Vascular access in the neonate

Thierry Detaille, MD, Paediatric intensivist\textsuperscript{b}, Thierry Pirotte, MD, Anaesthesiologist\textsuperscript{a}, Francis Veyckemans, MD, Anaesthesiologist\textsuperscript{a,}\textsuperscript{*}

\textsuperscript{a}Department of Anesthesiology, Cliniques Universitaires St Luc, Catholic University of Louvain Medical School, Avenue Hippocrate 10-1821, B 1200 Brussels, Belgium

\textsuperscript{b}Paediatric Intensive Care Unit, Cliniques Universitaires St Luc, Catholic University of Louvain Medical School, Avenue Hippocrate 10-1821, B 1200 Brussels, Belgium

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Up to recently, inserting venous or arterial ‘lines’ in the neonate was essentially based on clinical skill and experience. The recent advent of portable ultrasound (US) machines with paediatric probes has resulted in the development of new approaches that, if correctly learned and used, should allow quicker and safer vascular access in this population. Both classic and new techniques are reviewed on the basis of literature and authors’ experience. Live illustrations are freely available at www.

Obtaining vascular access in the neonate is a challenging and important aspect of their care. Some of the challenges are unique to the neonatal population. New equipment such as ultrasound (US) and newer types of catheter, such as peripherally inserted central catheters (PICCs), have produced substantial changes and opportunities, and increasingly the choice of access and management of the lines is becoming evidence based.

Ultrasound for vascular access in the neonate

The use of US has greatly increased the efficiency of gaining intravenous access in the neonate. The advantages are greatest when using the correct equipment. In the neonate, the structures are small and room for the US probe is limited; the equipment should include Doppler (screening for occlusion and thrombosis) and zoom functions, and a high-frequency (>10 MHz) ‘small’ (<30 mm width) linear US probe. Sterile gel and probe covers should be used for US guidance (Video 1).

US visualisation of vessels can be done

\textsuperscript{*} Corresponding author. Tel.: +32 2 764 1821; Fax: +32 2 764 3699.
E-mail address: francis.veyckemans@uclouvain.be (F. Veyckemans).
• in the short-axis view (SAX), where the probe is placed transversally to the direction of the vessel, which is seen in cross section; and
• in the longitudinal view or long-axis view (LAX), where the probe follows the direction of the vessel, which is seen in its length.

Research is underway to develop multiplanar US imaging, allowing simultaneous SAX and LAX views of the vessels.3

The needle can be advanced under the probe using two approaches:
• out-of-plane (OOP) where the needle crosses the US beam perpendicularly and
• in-plane (IP) where the needle stays in the US beam.

The most common combinations are the SAX view with OOP approach for the internal jugular vein (IJV), femoral vein (FV) and femoral artery (FA), and the LAX view with IP approach for the subclavian vein (SCV). The keys for success and safety include following the basic rules (Table 1) and obtaining adequate training in US-guided vascular access on phantoms and adults before using it in neonates and infants1,2 (Video 2).

Peripheral venous access

The upper limb

Any visible vein in the upper limb can be used. Puncture of a deep humeral vein should not be attempted blindly at the antecubital fossa to avoid arterial or median nerve injury. The small vein at the anterior aspect of the wrist can be used for transient venous access in infants and children but is seldom usable in neonates. Transillumination can be used to locate small veins; a variety of portable light sources using light-emitting diodes are now available.4

The axillary vein

This is an alternative route for central venous catheterisation. In the child, in the head-down position with the arm abducted, the course of the axillary artery is determined by palpation. The skin is then punctured just below it, proximal to the humeral head.5 The catheter is directed parallel and inferior to the artery until blood is obtained. In neonates, the puncture site could be above the axillary pulse.6 As this technique carries a risk of arterial puncture and nerve damage, it should not be attempted without US guidance.

The lower limb

The most used veins are the internal saphenous vein, the small veins at the dorsum of the foot and the external saphenous vein. PICCs are often inserted at the ankle or at the antero-lateral aspect of the leg.

Intraosseous access

The intraosseous access is a true central venous access. It is usually a last-resort vascular access used in life-saving circumstances when no other venous access is quickly possible. It is usually only

Table 1
Basic rules for efficient use of ultrasound for vascular access.

<table>
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<th>Rule</th>
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<tr>
<td>adequate orientation of the probe</td>
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<td>careful identification of the vascular target: as a rule, veins are collapsible and arteries pulsatile; but the difference is often subtle in neonates: little pressure on the probe can make a vein disappear and an artery collapsible!</td>
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<td>placing the target in the center of the screen: so, “middle of the probe = middle of the screen”</td>
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<td>continuous visualization of needle tip during the procedure</td>
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a temporary measure. The preferred insertion sites are the proximal or distal end of the tibia, and the distal end of the femur. Any bone-marrow aspiration needle can be used but special needles with a luer-lock connection are better and easier to secure. They are available with different lengths (2.5, 3.0 or 4.0 cm) and needle design (lancet, trocart, screw needle, side ports or pencil-point end). Electric drills and other devices are available to aid insertion.

Possible complications of this route are cellulitis, osteomyelitis, bone fracture, fat or bone marrow embolism and extravasation of fluid into the extraosseous tissue leading to compartment syndrome. To avoid extravasation, the intraosseous route should not be attempted in a broken bone or after previous intraosseous access in the same bone. The needle should be properly secured and its insertion site regularly inspected.

Neck and scalp

Branches of the temporal vein are often prominent on the fronto-parietal aspect of the neonate’s head. Care must be taken to avoid accidental catheterisation of a branch of the superficial temporal artery.

The external jugular vein is easy to see in a crying baby. To gain access, place the neonate head-down with a rolled towel under the shoulders and the head turned slightly away from the puncture site. In the awake neonate, a skin wheel with local anaesthesia is useful to anesthetise the skin entry site. To facilitate cannulation, it is useful to ask a helper to press on the lower end of the vein, just above the clavicle. This avoids its collapse during inspiration.

Technical tips

Strict asepsis should be observed. The inner needle of the catheter being slightly longer than the cannula, it should be advanced a few millimetre further after blood appears in the needle hub to make sure the cannula has also entered the vessel. The needle is then slightly withdrawn and kept immobile, while the cannula is gently advanced over it. Venous flashback is sometimes not immediate. Experience is required to recognise entering the vein by feeling a ‘click’ when its wall is pierced. Waiting a few seconds instead of advancing the catheter further allows blood to appear at the needle hub.

Complications

Phlebitis is caused by mechanical and chemical irritation of the venous endothelium. Contributing factors include the material of the cannula (polyurethane is less phlebogenic than Teflon), duration of catheterisation, nature (pH, tonicity and composition) of the solution and site of insertion (upper limb veins are less prone to phlebitis).

Extravasation can have significant consequences such as skin necrosis, compartment syndrome and delayed limb deformation. It should be prevented by a careful insertion technique and surveillance. In the absence of blood return, correct cannulation of the vein must be confirmed by manual injection of a few millilitres of saline.

Some teams add a small dose of heparin to the IV solution to prolong catheter patency. However, in one study performed in neonates, adding 0.5 IU of heparin ml⁻¹ of solution prolonged catheter (24 or 26 G) patency by a mean of only 7.4 h: 33.8 h ± 23.1 with heparin versus 26.4 h ± 16.4 without (p < 0.0001).

Central venous access

Equipment

Central venous catheters are inserted using the Seldinger technique. They are made of polyurethane or silicone and should be radiopaque, making X-ray visualisation easier. Length marks help diagnose ongoing decannulation or partial embolisation. Polyurethane softens at body temperature and becomes more flexible, which reduces the risk of perforation. The guide wire should be
atraumatic and equipped with a J tip. In neonates and infants, the radius of curvature of the J tip is close to, or larger than, the vein.\textsuperscript{9} This can produce difficulties when introducing the guide wire.\textsuperscript{10} Recommended catheter sizes are 22 G (or 2 Fr) if the neonate is less than 2 kg and 20 G (or 3 or 4 Fr) above 2 kg.

**Position of catheter tip**

Whatever the site of insertion, verifying catheter tip position with X-ray is mandatory. For catheters placed in the superior vena cava (SVC), the tip should be (1) outside the pericardial sac, which ascends alongside the medial wall of the SVC (to avoid perforation and tamponade), and (2) parallel to the vessel wall (to avoid perforation). The ideal position therefore varies according to the side of insertion. For right-sided catheters, being in the upper SVC outside the cardiac silhouette is safe, while for left-sided catheters, the angle the catheter tip makes with the vessel or cardiac wall is crucial; the more perpendicular it is, the greater the risk of perforation. Therefore, for left-sided catheters the tip is placed lower, that is, in the lower third of the SVC or in the upper part of right atrium (RA).

Placement inside the RA increases the risk of dysrhythmias, thrombosis and perforation.

In cadaver studies, the pericardial reflection is 0.5 ± 0.04 cm below the carina in infants and children\textsuperscript{11} but can extend up to 5 mm above it in neonates. The level of carina on X-ray is thus not a good landmark in neonates.\textsuperscript{12} Oesophageal echocardiographic studies in infants have shown large inter-individual distance variability between the carina and the junction of SVC with RA.\textsuperscript{13} A persistent left SVC is present in 0.3–4.3% of patients; whether the vessel catheterised is a persistent left SVC and drains in the RA or LA (rare) should be confirmed radiologically with dye.\textsuperscript{14}

In case of femoral access, the ideal position of the tip of catheter is either in the ipsilateral iliac vein or in the inferior vena cava (IVC) below the level of the renal veins (L1) to avoid blocking their drainage. Catheter tip at the level of L3 is satisfactory.

**Internal jugular vein (IJV)**

**Landmark approach**

The neonate is placed 15–30° head-down with a rolled towel under the shoulders. Whether the head should be in neutral position or moderately turned away from the puncture site is an unsolved issue. In neonates and infants, US screening shows that the relationship between the carotid artery (CA) and the IJV is highly variable and unpredictable. When US scanning is performed at the level of the cricoid cartilage or apex of the sternomastoid muscle triangle with the head in neutral position, the IJV covers CA in 25 (R)–44% (L) of the cases, and is internal to it on the right side in 6%.\textsuperscript{15} When the head is progressively turned away up to 45°, the incidence of overlapping of the IJV to the CA increases.\textsuperscript{16} In contrast to older infants and children, a simulated Valsalva manoeuvre, liver compression and/or Trendelenburg position increase only marginally (by a mean of 12–15%), the cross-sectional area of the IJV in infants less than 6 months of age.\textsuperscript{17} This is probably due to the shorter distance between the RA and the IJV and to the high compliance of the venous system at that age. The head-down position is nevertheless used to increase venous pressure and reduce the risk of air embolism. Simultaneous palpation of CA, needle progression into tissue and full neck extension reduces the surface area of the IJV.\textsuperscript{17} However, stretching the skin over the IJV with tape lifts it up, increases its anterio-posterior diameter and decreases the occurrence of vein collapse during needle progression.\textsuperscript{18} This taping manoeuvre probably has the same effect as stretching the skin with the non-dominant hand when no US guidance is used. During spontaneous ventilation, IJV diameter decreases during inspiration. The exploratory needle should thus be advanced only during expiration; moreover, this keeps the apex of the lung farther from needle tip.

Many approaches to the IJV have been described; the most used are

- The anterior approach: The needle-entry site is the convergence of the sternal and clavicular heads of the sternomastoid muscle. The needle is inserted 30–45° into the skin aiming initially at the ipsilateral nipple.
- The posterior approach: The needle-entry site is on the lateral border of the clavicular head of the sternomastoid muscle, at a point situated 1/2 to 2/3 on the line joining the mastoid process to the clavicle. The needle is advanced underneath the muscle toward a point just beneath the ipsilateral sternoclavicular joint.

Using another approach, the needle entry site is at the level of the cricoid cartilage, midway between the carotid pulse and the sternomastoid muscle. The child’s head is turned <30° away and the needle is directed toward the ipsilateral nipple at an angle of 30° with the skin. With this technique, a reduced incidence of carotid puncture has been claimed. Prior IJV localisation with a small (24-G) pilot needle before inserting the IV needle is controversial; it carries a risk of venous haematoma or arterial puncture but, when left in place, seems to facilitate IJV cannulation in infants less than 6 months.

US guidance

‘US screening’ of the neck area determines the position, size and patency of the IJV. If the IJV is collapsing during inspiration, (relative) hypovolaemia is possible and administration of an IV fluid bolus may make the procedure easier. Only ‘real-time US guidance’ has been shown to increase the safety and efficacy of IJV catheterisation in neonates and infants compared with use of classical landmarks. With US use, fewer attempts are needed and the incidence of CA puncture is decreased, but the results are less impressive than in older children. To access the IJV, the US probe is placed transversally to the neck to obtain a cross section, or SAX view, of the IJV and CA. In neonates, the US is best used for the anterior approach. The probe is placed above the clavicle with the IJV in the middle of the screen. The needle tip is tracked OOP. By tilting the probe cranially, the needle tip can be seen progressing in the subcutaneous tissue and progressive tilting it toward the chest follows needle tip progression into IJV (Video 3). The increased risk of accidental subclavian artery or pleural puncture is explained by their proximity to the distal part of the IJV.

Difficulties may be encountered in small pre-term neonates. The size of the needle is often close to the IJV diameter and the vein is very mobile, slipping away from the needle tip. Vein transfixion without flashback of blood is frequent, with blood flow usually obtained during slow needle withdrawal.

Subclavian vein (SCV)

The SCV is extrathoracic up to approximately 1 year of age. The initial direction of the exploring needle is therefore more cephalad in that age group. To access the SCV, place a rolled towel under the shoulders, and keep the head in a neutral position or moderately turned away from the puncture site with the arms are along the body and the table tilted 15–30° head-down. In children, the classic position (placing a towel between the scapula to arch the shoulders) decreases the vein cross-section area and is no longer recommended, although no data are available in neonates. With US, it can be seen that in the spontaneously breathing neonate/infant, the intrathoracic SCV diameter decreases dramatically during inspiration; therefore, the exploratory needle should be advanced only during expiration. Although changes in vein diameter are less important during intermittent positive pressure ventilation (IPPV), the exploratory needle should also be advanced only during expiration to decrease the risk of pleural puncture. Lastly, slight downward traction on the arm increases the visibility of SCV in the periclavicular area, facilitating its identification and cannulation. The left SCV is often preferred because it continues into the innominate vein in a smoother way to the SVC than the right SVC that enters it at an acute angle.

Landmark approach

The puncture site is below the clavicle, in the deltopectoral groove, between the first rib and clavicle, approximately where the latter is crossed by the external jugular vein. The skin should be entered 5 mm below the lower border of the clavicle so that the pathway of the needle stays altogether parallel to and just under it. The needle should be slightly bent in its middle to make it progress...
upwards and away from the pleura when passing under the clavicle. In neonates, the needle should initially be directed toward the cricoid as soon as it passes under the clavicle. The attached syringe is then lowered to make sure the needle remains just beneath it. The vein is usually found close to the skin. If no blood is aspirated during slow insertion or removal during expiration, then the needle should be redirected from beneath the clavicle aiming at a point midway between the cricoid and the suprasternal notch. When inserting the guide wire into the vein, tilting the head toward the catheterisation side helps prevent catheter malposition into the ipsilateral IJV.26

**US-guided approach**27

For the beginner, it is useful to start in the neck obtaining an SAX view of the IJV and to follow it caudally until it joins the SCV. The probe is then placed at the supraclavicular level to obtain a LAX view of the SCV. The 2.5 mm ‘Hockey-Stick’ probe is placed with its foot on the clavicle and stick directed medially and slightly cranially to allow simultaneous visualisation of the needle passing under the clavicle and the entire SCV up to its fusion with the ipsilateral IJV. The vascular structures pass between two bony structures: the superficial and lateral one is the clavicle, the deep and medial is the first rib just above the lung. It is critical to distinguish the SCV from the subclavian artery. The former is more anterior, more superficial, not pulsating and its size varies with respiration, and valves may be seen in it. The external jugular vein usually reaches the SCV close to the IJV, coming from above the clavicle. The SCV is short in small neonates. Its length can be increased by slightly pulling the arm downwards.

Using the IP approach, the needle is passed under the clavicle and the probe, taking care to maintain the LAX view of the SCV. When the needle tip has passed the anterior wall of the SCV, it may be advanced up to junction with the IJV. The correct path of the guide wire can be checked by US. If it goes into the ipsilateral IJV, it can be withdrawn and redirected under US guidance by compressing the distal IJV with the probe (Video 4).

**Femoral vein (FV)**

This vein is often used during resuscitation; being far from the neck and chest, it allows managing the airway, lungs and circulation without interruption. Even though it is safe, with easy landmarks and few complications, the use of the FV for vascular access has traditionally been discouraged in neonates, being used only for cardiovascular resuscitation. It should, however, be considered when other sites are unavailable.28 In infants and children, FV catheterisation shows the same incidence of infection and mechanical complications as subclavian or jugular central venous access.29

In a recent study, US examination at the level of the inguinal ligament in 14 neonates with the hips slightly externally rotated showed wide variation in the relationship between the FV and the femoral artery (FA). In 11 neonates, the FV was medial to the FA, in two neonates the FV was completely below the FA, while, in one, the FV was partially overlapped by the FA.30 Moreover, mean FV diameter increased slightly when normovolaemic babies were moved from the supine to the reverse Trendelenburg position.30,31 Given this variability in relation to the FA, US screening before puncture or US guidance is recommended.

Lastly, firm inguinal compression 1–2 cm above the inguinal ligament with two or three fingers at the point of arterial pulsation increases the FV cross-sectional area by an average of 60% in infants.32

**Landmark approach**

The femoral pulse below the inguinal ligament is the key landmark with the FV usually running medially to the FA. If there is no palpable pulse, the vessel position usually corresponds to the junction between the internal and medial third of the inguinal crease. To access the FV, place the child in the reverse Trendelenburg position with the hip slightly rotated externally, in straight position. The puncture is made 1 cm below the inguinal crease, using a 30–45° angle and pointing the needle to the head of the child. The first attempt should start 5 mm medial to the arterial pulse. Following attempts should be made 6 mm medial, then 4 mm medial.33

Because of anatomical variations among patients, a few failed attempts or difficulties in pulse palpation should prompt an US-guided localisation of the vessels.
In one study in pre-term infants weighing less than 1000 g, a 79.6% success rate was obtained by placing a small 5 cm-thick pad under the infant’s buttocks to expose the groin, but the incidence of arterial puncture was 10.2%.34

US guidance

‘US screening’ of the inguinal area determines the size (usually 3–5 mm), patency and position of the FV. Iliac vein thrombosis is suspected if the FV diameter does not increase after abdominal compression. ‘Real-time US guidance’ lowers the incidence of accidental FA puncture35 and should increase success rate and lower procedural time but studies are still needed in infants and neonates.

The US probe is placed just below and parallel to the inguinal ligament to obtain a SAX view of the vessels. If the FV is located below the FA, external leg rotation or even knee flexion can reposition it medially to the FA. With an OOP approach, the needle tip is directed towards the centre of the FV. A helper is needed to apply low abdominal compression and increase the lumen size. Transfixion of the FV occurs frequently but can be reduced by experience (Video 5).

Peripherally inserted central venous catheter (PICC or epicutaneo-cave catheter)

Peripherally inserted central venous catheter is a semi-invasive way to provide intermediate to long-term central venous access in neonates for parenteral nutrition, antibiotic treatment or inotropic support. It combines the advantages of peripheral and central access: bedside insertion, relatively low cost, safety and compatibility with a wide variety of medications and long-term use. Its main disadvantages are hazardous venous progression after initial cannulation and a small-calibre catheter that may preclude blood sampling, transfusion and rapid fluid rates. A Cochrane review suggested that PICC use improves nutrition in the newborn without evidence of increased adverse events, including systemic infection.36

Equipment

PICCs are provided in different sizes (28–23 G) and lengths (15–50 cm). Single and double lumen catheters made of silicone or polyurethane are available. Silicone catheters are easier to insert but are associated with an increased risk of technical problems and bacterial colonisation upon removal.37 Polyurethane catheters seem to be less likely to burst or rupture.38

Technique

Preferred sites include the cephalic, basilic, median antibrachial and accessory cephalic veins for the upper limb, and the internal and external saphenous veins for the lower limb. The occipital, metopic and temporal veins can also be used. If a vein from the upper extremity is selected, the head should be turned toward the arm of insertion. A local anaesthesia with an eutectic mixture of lidocaine and prilocaine (EMLA®) and/or sucrose by mouth must be provided for analgesia.

Catheter length of insertion is estimated from the insertion point to the midline of the sternum if inserted from an upper extremity or to at least 2 cm above the umbilicus if inserted from a lower extremity.39 After selection of a suitable vein, helped by US guidance if necessary, the skin is carefully cleaned and draped. The vein is cannulated using a removable needle, peelable cannula or semi-Seldinger technique. The PICC is then inserted into the vein and slowly advanced up to the desired length. Correct catheter tip location must be verified radiologically, using contrast if necessary. In experienced hands, US can be used to check the position of the catheter tip.40 The catheter should be repositioned if required and carefully secured. Cardiac dysrhythmias41, myocardial perforation and tamponade have been described with PICCs because movements of the limb affect the tip position. Abduction of the arm moves the catheter tip toward the heart when it is inserted in the cephalic vein, whereas adduction causes the same displacement when the basilic or axillary vein is used.42 The catheter tip should be positioned outside the pericardal reflection line, that is, above the second thoracic vertebra on the chest X-ray, while the arm is in the position that leads to maximum migration toward the heart. Cases
of pleural effusion or catheter rupture with migration into a pulmonary artery with subsequent hemorrhage have been reported.43

**Complications of central venous access**44

Perforation, infection and thrombosis are the three major complications of central venous access. As a rule, in a neonate with a central venous line, and whatever its insertion site, sudden haemodynamic or respiratory degradation should prompt immediate X-ray to exclude tamponade or pleural effusion.45,46 In the presence of signs of sepsis, blood cultures should be taken to exclude catheter infection or contamination. In the absence of blood on aspiration, the central and intravascular position of the catheter should be confirmed and the absence of thrombosis confirmed by US.

**Complications common to all sites**

**Immediate**

- Arterial puncture. Depending on the puncture site, any artery close to the vein can be injured; the smaller the child, the greater the risk. It can produce a haematoma (mass effect, displacement of vein) but also an arteriovenous fistula later.
- Haematoma. This can occur from venous or arterial puncture.
- Air embolism. This occurs mainly at the time of insertion in the spontaneously breathing neonate.

**Immediate or late**

- Tamponade. The clinical presentation is often atypical in neonates. It should be suspected in case of sudden haemodynamic deterioration.45 Although the catheter itself can be used, the pericardium is usually drained by subxyphoidal pericardiocentesis.
- Vessel perforation. Consequences depend on the structure involved, size of the hole and fluid infusion rate. Risk factors for vessel wall perforation are repeated contact of the vessel wall and catheter tip (see Section titled ‘Position of catheter tip’), occlusive thrombosis and local septic or chemical phlebitis. For central catheters inserted from a limb (PICC, femoral), limb movement can favour vessel erosion.
- Thrombosis. Although clinical signs are sometimes obvious (collateral circulation and limb oedema), it is often subclinical. The risk is increased in the neonatal period because of the small size of the vessels and the patient’s critical condition (sepsis, shock and vasopressors). Duration of catheter placement is not a risk factor. Thrombosis and catheter occlusion is the most frequent mechanical complication of PICCs, with a risk of 10%.47, being more frequent with lower extremity catheterisation. Prophylactic continuous heparin infusion or administration of heparin in the infused solution have been proposed, but without beneficial evidence.48,49 In cases where thrombosis is suspected, the diagnosis should be confirmed by US or Doppler and, if needed, angiography. The treatment can include heparin, streptokinase or alteplase. The catheter can be removed or left in place to provide local thrombolysis.
- Infection. The incidence varies from 3.7 to 10 per 1000 catheter days. One study reported similar infection rate for PICCs as for peripheral venous access.50 The risk of catheter-related septicemia is inversely proportional to gestational age and weight, and directly proportional to duration of catheterisation, use of parenteral nutrition or mechanical ventilation.51 Differentiation between catheter infection and contamination is often difficult; catheter tip culture, and peripheral and central blood cultures may clarify the diagnosis. Coagulase-negative *Staphylococcus* is the most common organism, which can usually be treated with IV antibiotics (vancomycin) without removing the catheter. In case of Gram-negative infection, the catheter should be removed and the anticoagulation adapted accordingly. If fever persists despite catheter change and antibiotics, endocarditis should be excluded.
- Rupture of catheter. This complication is almost unique to PICCs. There is a risk of rupture and intravascular migration of the distal part of the catheter. In one series, 11 cases were observed in 1650 PICCs. A forceful attempt to flush a blocked line carries a recognised risk of rupture.\(^{52}\)

**Complications of access to the SVC**

**Immediate**

- Pneumothorax
- Haemothorax
- Malposition. The catheter can be misplaced directly or migrate later into branches of the brachiocephalic veins such as the thymic vein or the first superior intercostal vein, into the azygos vein or abnormal vessels in the presence of congenital heart disease. This can lead to local thrombosis or perforation (see Section titled ‘Late complications’) and should thus be corrected as soon as possible. The diagnosis of malposition in the azygos vein is not easy on an antero-posterior chest X-ray; a lateral view is necessary to detect the aberrant catheter position.\(^{14}\) As a rule of thumb, a lateral X-ray or opacification is necessary in any case in which the catheter path on an antero-posterior X-ray is atypical. A few cases of initial misplacement of the catheter in the epidural or subarachnoid space have been described.\(^{53,54}\) In these cases, no blood could be aspirated from the catheter.

**Late**

Chylothorax: In an infant with a history of central venous catheterisation, it can be caused either by direct trauma to the thoracic duct (left) or great lymphatic vein (right) at the time of catheter insertion (needle or dilator) or by venous thrombosis in the area where those lymphatic vessels drain into the SVC.\(^{55,56}\)

**Complications of access to IVC**

These include extravasation of fluids in the retroperitoneal space and migration of the catheter tip into the perimedullar space via the left lumbar and epidural veins. The right FV seems better to avoid this because of the increased angulation between the FV and lumbar vein on the right side.\(^{57-59}\) Radiologic confirmation of the correct position of the catheter tip is necessary to avoid these complications.

**Peripheral arterial access**

Despite non-invasive monitoring techniques such as transcutaneous PO\(_2\), PCO\(_2\) and SpO\(_2\), indwelling arterial catheters are often required in the management of critically ill neonates for continuous haemodynamic monitoring and blood sampling. The temporal artery site is no longer recommended because of the risk of cerebral embolisation when flushing the line. The radial and femoral arteries are the most commonly used. The ulnar artery is the largest terminal branch of the brachial artery.\(^{60}\) Its catheterisation is associated with two major concerns: (1) ischaemic complications due to abnormal collateral supply of the arterial vascularisation of the hand; and (2) ulnar nerve injury. Cannulation of the ulnar artery should be avoided when cannulation of the radial artery has already been attempted on the same wrist because this could result in total occlusion of the arterial supply to the hand.

It is usually recommended that the brachial (humeral) artery should be used with caution due to the absence of collateral blood flow at its level and the proximity of the median nerve. However, in a large series of neonates and infants with congenital heart disease blind catheterisation of the brachial artery was not associated with more complications than the radial artery.\(^{61}\) The axillary artery must be used with caution. There is some collateral flow at its level but the artery is surrounded by branches of the brachial plexus, which may be injured. The posterior tibial artery runs posterior to the internal
malleolus. It is best palpated with the foot in dorsiflexion. The dorsalis pedis artery runs on the dorsal aspect of the foot, usually between the first and second toes. It is best palpated with the foot in plantar extension.

These two arteries can be cannulated without major complications but measured peak systolic pressure may exceed aortic values due to pressure-wave amplification in the vascular tree.

The femoral artery is usually easy to locate and cannulate. Although there is a theoretical increased risk of contamination due to the proximity of the perineum, the incidence of infection is no greater than with radial catheters but the incidence of perfusion-related complications is greater.62

**Technique**

Performing the modified Allen’s test to check the collateral circulation to the hand is recommended before radial or ulnar artery puncture63; however, its ability to predict ischaemia has recently been questioned in adults 64 and it is not validated in neonates. In case of doubt regarding collateral circulation, another site should be considered. Slight extension of the wrist or ankle helps locate and fix the artery. Its course can be identified by palpation, transillumination65 (Video 6) or US. Results regarding US guidance are controversial and are probably experience dependent.66,67 Neonates’ radial arteries are very small (around 1 mm). A higher success rate is achieved if a very high frequency US probe (>13 MHz) and a zoom function are used. A SAX view of the artery is usually used with an OOP approach. Correct visualisation of the artery is obtained by using the zoom function. To ensure successful catheterisation, the needle tip should be seen progressing into the arterial lumen over a few millimetres by translating the probe slowly cephalad (Video 7).

Using a sterile technique is mandatory. A 24-G cannula is used for preterm and term newborn.

Nicking the skin with a 22-G needle can prevent damaging the cannula when it pierces the skin. The cannula is slowly inserted through the skin, with a 20–30° angle, watching for blood return in its hub. Whether the cannula is used alone or mounted on a syringe is a matter of preference. Slow insertion of the cannula prevents vasospasm and arterial trauma. Once into the artery, the cannula is carefully fixed to avoid both accidental removal and kinking at the puncture site. Connections should be secured to avoid blood loss by disconnection. The dressing should allow visual inspection of the skin proximal and distal to the catheter to detect early signs of a thrombotic complication (skin blanching or cyanotic discolouration). Before inserting an arterial catheter, the tubing and transducer are carefully flushed with the heparinised solution, taking care to eliminate any bubble of air. The pressure transducer is placed at a level with the child’s mid-axillary line and zeroed.

The stopcocks of the arterial line should be clearly identified to avoid the accidental intra-arterial injection of anaesthetic agents, antibiotics, etc.

**Maintenance of the catheter**

The fluid used to maintain arterial line patency is a heparinised solution of 0.9% saline, 0.45% saline or 5% dextrose. The saline solutions have the advantage of allowing blood-glucose measurements and to be less favourable to bacterial growth. The recommended concentration of heparin is 0.5 IU ml⁻¹. The heparinised solution is flushed at a constant rate (1 ml h⁻¹) through an automatic disposable pressurised system, usually a syringe pump, in neonates.

Blood sampling should be performed slowly to avoid collapsing the vessel and damaging its endothelium. After blood sampling, the tubing should be flushed gently. Too rapid or forceful flushing results in blanching of the skin proximal to the cannula, and transmission of the iatrogenic pressure wave to distal sites such as the cerebral or the splanchnic circulation. Flushing no more than 0.5 ml with a 1 ml syringe over a period of 5 sec recommended. In case of damping of the arterial waveform, the tubing and stopcocks should be inspected to eliminate bubbles of air; however, gentle flushing is sometimes necessary to obtain a satisfactory waveform from a partially blocked cannula.
Complications

Ischaemia

Aetiologies of ischaemia are multiple, including thrombosis, vasospasm and emboli. Vasospasm can occur within minutes or hours after insertion. The first sign is skin mottling distal to the insertion site. Pallor, loss or reduced pulse and, sometimes, gangrene follow. Either injecting a small dose of lidocaine into the catheter or warming the contralateral limb to produce reflex vasodilation can be used. If it does not succeed, the catheter should be removed.

The incidence of arterial thrombosis varies according to the child’s age. In one prospective study in which the radial artery was cannulated with a Teflon cannula, complete occlusion of the artery was diagnosed by Doppler flow examination in 20 out of 32 infants (median weight 1935 g), but arterial blood flow resumed within 1–29 days after cannula removal. The duration of occlusion was directly related to the duration of cannulation and inversely related to birth weight. Although permanent ischaemic damage following arterial catheterisation is rare, removal of the cannula is recommended in case of increasing difficulties with blood sampling or appearance of cyanotic discoulouration of the skin distal to the entry site. Ischaemic damage is more likely in case of low cardiac output and/or of use of vasopressors and can lead to dramatic consequences such as amputation.

Embolisation can occur distally or proximally. Distal embolisation results from propagation of a thrombus formed near the cannula; proximal embolisation of air or debris occurs in case of aggressive flushing. Careful inspection of the skin proximal and distal to the cannula entry site and gentle flushing by hand are mandatory to avoid these complications.

In case of an ischaemic complication, local warming and systemic anticoagulation can be useful. Topical vasodilatation using a nitroglycerin ointment or patch, or a brachial plexus block have been proposed.

Infection

Local infection is rare if the rules of asepsis are observed and if the cannula is left in place for less than 4 days. However, colonisation of the cannula is more frequent when multiple attempts have been required for its insertion. This is probably due to breaks in the rules of asepsis when dealing with technical difficulties.

Other complications

These include nerve damage by the needle or by a compressive haematoma, tendon sheath injury, accidental intra-arterial injection of anaesthetic drugs, formation of an arteriovenous fistula and compartment syndrome.

Umbilical access

The umbilical vein and arteries can easily be accessed during the first few days of life, sometimes up to the end of the first week. The umbilical vein is the recommended emergency access for neonatal resuscitation. It can be used as any other central line to sample blood or to administer fluids, parenteral nutrition and blood. The umbilical cord contains two arteries and one vein. It emerges from the baby’s body with a short skin-covered portion, the future umbilicus and a distal membranous part. The vessels are buried within Warthon’s jelly.

Within the body, the umbilical vein goes cephalad, enters into the liver and divides. One division joins the left branch of the portal vein and directs 20% of the blood to the liver. The other division, called the ductus arteriosus, bypasses the liver and carries remaining blood flow into the IVC via the left suprahepatic vein. After entering the abdomen, the umbilical arteries turn inferiorly and enter the pelvis to connect with the internal iliac arteries. There are some contraindications to umbilical vein and artery catheterisation. These include omphalitis, omphalocele, gastrochisis and peritonitis. Necrotising enterocolitis is a relative contraindication to the use of the umbilical artery.
Umbilical vein

Catheter tip position

There are high and low positions for the tip of the catheter. The high position is ideal and is when the catheter is advanced through the ductus venosus into the IVC. On a chest X-ray, the tip should be above the diaphragm. The insertion length from the base of the cord can be estimated according to birth weight by using the formula: $1.5 \times \frac{k}{2} + 5.5 \text{ cm}$\textsuperscript{75} or by using standardised graphs.\textsuperscript{74}

The low position is used for emergency venous access to avoid placement of the catheter in the liver. The tip is between 3 cm (pre-term) and 5 cm (full term) from the base of the cord.

Technique (Video 8)

The umbilical cord is cut 0.5–1 cm above its skinny part. The stump is gently tied using a tissue lace. The vein is a wide, thin-walled and gaping vessel. Before catheterisation, it is cautiously opened and clots may need to be removed. The catheter is then slowly inserted aiming for the upper part of the body.

Recommended catheter size for neonates less than 1500 g is a 3.5 Fr and for greater than 1500 g is a 5 Fr. Single- or double-lumen catheters are available. If an umbilical catheter is not available, a sterile 6 to 8 Ch feeding tube may be used.\textsuperscript{76}

Umbilical artery

Ideal catheter tip position

The high position is ideal with the tip being in the descending aorta, above the diaphragm at the Th7–Th9 level. The insertion length from the base of the cord can be calculated according to birth weight using the formula: $3 \times \frac{k}{2} + 9 \text{ cm}$, or using standardised graphs.\textsuperscript{74} The less ideal low position is above the aortic bifurcation and below the renal vessels, usually corresponding to L3–L4.

Technique (Video 9)

The arteries are thick walled and usually have a degree of spasm. To be catheterised, they need to be carefully dilated using small forceps. The catheter is then carefully inserted aiming for the lower part of the body. The ideal catheter size for babies less than 1200 g is 3.5 Fr and for babies greater than 1200 g is a 5 Fr.

Complications of umbilical access

There are a number of possible complications with umbilical access including:

- infection;
- thromboembolism with clot, Wharton’s jelly or even cotton swabs;
- vessel trauma such as perforation and aneurysm formation;
- umbilical vein catheter tip malposition resulting in fluid accumulation in the pleura, pericardial space, or peritoneum, pulmonary venous return obstruction, arrhythmias and hepatic haematoma\textsuperscript{77};
- umbilical artery catheters may lead to renal artery obstruction and hence systemic hypertension;\textsuperscript{78,79}
- vasospam and ischaemia\textsuperscript{78,79};
- blood flow obstruction resulting in enterocolitis or hepatic necrosis;
- portal vein thrombosis\textsuperscript{80};
- nerve lesions resulting from arterial umbilical catheter have also been described.

Different strategies have been evaluated to minimise the risk of thrombo-embolic complications. Heparin use does not show any significant impact on aortic thrombosis but decreases the incidence of
The use of end-hole versus side-hole arterial umbilical catheters appears to decrease the incidence of thromboses.\(^8^2\)

**Summary**

Vascular access in neonates and small infants is often challenging. US screening and guidance improves its safety and efficacy. However, safe use of US needs education and training to interpret correctly the images and achieve eye–hand coordination. Moreover, vigilance remains necessary during insertion and maintenance and also following a recent failed insertion or the removal of a central venous catheter.\(^4^6\) Lastly, whether venous and arterial lines should be heparinised or not to prevent thrombotic complications remains controversial.\(^8^3\)

**Practice points**

1. Adequate training in US-guided vascular access on phantoms and adults to acquire eye–hand coordination is mandatory before using it in neonates and infants.
2. US-guided vessel puncture requires the meticulous application of basic rules.
3. Vigilance is necessary to detect complications of central venous catheterisation early during insertion and maintenance but also following recent failed insertion or removal of the catheter.
4. Sudden haemodynamic or respiratory degradation in a neonate with a central venous catheter requires immediate X-ray to exclude tamponade or pleural effusion.

**Research agenda**

1. Education and training in US should become part of the neonatologist’s and paediatric anaesthesiologist’s curriculum;
2. What is the risk/benefit ratio of using heparin to maintain patency of venous and arterial catheters?\(^8^3\)
3. Incidence of asymptomatic vessel thrombosis after central venous access or PICC in neonates and small infants;
4. Development of multi-planar probes to provide simultaneous SAX and LAX views.

**Conflict of interest statement**

None.

**Appendix Supplementary data**

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.bpa.2010.02.017.

**References**


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