed underneath them to open the gap between the lower end of the rib cage and the iliac crest. Spontaneous ventilation with a supraglottic airway device (SAD) is acceptable. Patients should be observed carefully over the next six hours for signs of ongoing blood loss (pain, tachycardia, hypotension). If the clotting is grossly deranged and the risk of bleeding from the biopsy site is deemed to be great, then a biopsy may be taken via a catheter inserted into the internal jugular vein and passed into the liver via the hepatic vein. If bleeding from the liver does occur, it is contained within the venous circulation.

Renal Biopsy

Renal biopsy of a native kidney may be required to establish a diagnosis or monitor disease progression, or post-transplant to help confirm or rule out rejection. In order to biopsy a native kidney, the patient is positioned on their side with a bolster placed underneath them, as for liver biopsy. For renal transplants, the kidney is in the iliac fossa, so the patient can remain supine.

Tumour Biopsies

The same principles apply for liver and renal biopsies. The site of the tumour determines the anaesthetic technique and positioning. Biopsies may be either ultrasound or CT guided. The latter can be quite a logistical feat, as the patient may need to be positioned prone in the CT scanner for the radiologist to locate and biopsy the tumour. All patients must be closely observed after the biopsy for signs of ongoing blood loss.

Gastrostomy

Percutaneous gastrostomy insertion is another procedure that is being performed more commonly in the radiology suite (see Figure 36.3). The major advantage of fluoroscopic control over the traditional endoscopic method is that the patient can be given a barium meal the day before to outline the colon, which reduces the risk of inadvertent colonic perforation.

A nasogastric tube is inserted under fluoroscopic control, and the stomach is inflated with air to aid distension and ease of percutaneous puncture. A dose of glucagon (40 mcg kg^{-1} IV) is given to cause gastric paresis. Once the stomach has been punctured, a catheter over a wire is passed retrograde up the oesophagus and out of the mouth. A thread is then passed via the catheter, and the gastrostomy tube is attached to this thread. The thread is used to pull the gastrostomy back down through the mouth and oesophagus so that the flange is in the stomach

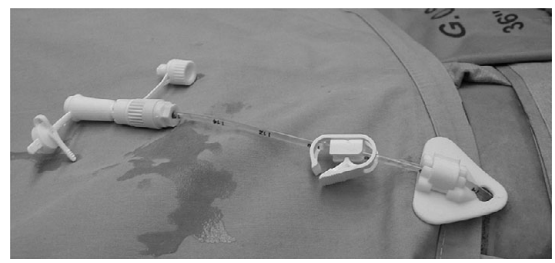

Figure 36.3 Percutaneous endoscopic gastrostomy tube (PEG). A Freka® PEG feeding tube is shown.

and the tube protrudes from the abdominal wall. The position is confirmed fluoroscopically.

As with any percutaneous gastrostomy, there is a risk of contamination of the abdominal cavity with gastric contents, so prophylactic antibiotics (co-amoxiclav or metronidazole) are given before the start of the procedure. The stomach is usually rested for 6–24 hours after gastrostomy insertion, so postoperative IV maintenance fluids are required.

Oesophageal Dilatation

There are two main groups of children who present to the radiology suite for oesophageal dilatation: those with a stricture following surgical repair of oesophageal atresia or tracheo-oesophageal fistula (TOF); and those with a stricture secondary to other scarring processes, such as dystrophic epidermolysis bullosa (DEB) or, less commonly, ingestion of caustic soda.

DEB is a hereditary skin disease that is characterised by painful blistering when skin or other stratified squamous epithelial membranes are exposed to shearing forces. Direct pressure does not cause new bullae to form, only shearing forces. Swallowing food boluses results in chronic bullae in the oropharynx and oesophagus, with subsequent scarring and stenosis.

Oesophageal dilatation involves passing a wire, usually via the mouth, across the stricture under fluoroscopic control, followed by balloon inflation. Patients with the most severe form of DEB may have limited mouth opening due to oral strictures, and intubation may be very difficult. These patients usually have a gastrostomy in situ, and a retrograde technique may be used.

Anaesthesia for patients with DEB can be very challenging, and the following precautions should be taken:

- Intravenous access is often difficult due to multiple dressings. Access should be secured with a non-adhesive silicone dressing such as Mepitel®.
- Electrocardiogram (ECG) electrodes should not be stuck to the patient. Placing the electrodes onto pieces of defibrillator pad on the skin makes good electrical contact.
- An adhesive pulse oximeter should be placed on a digit over a covering of plastic food wrap and not straight onto skin.
- The blood pressure cuff should be padded.
- If the patient is intubated, the tracheal tube should be tied using plastic food wrap rather than taped in place.
- The face mask should be lined with paraffin gauze. Gloves should be worn, and it is sensible to protect pressure points on the chin and jaw with paraffin gauze.
- The eyes should be covered with gel pads, and artificial tears may be used to protect the cornea.
- A well-lubricated SAD may be used if a retrograde technique is used, but the mouth opening is often too limited for SAD insertion.
- Great care is needed in transferring the patient onto the X-ray table, using a straight lift rather than a slide.

Even when the utmost care has been taken, anaesthesia is often associated with new bullae formation, and it is sensible to warn the family that this may occur.

Airway Procedures

Bronchoscopy, Bronchogram, Tracheal Dilatation or Insertion of Airway Stents

Patients may come to the radiology suite for bronchoscopic, radiographic and intrauminal ultrasound assessment of the airway as part of the management for both congenital and acquired tracheal stenosis or tracheomalacia (see Figure 36.4). Direct bronchoscopy is useful to document the nature and extent of tracheal disease and the presence of abnormal complete tracheal rings. A dynamic contrast bronchogram is required to delineate distal tracheobronchomalacia and define the level of CPAP required to keep the airway patent. Bronchoscopy and bronchogram are both vital parts of the surgical work-up and postoperative follow-up for patients with tracheobronchial abnormalities. Balloon dilatation or insertion of intraluminal stents may be required at suture lines or in the presence of residual stenosis. Granulation tissue may also be managed with stenting (see Figures 36.5 and 36.6).

Patients with congenital tracheal stenosis may have an underlying cardiac abnormality, and an echocardiogram is required as part of their preoperative work-up.

Our preferred anaesthetic technique for bronchoscopy is spontaneous ventilation via a

SAD so that dynamic assessment of the airway can be made during the respiratory cycle, particularly if tracheobronchomalacia is suspected. A pressure manometer inserted into the Ayres T-piece circuit will give an indication of opening pressures required to overcome inspiratory collapse due to tracheobronchomalacia. This method using a SAD may not always be possible, for instance in neonates or those already ventilated, in which case a bronchoscope of appropriate size may be passed via a tracheal tube (see Table 36.1).

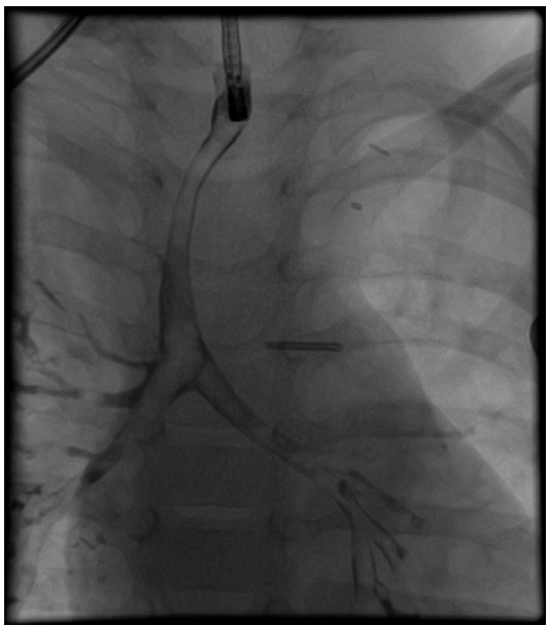

Figure 36.4 Bronchogram to demonstrate congenital tracheal stenosis.

An angle piece with a self-sealing valve is used to minimise leakage of anaesthetic gases when the bronchoscope is passed down the SAD. Atropine 20 mcg kg^{-1} IV may be given to dry secretions. Topical lidocaine (3 mg kg^{-1}) to the larynx and between the cords before endoscopy reduces coughing, although this has the disadvantage of preventing the child from eating or drinking for two hours post-procedure. Passing the bronchoscope through the vocal cords rarely causes coughing/spasm in patients if the child is relatively deep (end-tidal sevoflurane concentration of around 4%). The child may cough if the bronchoscope 'tickles' the carina, and a bolus of 1–2 mg kg^{-1} of propofol is usually enough to prevent or treat this. Transient apnoea associated with the propofol bolus can be overcome by assisting ventilation until spontaneous respiration returns.

A dynamic assessment of the airway is made with the child breathing spontaneously prior to airway stent insertion or balloon dilatation. A bolus of propofol is administered just before the balloon is inflated so that the child is apnoeic and does not cough. This technique allows spontaneous ventilation to return rapidly after the procedure so that the dynamic assessment of the airway can be repeated.

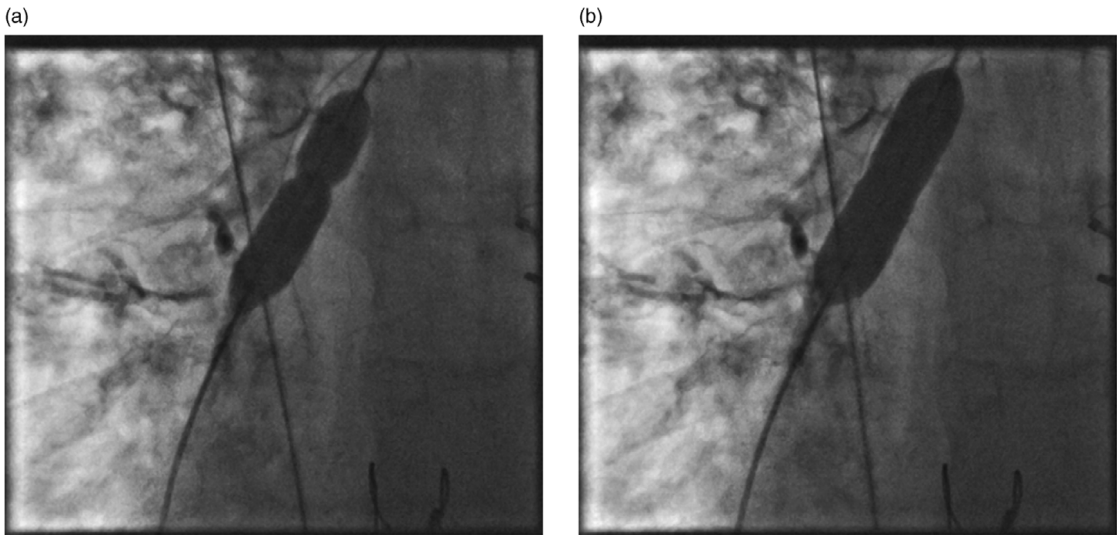

Figure 36.5 Balloon dilation of residual stricture after repair of congenital tracheal stenosis. (A) Bronchial waist on balloon. (B) Bronchial waist abolished after dilation.

Table 36.1 Sizing guide for fibreoptic bronchoscopes

Scope diameter	Minimum internal diameter of tracheal tube (mm)
Olympus 2.2 (no suction channel)	2.5
Storz 2.8	3 (tight) 3.5 acceptable
Olympus 3.8 Storz 3.7	4 (tight) 4.5 acceptable

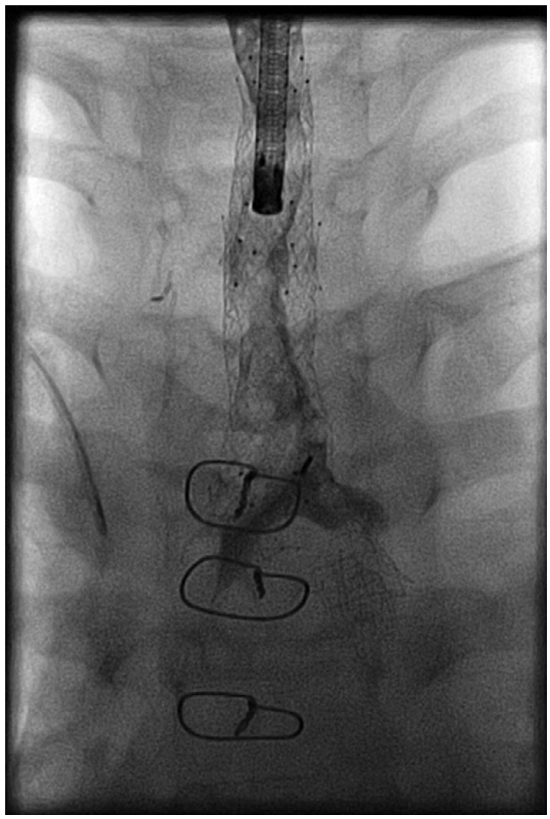

Figure 36.6 Tracheal stent in situ for residual stricture in severe congenital tracheal stenosis.

Visceral Angiography

Access for most angiographic procedures is via a femoral artery. It is often best to paralyse and ventilate the patient, as repeated periods of apnoea may be required after injection of contrast, and small movements, even those associated with respiration, cause significant artefacts.

Conventional X-ray contrast (Omnipaque® 240 mg I ml^{-1}) is used. As with all contrast media, there is a small risk of prior sensitisation, and a full allergy history should be taken during preoperative assessment in case an alternative is required. A cumulative dose of 5 ml kg^{-1} is the usual maximum, although up to 7 ml kg^{-1} may be given safely. Radiographic contrast media are usually osmotic diuretics, and intravenous fluids should be given during the procedure. 'In-out' catheterisation may be required at the end of the procedure if the bladder is distended. Occasionally, carbon dioxide gas (1 ml kg^{-1} to the nearest 5 ml aliquot) is used as a contrast medium to keep the dose of iodinated contrast medium to a minimum. Hyoscine butylbromide (0.3 mg kg^{-1} IV) is useful to counteract spasm of the gastrointestinal tract before enteric angiography.

The arterial sheaths used for angiography are relatively large, and it is helpful if the child does not cough vigorously during emergence, as this will lead to hematoma formation. For this reason, some advocate topical lidocaine to the cords prior to intubation and plan for deep extubation at the end of the procedure.

Renal Vein Sampling and Angioplasty

Approximately 10% of children with secondary hypertension have renovascular disease that results from one or more lesions that impair renal blood flow. This is usually secondary to fibromuscular dysplasia of the renal vessels, which is often bilateral. Patients may be taking multiple antihypertensive agents and may have evidence of left-ventricular hypertrophy or even hypertensive cardiomyopathy on preoperative echocardiogram or ECG. There is a common association between renal artery stenosis and disease in other vascular beds, and 20–25% of these patients have cerebral vascular involvement. Cerebral angiography is often performed at the same time as renal imaging.

Children who have severe hypertension resistant to treatment may benefit from either angioplasty or from surgical resection or stenting of a stenosed renal artery. Selective renal vein angiography and sampling allows measurement of local renin secretion to identify those who may benefit from this intervention. It may also be of diagnostic value and helps differentiate these children from those with hypertension due to nephropathy or vesicoureteric reflux.

Angiographic treatment alone (stenting or balloon dilatation) results in improvement in

blood pressure control in approximately half of these patients, although re-stenosis may require further treatment. This is especially true when a stent is inserted. Those with severe disease involving the aorta require surgical repair with a Gore-Tex® graft, but they may develop stenosis at the graft site, which will also benefit from angiographic dilatation.

Good control of blood pressure preoperatively is difficult in these children, despite the use of combination therapy. Treatment may be compromised by poor compliance or limitation of dose due to adverse drug side effects.

As with all angiographic procedures, the patient must be completely still during the procedure, and multiple episodes of breath-holding are required. The child should therefore be intubated and ventilated. A loading dose of heparin (75–100 IU kg^{-1}) is given prior to balloon inflation if angioplasty is undertaken.

The major complication of any angioplasty is vessel rupture, and vascular surgeons should always be readily available before this procedure is undertaken.

Pancreatic Venous Sampling

The most frequent cause of prolonged severe hypoglycaemia in infancy is congenital hyperinsulinism, usually secondary to one or more insulin-secreting lesions within the pancreas. This is treated by surgical resection and partial pancreatectomy after localisation of the tumour by pancreatic arterial stimulation and venous sampling.

Pancreatic venous sampling of insulin is usually performed under general anaesthesia in children but may be performed under sedation in the adult population. Both venous and arterial catheters are inserted, and timed samples are taken from the right hepatic vein after injection of calcium gluconate into pancreatic arteries that supply different parts of the pancreas. Diagnosis requires at least doubling of the insulin level sampled from the hepatic vein.

High levels of endogenous catecholamine released due to stress such as intubation may cause a rise in blood glucose concentrations, which in turn can interfere with the interpretation of test results. Deep anaesthesia is therefore ideal. Theoretically, using high concentrations of volatile agents may also interfere with test results, as volatile agents block calcium channels, which in turn reduces insulin release. A balanced anaesthetic to maintain heart rate and BP to within 20% of baseline may be achieved using remifentanil (0.5–1.5 mcg kg^{-1} min^{-1} IV) and volatile anaesthesia with end tidal concentration of 0.5 MAC.

These infants usually require a glucose infusion to prevent profound and dangerous hypoglycaemia due to their insulinoma. The amount of glucose required may be quite substantial, and they commonly require a tunnelled PICC or Hickman line so that glucose 20% or more can be given to maintain normoglycaemia. Regular blood sugar measurement should be taken throughout any intervention and the glucose infusion rate altered accordingly.

Extracranial Sclerotherapy

This is used to treat cutaneous or peripheral lymphangiomas, either simple or macrocystic-type (cystic hygromas) or vascular arteriovenous malformations (AVM). A sclerosing agent is injected under ultrasound or fluoroscopic guidance into the malformation. The choice of sclerosant depends upon the type of malformation and preference of the radiologist. For microcystic (solid) lymphatic malformations, either doxycycline or bleomycin is used; for macrocystic lesions, either doxycycline or STS 3% (sodium tetradecyl sulphate) is used. Bleomycin injection requires specific anaesthetic considerations. To minimise the risk of lung fibrosis, additional inspired oxygen should be kept to a minimum, with inspired air being ideal. Also, removal of adhesives applied to the skin can cause significant, permanent skin discolouration. Therefore, all adhesives should be avoided. A non-adhesive dressing such as Mepitel® can be used to secure venous access, and ECG dots stuck onto a gel-type defibrillator pad on the chest avoids sticking these dots directly onto the patient's skin.

A course sclerotherapy of sessions is usually required. This may be as a prelude to surgical excision if required. In head and neck lymphangiomas, approximately 90% show improvement after sclerotherapy, and 40% of lesions show complete regression. The anaesthetic technique will be dependent on the site of the lesion. Spontaneous ventilation is usually adequate for extracranial lesions.

Patients with malformations on the face or oral area require a single dose of prophylactic

antibiotics (co-amoxiclav or teicoplanin and an aminoglycoside for penicillin allergic patients). A single dose of dexamethasone 0.25 mg kg^{-1} IV up to 8 mg should be given to reduce inflammation in patients with facial or oral lesions.

Sclerotherapy may be quite painful postoperatively and patients may require opioid analgesics such as oral morphine in addition to regular paracetamol and NSAIDs such as ibuprofen or diclofenac.

There is a small risk of hypoglycaemia after sclerotherapy, and so blood glucose level should be monitored twice hourly for the first six hours after the procedure and oral intake encouraged.

Neuroradiological Interventions

Cerebral Angiography

Children may require cerebral angiography and/or embolisation of intracranial congenital AV malformations and shunts. These are often first diagnosed after an intracranial bleed. The initial visit to the angiographic suite may be during the acute phase whilst intubated and ventilated in the intensive care unit, possibly whilst requiring inotropic support to maintain cerebral blood flow.

There are three methods of embolising cerebral AVMs: coils, micro-particles or glue. In children, the use of coils is uncommon, as most large, rapidly shunting AVMs are thin walled and may rupture when coiled. Most malformations, shunts and tumours are embolised using either micro-particles or glue. Micro-particles are usually employed in tumours and glue in the embolisation of AVMs, although some operators may wish to use micro-particles for AVMs that have a small shunt component. Where there is a large atrioventricular (AV) shunt, such as vein of Galen aneurysmal malformation, glue is always used. Glue used for embolisation starts to polymerise when the glue comes into contact blood.

The extent of glue dispersion depends upon three variables: the concentration of glue, the speed of injection and the flow velocity within the AV shunt. This last factor is affected by the nature of the lesion and where, in relation to the lesion, the neuroradiologist can place the micro-catheter. The process of glue polymerisation is exothermic, so dexamethasone (0.2–0.25 mg kg^{-1} IV) should be given to reduce inflammation and reduce the risk of 'peri-glue' oedema.

Cerebral angiography carries a small risk of stroke and blindness, which is increased when a lesion is embolised. The neuroradiologist looks specifically for signs of retinal 'blush' during angiography, as embolisation near the origin of the ophthalmic artery would cause permanent visual loss.

There are three possible major intracerebral complications if glue has been used:

- The micro-catheter tip may be retained within the glue.
- Proximal spread of glue due to invagination of the 'glueoma' when the embolisation catheter is removed.
- A vessel is torn when the catheter is removed. This may occur if the catheter has become lodged within the glue ball stuck to the vessel wall and may result in cerebral haemorrhage.

The second two complications are fortunately very rare but contribute to the risk of stroke during the procedure. Cerebral haemorrhage may require further embolisation or surgery such as ventricular drain insertion. Retention of the micro-catheter tip within the glue mass does not usually cause a problem, as the catheter becomes epithelialised with time.

The main systemic risk of cerebral embolisation is that of migration of the embolising material into the extracranial venous circulation and the pulmonary bed. The anaesthetist should look for signs of systemic spread such as a fall in end-tidal CO_2 or oxygen saturation. Fortunately, these pulmonary emboli are very small, and the effect is not usually long-lasting.

Vein of Galen Aneurysmal Malformation (VGAM)

Large AV shunts often present with signs of high-output right-heart failure rather than an intracranial bleed. This is due to the rapid recirculation of blood from the arterial circulation through the AV shunt back to the right heart without passing through the systemic vascular bed. The vein of Galen aneurysmal malformation is a rare but important cause of high-output cardiac failure presenting in neonates (see Figure 36.7).

The vein of Galen aneurysmal malformation (VGAM) is a heterogenous collection of rare midline intracranial choroid arteriovenous (AV) vascular malformations. A VGAM consists of

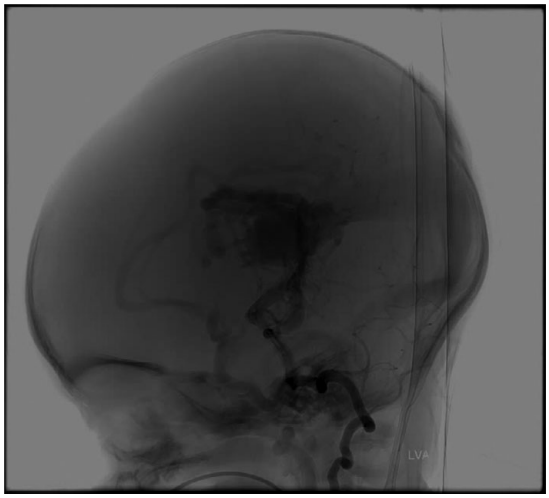

Figure 36.7 Vein of Galen aneurysmal malformation.

multiple AV shunts draining into a dilated median prosencephalic vein of Markowski, a persistent embryonic vein that is normally absent in adults. The normal vein of Galen is formed by the junction of the internal cerebral veins and passes between the corpus callosum and pineal gland to form the straight sinus as it joins with the inferior saggital sinus. A VGAM is anatomically different from an AV malformation, where the venous drainage is into a dilated, but already formed, vein of Galen.

Without treatment, VGAMs are invariably fatal. Advances in cerebral angiography with early embolisation have improved outcomes significantly, so that in some series, 74% of those who are treated are neurologically normal at follow-up.

Babies presenting with VGAMs have a massive intracranial AV shunt. They usually present in the neonatal period with signs of poor systemic perfusion, pulmonary hypertension and right-heart failure. The systemic vascular resistance is higher than AV shunt resistance; thus blood leaving the left side of the heart goes preferentially to the carotid arteries, through the AV shunt and back to the right heart to cause volume overload and subsequent right-heart failure. Increased pulmonary blood flow may result in pulmonary hypertension (PHT), particularly in the newborn period, and right-ventricular pressure may approach or exceed systemic values.

Diagnosis is made by demonstration of the AVM on cranial ultrasound. A loud bruit may also be heard over the anterior fontanelle. Occasionally a VGAM can be diagnosed antenatally if a third trimester scan is done.

Babies presenting in the first few days of life with poor systemic perfusion and cardiac failure require pre-intervention ventilation and inotropic support in the neonatal intensive care unit (NICU). Milder cases of cardiac failure presenting in the first few weeks of life usually respond to diuretics.

Close cooperation with the neuroradiologist is essential. If the arterial pressure is high during an embolisation run, the glue may spread further than intended, thus unintentionally embolising other areas of the brain. The neuroradiologist will usually ask for a drop in systemic blood pressure (BP) to about two thirds of awake values. Fentanyl 1–2 mcg kg^{-1} and sevoflurane 2–3 MAC is usually sufficient if the patient is fully paralysed. The diastolic BP is often very low and starts to normalise once the AV shunt is embolised. Tachycardia often becomes less pronounced as systemic blood flow increases, though this may not be as obvious in the anaesthetised patient.

All neonates are kept sedated, intubated and ventilated in NICU after VGAM embolisation. Closure of the AV shunt will cause a sudden increase in cerebral (rather than shunt) perfusion, as well as increased systemic perfusion. These factors may result in reperfusion injury, and there is a risk of post-embolisation cerebral bleed. Although right-sided heart failure may start to improve after embolisation, an element of left-sided heart failure often develops, as the left ventricular afterload is now increased.

Blood pressure must be carefully controlled post-embolisation, and an agent such as glyceryl trinitrate (GTN) or sodium nitroprusside (SNP) may be required if simple sedation is not sufficient. Some neuroradiologists heparinise patients after embolisation to prevent retrograde blood clots resulting in ischemic stroke. Heparin should only be started if there has been no bleeding during or after the embolisation procedure. A CT scan is routinely performed at the end of the procedure to determine if this is a safe course of action.

As there are potentially huge changes in both cerebral blood flow and physiology, the AV shunt is usually closed in stages in the first two to three months of life. Children for repeat embolisation are not usually as sick and may no longer require anti-failure medication. Post-

embolisation management of these patients, including admission to NICU for ventilation after the procedure, depends on the residual AV shunt and operator preference.

Intra-ophthalmic Artery Chemotherapy

Selective catheterisation of the ophthalmic artery for intra-orbital chemotherapy is a relatively new but expanding area of interventional neuroradiology.

This is currently reserved as second-line treatment for children with retinoblastoma who have relapsed during or after conventional systemic chemotherapy and cryotherapy. It avoids the need for radiotherapy during a critical time of brain development with the attendant risks of secondary malignancy and developmental delay. Initial results are encouraging, and with more experience this treatment option may become more widely available for other patients.

Access is via the femoral artery as per standard cerebral angiography. A micro-catheter is placed directly into the ophthalmic artery and the chemotherapy agent (e.g. melphalan, topotecan) is slowly infused into the orbit over a period of at least 20 minutes. Response to treatment is assessed two to three weeks later by formal examination under anaesthesia, and if responding, the child will receive further two treatments four to six weeks apart.

Standard cerebral angiography is performed, but there are some additional special considerations:

- The eye is at risk from arterial thrombosis, so a loading dose of heparin (75 IU kg^{-1}) is given after femoral access has been obtained.
- Dexamethasone (0.25 mg kg^{-1}) is given to reduce orbital and peri-catheter oedema.
- Chemotherapy is very emetogenic, so a dose of ondansetron (150 mcg kg^{-1}) is given.

The procedure may also stimulate an unusual oculocardiac reflex. The reaction is unpredictable and can be quite extreme. The first sign is sudden reduction in lung compliance and fall in tidal volume. The end-tidal CO_2 trace is like that seen in a patient with bronchospasm, although this is not heard on auscultation and is probably due to acute pulmonary venous congestion. The reaction is accompanied by a fall in oxygen saturation and hypotension, which may be profound. Screening with fluoroscopy shows the heart appears to be poorly contracting ('myocardial stunning'), although the heart rate does not usually fall initially. Bradycardia may occur a few minutes later. The child should be treated with atropine (5–10 mcg kg^{-1} IV), and a bolus of IV isotonic fluid (10 ml kg^{-1}) may be required. Resistant hypotension should be treated with IV adrenaline (1–2 mcg kg^{-1}).

This reaction is seen when the micro-catheter is flushed, prior to chemotherapy injection. It typically occurs on repeat administration of intra-arterial chemotherapy but has been known to occur on the first treatment. The exact mechanism is unclear but is thought to be due to sensitisation of the ciliary ganglion, the parasympathetic ganglion located in the posterior orbit. Thermal or mechanical stimulation during a repeat procedure results in this unusual phenomenon. Prophylactic IV atropine and slow injection of intra-ophthalmic contrast seems to reduce the severity of the reaction.

Anaesthesia for CT

CT is used as a diagnostic modality and to monitor treatment in children. It is particularly useful to delineate bony or vascular anatomy with 3D reconstruction to image the lungs or identify intracranial bleeding. High-quality scans require the child to remain still to reduce motion artefact, with breath-holds required for cardiac CT. CT scans are quick (although the dose of radiation is high), and most children do not require anaesthesia. Babies may be managed with 'feed and wrap', and older children will lie still in the scanner, but sedation is generally used for younger children (see Chapter 16). Anaesthesia is required for CT-guided biopsy, cardiac CT (frequent breath-holds) and those children unsuitable for sedation. Particular issues relate to anaesthesia in remote locations, with the added challenge of limited space in the scanner and limited access during the scan. Monitors must be visible from the control room, although the anaesthetist may stay in the scanner if wearing appropriate radiation protection.

Anaesthesia for MRI

MRI is particularly useful for providing high-quality images of soft tissue and is the technique of choice in neurological, cardiovascular, oncology and musculoskeletal imaging. MRI imaging is based on the physical behaviour of protons in hydrogen atoms in water and phosphorus in ATP when placed in externally applied magnetic

fields. Magnetic resonance (MR) scanners therefore contain very strong magnets, between 0.2 and 3 Tesla, and specific safety precautions are required to prevent ferrous objects from being sucked into the scanner. The presence of ferromagnetic implants, including pacemakers, are an absolute contraindication to MRI scanning. The scanners generate weak signals, and it is important to shield external radio-frequency sources such as from monitors.

MR scans are often long, between 30 minutes to 2 hours, depending on the area of interest, and the child must remain still during acquisition of images. The child is relatively inaccessible during the scan, and additional precautions need to be taken because of the magnet. Many older children will be able to manage by watching videos; however, younger, well children may be suitable for non-anaesthetist delivered sedation (e.g. via dexmedetomidine infusion; see Chapter 16). Younger patients who are unsuitable for nurse-led sedation or who require breath-holds during the scan will need general anaesthesia.

Induction of anaesthesia should take place in an anaesthetic room adjacent to the MR room after metal checks have been completed. A spontaneously breathing technique with SAD is suitable for most scans, although small infants should be intubated, as access is limited. Children undergoing cardiac MR require frequent breath-holds and should also be intubated and ventilated. Specific MR-compatible ECG electrodes, cables, saturation and blood pressure cuffs should be used. In an emergency, the child should be taken out of the scanner back to the anaesthetic room, as metal objects such as laryngoscopes and stethoscopes cannot be taken into the scanning room. Ward infusion pumps may malfunction close to the magnet, will need to be transferred to MR-compatible machines, which must be kept outside the immediate vicinity of the magnet (the 50 gauss line). Unstable patients requiring inotropic support may not be suitable for MR scanning for this reason.

Key Points

- Interventional radiology is a rapidly expanding area in paediatric anaesthesia, with a range of complex procedures now being possible for some of the sickest patients in the hospital.
- Limited access due to X-ray equipment and dimmed lighting requires constant vigilance.
- Scrupulous attention to detail is required, including choice of anaesthetic technique, patient positioning and monitoring.
- Good communication and teamwork are essential to ensure patient safety during radiological procedures. Although both technically and logistically challenging, overcoming these obstacles makes this a very rewarding area in paediatric anaesthesia.
- Special precautions are required for safe anaesthesia in MRI.

Further Reading

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