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Paediatric vascular access

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Key points

- Obtaining vascular access in children can be challenging.
- Good prospective vascular access management is essential in children who are likely to need prolonged intravenous therapy.
- The choice of long-term vascular access device in children is guided by duration and frequency of therapy, the infusate's properties, and the condition and preferences of the patient and care givers.
- Knowledge about correct usage of vascular access devices is fundamental to safe anaesthetic practice.
- Intraosseous access should be considered early in an emergency situation.

Obtaining reliable vascular access in small children is frequently made challenging by anatomical factors—in particular, small, mobile veins and an excess of subcutaneous fat which make visualization and palpation of veins difficult. Paediatric patients are often less co-operative, and the potential for psychological trauma, especially with repeated procedures in the conscious patient, further complicates matters.

Short-term vascular access is frequently required in hospitalized children for the delivery of i.v. fluids, medication, and blood product administration. Longer-term vascular access devices are required for repeated medication delivery (e.g. enzyme replacement therapy in inherited metabolic diseases), chemotherapy, immunotherapy, total parenteral nutrition, and extracorporeal procedures such as plasmapheresis and haemodialysis. In addition, vascular access devices may be needed for repeated blood sampling and invasive haemodynamic monitoring.

Choice of venous access device

The choice of vascular access device depends upon the condition and preference of the patient or parent/guardian, the likely duration and frequency of treatment, and the properties of the infusate. Infusates with vesicant properties (drugs with the potential to cause blistering with tissue injury, e.g. calcium solutions and amphotericin B), hypertonic solutions, and those with pH <5 or >9 will necessitate central venous access. Vasopressors and inotropes are preferentially administered centrally as they require reliable access and extravasation may cause tissue necrosis.

It is important to try to predict future needs for vascular access as poor prospective management can lead to interruptions in therapy, exhaustion of the peripheral vasculature, and the psychological trauma of repeated procedures. Children who are anticipated to require arteriovenous fistula formation for haemodialysis in the future should have particular efforts made to preserve their upper extremity and subclavian veins. In these children, central venous access should be via the internal jugular or femoral veins only.

Aspects of peripheral cannulation

Skin preparation

Concerns have been raised over the use of alcoholic chlorhexidine for skin preparation in small infants as a result of multiple case reports highlighting skin damage and concerns over systemic absorption of chlorhexidine.[1] ChloraPrep® (chlorhexidine gluconate 2% in isopropyl alcohol 70%) is not licensed for use in children <2 months of age, and therefore, it is our practice to use 70% isopropyl alcohol wipes for cannulation in children <2 months, with chlorhexidine acetate 0.5% solution used for central access.

Visualizing veins

Several approaches utilized in adults to enhance the visibility and palpability of peripheral veins (tourniquet use, gentle tapping of the overlying skin, local warming) are useful in children. Specific devices to aid visualization of veins include the use of transillumination and near-infrared light devices (see Fig. 1 for an example of transillumination). The latter detect the presence of haemoglobin by a process of differential absorption and project an image of the veins back onto the patient's skin. The use of ultrasound to aid vascular cannulation in children has been described previously in this journal.[2]

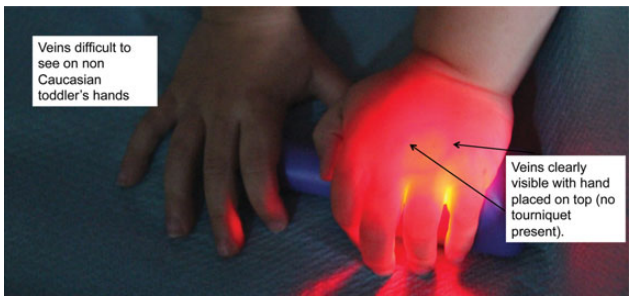

Fig 1 The use of red LED-based translumination to highlight veins in a toddler's hands.

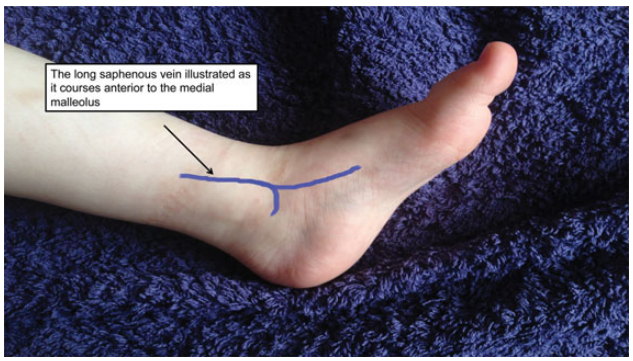

Fig 2 The anatomy of the long saphenous vein.

Reducing pain and distress associated with cannulation

Eutectic mixture of local anaesthetics (EMLA) is a mixture of 2.5% lidocaine and 2.5% prilocaine in a cream base. It is applied to the skin over the target veins then covered with an occlusive dressing for at least 1 h, providing localized anaesthesia for at least 2 h after removal. *O*-toluidine, a metabolite of prilocaine, can induce methaemoglobinaemia, and therefore, EMLA is not recommended for use in preterm infants or in those <12 months old who are receiving methaemoglobin-inducing drugs, for example, phenytoin.

Four per cent tetracaine gel (e.g. Ametop®) is applied with an occlusive dressing for 45 min, after which its duration of action is 4–6 h. It should not be used in infants <44 weeks post-gestational age, in whom the metabolic pathway for tetracaine may not be fully developed. A useful side-effect of the drug is vasodilation.

Vapo-coolant sprays (e.g. ethyl chloride, fluorohydrocarbons, and alkane mixtures) act by rapidly cooling the skin, resulting in an immediate, temporary interruption of pain sensation. They are applied for 3–10 s and provide analgesia for <60 s.[3]

Other topical anaesthetics used to reduce cannulation pain in children include liposomal lidocaine cream and a self-heating lidocaine–tetracaine patch. Needle-free delivery systems which use compressed gas to inject lidocaine (e.g. J-Tip, National Medical Products, Irvine, CA, USA) have been developed and approved for use in children by the US Food and Drug Administration.

Breastfeeding and sucrose solutions administered orally by syringe or dummy reduce the distress of painful procedures in babies. Older children benefit from play-specialist procedural preparation and distraction where possible.

Sites for peripheral cannulation in children

These commonly include the hands, wrists, feet, antecubital fossae, and the scalp in babies, although the latter can present problems with stabilization of cannulae and increased risk of extravasation. In children, the recognized complication of inadvertent arterial cannulation while accessing the veins in the antecubital fossa is increased.[4]

Needle Gauge of common i.v. cannula	External Diameter (mm)	French Gauge	External Diameter (mm)
24	0.7		
22	0.9		
20	1.1	3	1.0
18	1.3	4	1.34
17	1.5		
16	1.7	5	1.67
14	2.1	6	2.0
		7	2.3

I.V. cannula sizes and French gauge equivalents. In small children care must be taken not to insert a device that causes complete obstruction to blood flow past it.
Internal diameters of vascular access devices vary with number of lumens and material used for the catheter.

Fig 3 Cannula sizes and French gauge diameters.

The long saphenous vein is usually palpable as it courses anterior to the medial malleolus (Fig. 2). Less usual sites of peripheral cannulation include the external jugular, abdominal, and axillary veins.

Cannula over needle devices are manufactured in sizes as small as 26 G. Although the use of safety cannulae in adult practice is now widespread, their use in children remains controversial. They are considered less easy to insert in difficult veins even by those experienced with safety cannulae insertion, and therefore, their exclusive use has the potential to cause both harm and distress in children and has been resisted by the Association of Paediatric Anaesthetists of Great Britain and Ireland after a members' survey.[5]

Central venous access

Non-tunnelled, non-cuffed devices

Peripherally inserted central catheter

Peripherally inserted central catheters (PICCs) are available in single-, double-, and triple-lumen configurations and in sizes ranging from 28 G catheters for use in premature neonates to 7 Fr triple-lumen catheters. By convention, single-lumen catheters are described by gauge, while multi-lumen catheters by French (Fr) size (Fig. 3). The size of the PICC to be used is determined by the size of the access vein and the therapy required and not simply by the age of the patient. In general, smaller catheters with the least number of lumens are associated with the fewest complications; however, very small catheters are more likely to become blocked. If blood sampling via the PICC is required, then at least a size 3 Fr will be needed.[6] Any i.v. infusate can be given by a PICC, but their time *in situ* (dwell time) is typically <2 months and rarely >6 months. PICCs labelled as 'power-injectable' are able to withstand high pressures, allowing i.v. contrast administration during CT scanning.

The preferred insertion site for PICCs is the basilic vein above the elbow as the cephalic vein makes an acute angle at its junction with the subclavian vein and so may not enter the central vasculature, and is also much more prone to vasospam.[7] The deeper brachial vein can be used with care to avoid the median nerve. The long saphenous vein is an alternative, especially in non-ambulant children. Figures 4 and 5 show two different commonly used lines.

PICCs are advanced from their peripheral insertion site until the catheter tip lies either in the distal third of the superior vena cava or at the cavo-atrial junction. Catheters inserted via the lower limb terminate in the inferior vena cava. Tip position should be confirmed with fluoroscopy or post-procedure chest X-ray when surface landmarks are used to guide insertion depth. Ultrasound can rule out jugular malposition before radiography. It should be noted that upper limb PICCs in children move an average of 2.2 rib spaces with arm movement[8] and so will not always remain in the optimum position. It is suggested therefore that, when inserted, the line is fixed so that the tip is optimally placed when the child's arm is positioned comfortably in a natural position (flexed elbow for neonates, arm by the side with slight elbow flexion for children).[8] Children aged 1–5 are more likely to have catheter tip malposition compared with adults and older children.[9]

Advantages of PICCs in children are that they may be inserted and removed without a general anaesthetic in some children and have the lowest complication rate of central venous access devices. They should be considered where duration of therapy is likely to be between 10 days and 2 months.

An alternative device is a midline catheter, which is shorter than a PICC line, but longer than a peripheral cannula. This is inserted peripherally and threaded proximally so that the tip lies in a larger portion of the vein with greater blood flow. The dwell time of these devices is on average 6–10 days with some lasting several weeks. Only infusates suitable for peripheral administration may be given by a midline catheter. They are available in single- or double-lumen configurations and can be inserted into any appropriate peripheral vein including those in the scalp, in which case their tip position will be in the neck.

Umbilical vein catheter

A size 2.5–8 Fr single- or double-lumen catheter may be passed via the umbilical vein within the first 7–10 days of life. It ideally terminates in the inferior vena cava above the diaphragm, but for resuscitation, the catheter may be used once free flow of blood on aspiration is achieved. Umbilical vein catheterization

Using a sterile technique A is inserted into a suitable vein. The internal needle is removed and B is inserted using forceps to a pre-determined distance to reach a central vein. The outer plastic cannula (A) part is then split and carefully removed over B. A securement device (C) should be used to keep the line in place as per hospital policy.

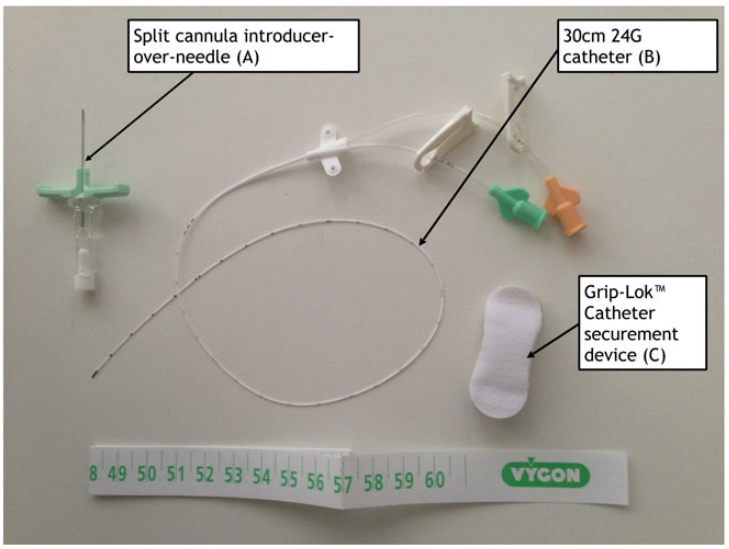

Fig 4 Nutrilline Twin-Flo—Neonatal Picc Line.

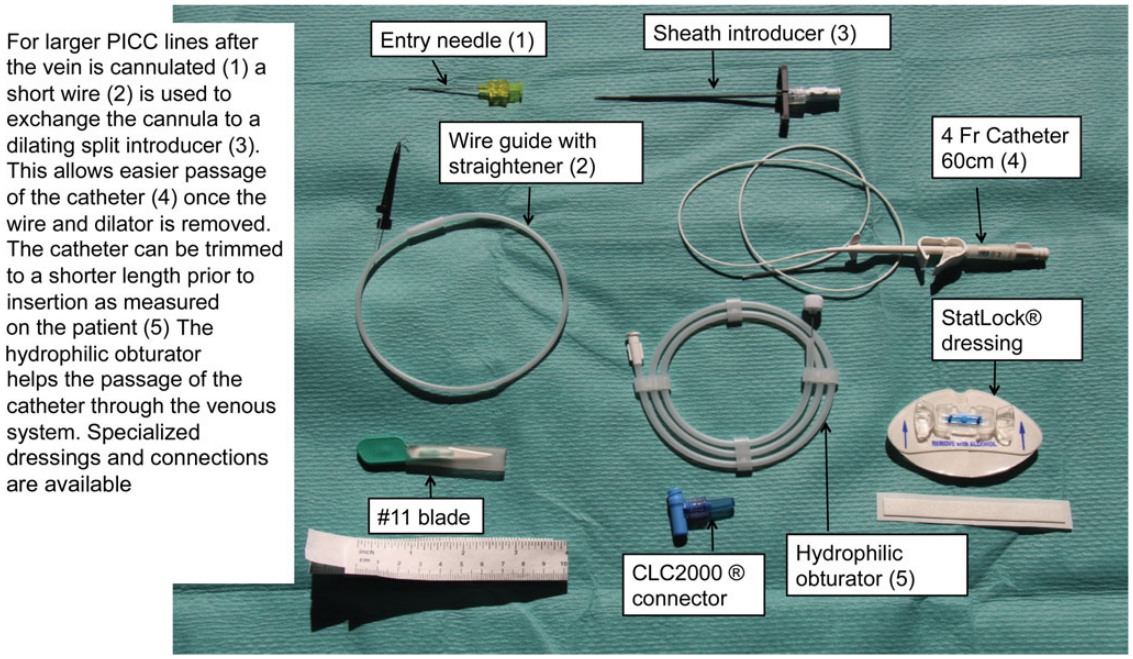

Fig 5 Peripherally inserted CVC set.

should not be attempted in the neonate with an abdominal wall defect, peritonitis, or necrotizing enterocolitis.

Short-term central venous catheters

These devices are indicated for short-term therapy (expected dwell time <7 days) or when urgent access is required. They are available in configurations of up to five lumens. Power-injectable devices are available. Common sites for access and techniques for insertion are as for adults, although the procedure carries a greater risk of complications in children with a lower success rate.[10] The use of ultrasound to guide insertion of these catheters is described elsewhere in this journal.[2]

The size of the catheter is determined by the size of the vein and the therapy required, as with PICCs, but as a guide, size 4–5 Fr catheters are usually suitable for infants <6 months, size 5 Fr for those aged 6 months to 5 yr, and size 7 Fr for those over 5 yr.[11] A number of height, weight, and surface-landmark based formulas have been developed to guide length of catheter insertion,[12] but in practice, for internal jugular insertion, 5 cm lines may be used for children ≤15 kg, 8 cm lines for patients 16–40 kg, and 13 cm lines for those ≥40 kg.[13] Adequate line tip position should always be confirmed by radiography as per central line access (see below). Line length for femoral insertion should take account of the body habitus of the child as short multi-lumen catheters may result in extravasation via proximal side holes in obese or oedematous children.

Tunnelled and cuffed devices

External catheters

These catheters are placed in a central vein using either an open surgical cut-down technique or percutaneously utilizing the Seldinger technique. The catheter is then tunnelled away from the vein insertion site to a skin exit site determined by comfort, patient preference, and safety considerations (e.g. a lateral site may be preferred for small children who may pull at or chew the line). Mounted on the line within the tunnel is a Dacron® cuff into which subcutaneous tissue grows over a period of weeks. This stabilizes the line and may serve as a barrier preventing the ingress of micro-organisms along the line.

Many types of cuffed central venous catheters (CVCs) are available including Broviac® and the larger Hickman® lines. The latter are available in single-, double-, and triple-lumen configurations. Wide-bore lines are required for haemodialysis and plasmapheresis. These lines are generally preferred to PICC lines when the duration of therapy is likely to exceed 6–8 weeks.

Implantable vascular access devices (Ports)

Port systems consist of a tunnelled central line connected to a titanium or plastic (MRI compatible) reservoir, which sits in a subcutaneous pocket. The entire system is internal which allows patients to bathe and swim, requires less maintenance, and has fewer adverse body-image considerations. The reservoir is covered with a thick self-sealing silicone membrane, which is accessed by puncturing the skin with a specially designed 'non-coring' needle. Accessing the port is therefore a painful procedure, although the application of local anaesthetic cream reduces this discomfort.

Ports are most useful for children requiring intermittent venous access over a long period of time. Such conditions include chronic diseases with frequent exacerbations, for example, cystic fibrosis and intermittent chemotherapy. Dual-lumen ports are available but are not commonly used, as these devices are difficult to manage, as when using one port lumen (e.g. for blood sampling or for an infusion) then afterwards both port lumens must be accessed and flushed with a heparin-containing solution.

The complications associated with central venous access devices are described in Table 1.

The removal of cuffed catheters and ports is a surgical procedure carried out in the operating theatre as the cuff or port requires dissection away from the tissues. This frequently requires general anaesthesia in children.

A detailed description of central venous access device insertion techniques can be found elsewhere in this journal.

Table 1 Complications of vascular access devices

On insertion	Post-insertion
All central venous access devices (depending on site)	
Air embolism	Accidental dislodgement
Arrhythmias	Catheter-associated blood stream infections
Arterial puncture	Catheter malfunction
Brachial plexus injury	Catheter migration/displacement
Cardiac tamponade	Device occlusion
Failure	Extravascular infusion
Guidewire knotting/fracturing	Infection at exit site
Haematoma at insertion site	Line fracture±embolization
Haemorrhage	Right atrial perforation±cardiac tamponade
Haemothorax	Subcutaneous extravasation
Phrenic nerve injury	Venous perforation
Pneumothorax	Venous stenosis
Thoracic duct trauma±chylothorax	Venous thrombosis
Tricuspid valve damage	
Vascular damage (e.g. perforation/dissection)	
Implantable vascular access devices (Ports)	
Port pocket haematoma	Damage to the reservoir
	Difficulty accessing the port
	Disconnection of the catheter to the port
	Port membrane luxation
	Port pocket seroma
	Skin breakdown at the reservoir site
Arterial catheterization	
Air emboli	Accidental drug administration
Failure	Arterio-venous fistula formation
Haematoma	Catheter-related blood stream infection
Nerve damage	Distal ischaemia
Trauma to arterial vessel	Embolization
	Extravasation of flush
	Inadvertant disconnection causing haemorrhage
	Pseudoaneurysm formation *vs* site infection
	Thrombosis
Intraosseous infusion	
Failure	Compartment syndrome
Fractures	Extravasation
Growth plate injury	Needle dislodgement
Haematoma	Osteomyelitis
	Skin necrosis

Tip position of centrally placed catheters

The ideal tip position of CVCs is generally the same as that described above for PICC lines, although catheters requiring high flow rates for their function (e.g. haemodialysis and plasmapheresis catheters) may be preferentially placed with their tips in the right atrium to ensure optimal function.[14] Ported catheters that are likely to be used for many years are also sometimes deliberately placed with an initial right atrial tip position to allow for the change in tip position as the child grows.

Alternative venous access strategies

Children who have undergone placement of many venous access devices can be left with poor peripheral access and central vein occlusion or stenosis. This may be suggested by prominent superficial veins or the disproportionately large appearance of the target vein on ultrasound in a patient with a history of central venous catheterization. Evaluation of the venous system with Doppler ultrasonography, magnetic resonance angiography, or contrast venography may guide further line placement.

Where standard venous access sites have been depleted, an interventional radiologist may attempt recanalization, balloon dilatation, or stenting of occluded or stenosed vessels to allow subsequent line placement. Alternatively, inferior vena cava catheterization via a translumbar, transhepatic, or direct suprarenal approach may be required using a combination of ultrasound, fluoroscopy, or CT guidance with or without a direct surgical approach. The placement of vascular access devices in a number of other non-standard vessels, including the hepatic and azygous veins, has been described in children, as has direct intra-atrial catheterization.

Perioperative use of long-term venous access devices

Catheters should be handled very carefully using strict aseptic-non-touch-technique. Before use, catheters should be aspirated to ensure removal of any heparin used to lock the line. Where possible, it is advisable to only use syringes of 10 ml volume or larger to flush lines as smaller syringes generate higher injection pressure which can rupture the catheter. Care must be taken not to inject large volumes of fluid when using a 10 ml syringe, particularly in a neonate.

Tunnelled, non-tunnelled, and peripherally inserted central catheters with Groshong® valves at the tip are available. These valves are formed by a slit at the tip of the catheter and replace the clamp used in other lines to prevent back-flow of blood into the catheter. These lines do not require a heparin lock. At low infusion rates, it is possible that the valve may produce intermittent boluses of drug, so their use with low flow rate infusions of vasopressors and inotropes may be problematic.[15]

In an emergency, ports can be accessed with small-bore standard needles, but this will damage the silicone membrane and reduce the lifespan of the port.

Arterial access

The indications, techniques, and sites for achieving arterial access in children are as for adults, except that in newborn babies, the umbilical artery may also be cannulated. The smaller diameter of the arteries, however, makes the placement of lines more challenging.

Smaller cannulas are required, with many operators choosing 24–22 G cannulas for infants and 22–20 G for children depending on the location of the catheter. Non-ported cannula-over-needle devices (e.g. Jelco®) are commonly used. Devices using the Seldinger technique for insertion are available, for example, 22 G Leaderflex®. It should be noted that standard 0.018 in diameter guidewires will not pass through needles of <22 G, and so 0.012 in 'babywires' are available. Very rarely, a surgical cutdown will be needed to achieve arterial access. The use of real-time ultrasound guidance with Doppler facility may aid a difficult insertion.

Transducer sets for paediatric arterial line monitoring use a syringe driver to limit the volume of fluid continuously infused to prevent clotting of the arterial line to 1–2 ml h^{-1} rather than the 3 ml h^{-1} delivered when a standard pressurized bag of fluid is used. These systems also often have low volume tubing to minimize flush volume and a 'closed' sampling system to reduce the

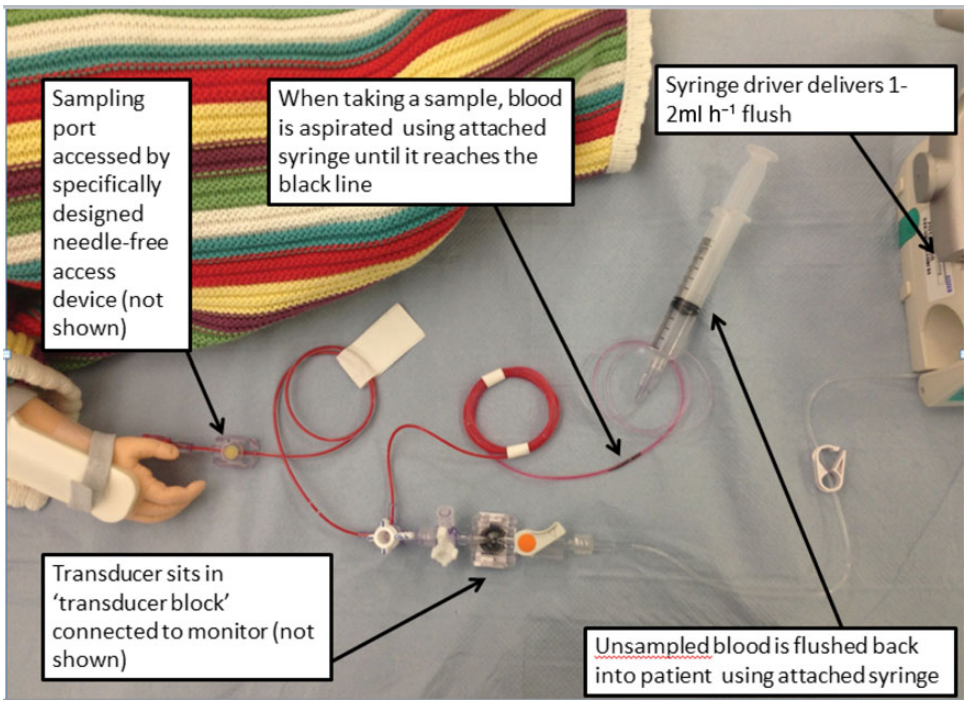

Fig 6 Medex Kids Kit® closed blood sampling system.

risk of contamination and allow 'deadspace' blood to be safely returned to the patient (Fig. 6). Most units use this equipment in all children <7 kg, while some will use it in children <30 kg.

Complications of non-umbilical arterial catheterization are described in Table 1.

Intraosseous access

Cannulation of the medullary cavity provides direct, non-collapsible access to the central venous circulation. Fluid and medications infused drain via the venous sinusoids into emissary veins and from there to the systemic circulation. Intraosseous (IO) access can be gained rapidly with a high success rate and so it is recommended in critically ill children if i.v. access cannot be gained within 90 s.

The most common site for (IO) access in children is the broad, flat anteromedial aspect of the proximal tibia. The distal tibia may be preferred in older children as it has less cortical thickening. Alternative sites include the proximal humerus and distal femur. Landmarks for insertion sites are described in Figure 7.

While spinal needles and i.v. cannulae have been used as IO needles, their use cannot be recommended. IO needles for manual insertion are 18–14 G in size and 3–4 cm long. Some designed for use in children >24 months have a reinforced steel hub, but all become more difficult to insert as children get older.

Power-driven IO needles have been developed which allow insertion in adults and children. These include the bone insertion gun (BIG), a spring-loaded device, the paediatric version of which inserts an 18 G needle to a pre-set depth determined by the patient's age. The EZ-IO® is a drill-powered device, which is used to insert 15 G needles available in three different lengths (Fig. 8). The manufacturer provides an age range to guide the choice of needle length, but in practice the length needed is determined by the depth of subcutaneous tissue overlying the bone at the chosen insertion site. To prevent the needle 'popping out' of the bone after insertion, one must ensure that the black 5 mm depth marking is visible on the needle after pressing it through the soft tissue to rest on the periosteum (Fig. 9). If it is not visible, the needle is not long enough. It is not unusual to need to use the blue 25 mm needle (for >39 kg) in a very chubby baby.

The complications of IO needle insertion are described in Table 1. In order to reduce the risk of compartment syndrome, the insertion of an IO needle into a bone in which a previous attempt occurred within 24 h is absolutely contraindicated as the fluid may leak from the previous cortex breach. For this reason, insertion into bones with fractures is also contraindicated. Other contraindications include local indwelling metalwork, bone disease such as osteoporosis or osteogenesis imperfecta, and local infection at the insertion site.

Any drug or fluid which can be given i.v. may be infused IO but must be delivered under pressure to overcome the intrinsic resistance of the marrow cavity. It is important to continuously monitor the limb for signs of extravasation. This is critical when vasopressors or irritant substances are delivered IO as the consequences of extravasation may be catastrophic. The IO needle should be removed as soon as alternative i.v. access is gained.

Multidisciplinary paediatric vascular access teams

Many children's hospitals have introduced specialized vascular access teams resulting in improvements in central line-associated blood stream infections, a reduced need for sedation and anaesthesia, and improved patient experience.[16] The teams may utilize the skills of specialist nurses, surgeons, interventional radiologists and play specialists, and also anaesthetists. The exact structure and scope of the team will be dictated by local needs and the available skill mix.

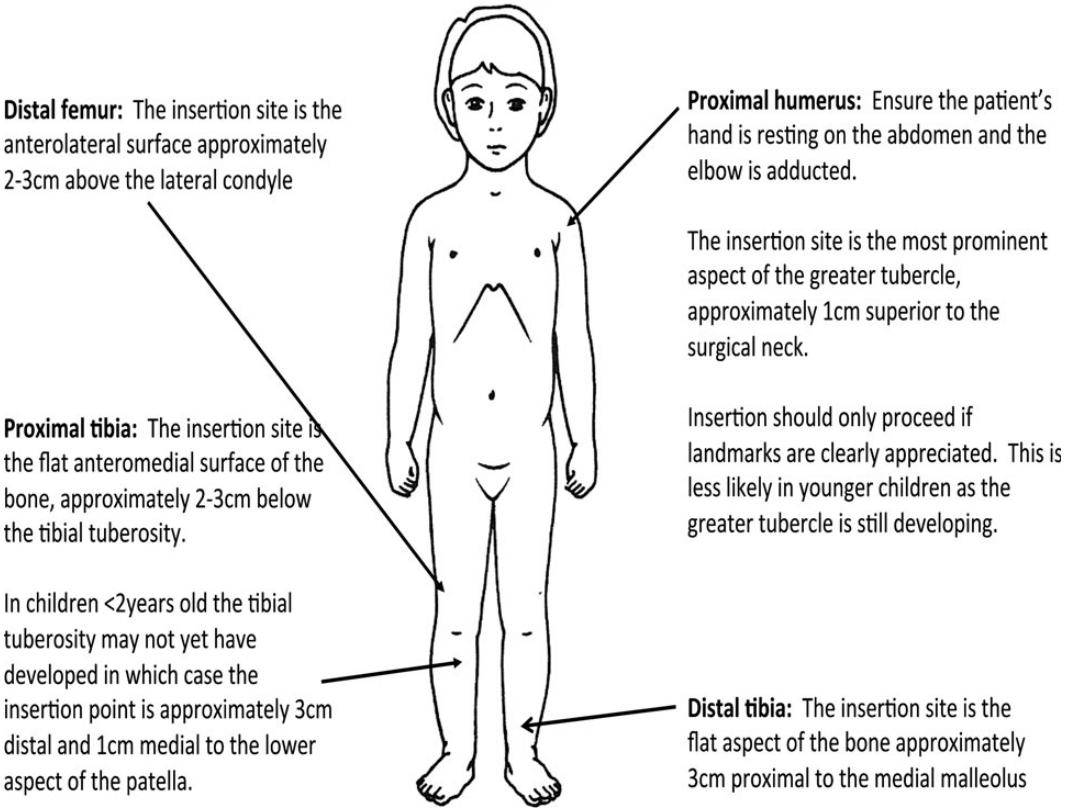

Fig 7 Landmarks for insertion of IO needles.

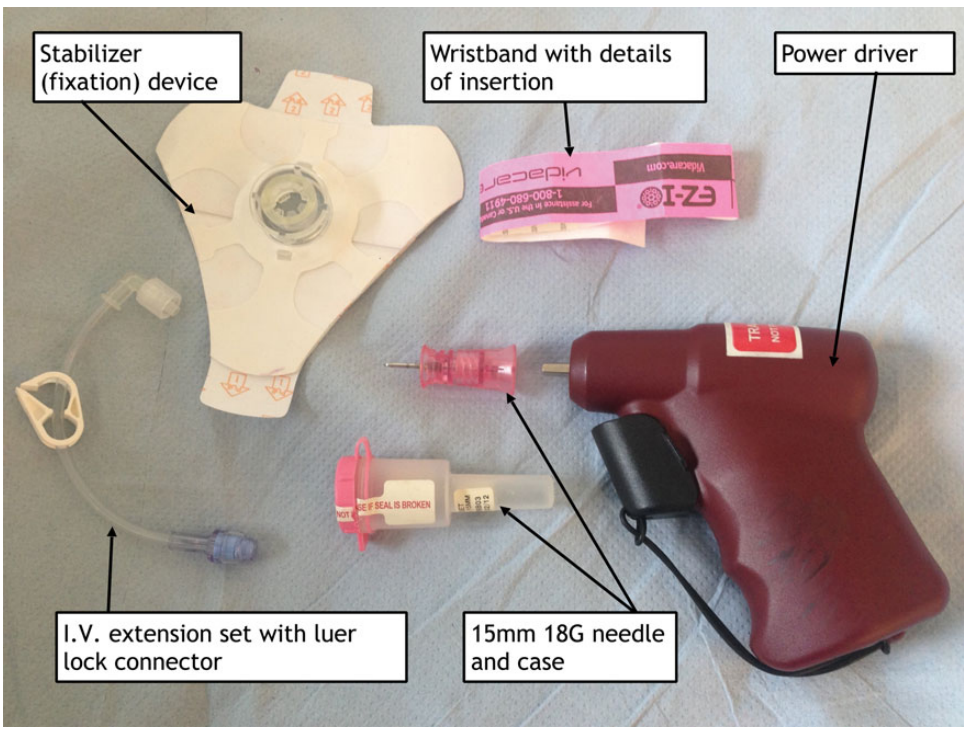

Fig 8 Equipment required for EZ-IO ® insertion.

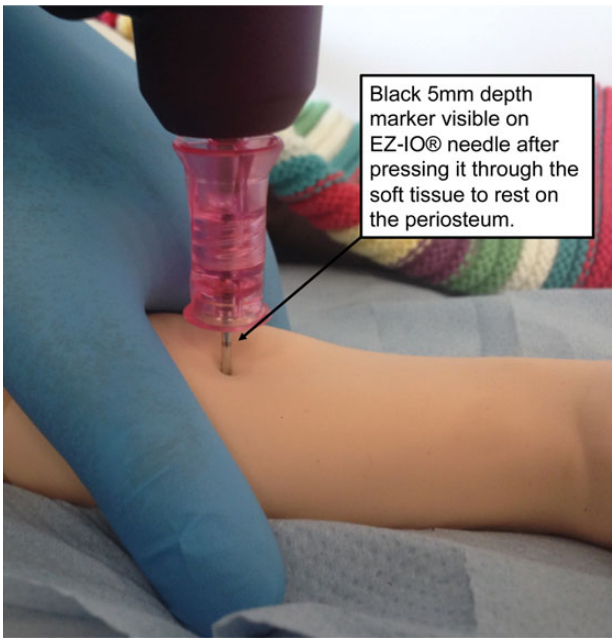

Fig 9 Correct insertion technique of EZ-IO®.

Declaration of interest

None declared.

MCQs

The associated MCQs (to support CME/CPD activity) can be accessed at www.access.oxfordjournals.org by subscribers to *BJA Education*.

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