Chapter 12
Ultrasound Guided Venous Access in Neonates

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12.1 Introduction

Ultrasound guidance permits the percutaneous placement of relatively large bore central venous catheters in extremely small weight infants. Such large bore catheters can be used for inotropes, parenteral nutrition, but also for transfusions, blood sampling, hemodynamic monitoring, and high flow infusions. This can have an impact on mortality and morbidity in critically ill, very small infants.

The recommended ultrasound-guided venous accesses in neonates are the brachio-cephalic vein and the common femoral vein. In the past, the short axis/out-of-plane cannulation of the internal jugular vein has been widely used; though, when adopting this access, the tip of the puncture needle is only poorly visible via sonography, and the vein collapses easily. On the contrary, the supraclavicular, long axis/in-plane cannulation of the non-compressible brachiocephalic vein displays the needle over the entire distance: this approach represents most likely the most appropriate access for the placement of a relatively large bore central venous catheter in neonates, the only potential limitations being local emphysema and non-availability of an ultrasound device.

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12.2 Definitions

By definition, a central venous access device is a catheter that has its tip in the superior vena cava (SVC) or inferior vena cava (IVC) or in the right atrium (RA). CICCs (centrally inserted central catheters) are central lines inserted via large veins of the infra- or supraclavicular region. FICCs (femorally inserted central catheters) are central lines inserted in large veins of the groin.

12.3 Indications

Central venous catheters in neonates are required perioperatively as well as in intensive care treatment. The most important indications include:

- major surgery with potential hemodynamic instability
- measurement of the central venous pressure and oxygen saturation in mixed venous blood
- blood sampling
- transfusion
- need for rapid volume repletion
- infusion of vasoactive drugs and other potentially irritant/vesicant drugs
- parental nutrition
- inability to obtain a central venous access by UVC or ECC, due to technical reasons
- expected long duration of the need of central venous access (more than two weeks)

In all these situations, the ideal central venous access is a large bore polyurethane power injectable catheter placed by ultrasound guidance.

In the past, central lines have been inserted in neonates by venous cutdown. Such obsolete technique is currently discouraged, because of the high risk of early and late complications (bleeding, infection, venous thrombosis, etc.) and because it implies a permanent damage to the venous patrimony of the neonate. Also, percutaneous puncture guided by anatomical landmarks has been adopted; though, this ‘blind’ approach is associated with severe early complications (accidental arterial puncture, pneumothorax, hemothorax, etc.) and it is currently discouraged, too.

On the contrary, ultrasound guided placement of central catheters has been proven a safe and effective procedure, even in extremely premature infants. Catheters of different size can be inserted (from 2Fr to 4Fr, depending on the size of the vein). They can be tunneled or non-tunneled, and in either case they can remain in place for many weeks (even two months) with very low risk of complications. If used consistently for hydration, nutrition, and blood sampling, they could indirectly improve the neurocognitive outcome by avoiding many painful stimuli and by reducing the overall stress to the newborn. The ECCs usually used by neonatologists (Fig. 12.1) are too small for blood sampling and do not have such

Fig. 12.1 Epicutaneo-cava catheter

advantage; also, especially in preterm babies, they often do not last more than 2 weeks.

The size and the age of the neonate are not a limit, since ultrasound guided approach to the brachio-cephalic vein has been described also in preterm infants weighing less than 500 g.

12.4 Venous Anatomy

Neonate's veins are small and - not surprisingly - cannulation success by the 'landmark technique' decreases with decreasing weight. Also, in low-birth-weight newborns, the muscle and bone landmarks are often difficult to palpate or locate, making the use of ultrasound absolutely necessary.

In neonates, internal jugular veins (IJV) and axillary veins (AxV) are particularly mobile, compressible, and they often collapse completely under the pressure of the approaching needle. A certain degree of immobilization of the IJV can be achieved by a hyperextension of the neck, when possible. As opposed to the IJV and AxV, the external jugular vein (EJV), the subclavian vein (SV) and the brachio-cephalic vein (BCV) are fixed to surrounding tissue structures making them non-compressible, non-collapsible, immobile, and patent even in most hypovolemic neonates. The IJV and BCV are significantly larger than EJV, SV or AxV in neonates. Figures 12.2 and 12.3 show the main veins of the supra/infra-clavicular area.

The deep veins of the upper limb (brachial, basilica, and axillary vein at the axilla) are too small for a safe ultrasound-guided cannulation (Fig. 12.4). As regards the deep veins of the lower limb, the common femoral vein (CFV) is of appropriate caliber only in neonates >2500 g. The saphenous vein and the superficial femoral vein are consistently very small. Figure 12.5 shows the CFV and the saphenous vein at the groin.

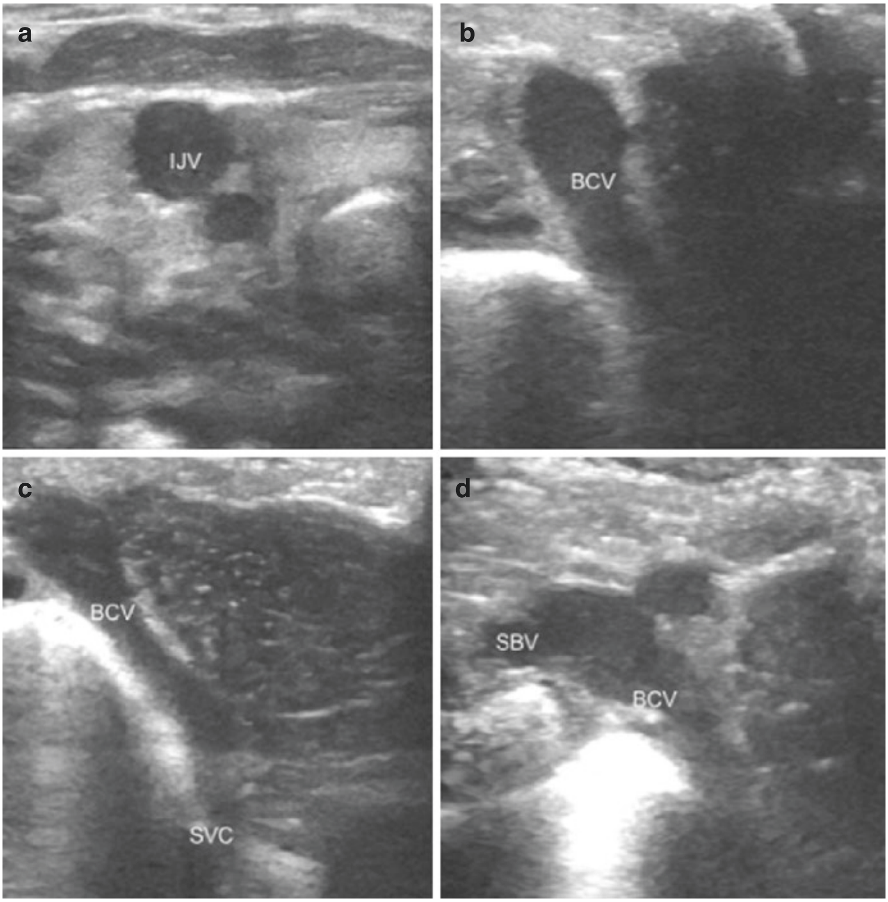

Fig. 12.2 Ultrasound imaging of the main central veins as visualized in the supraclavicular area with a linear probe. IJV = internal jugular vein (**a**); BCV = brachio-cephalic vein (**b–d**); SVC = superior vena cava (**c**); SBV = subclavian vein (**d**)

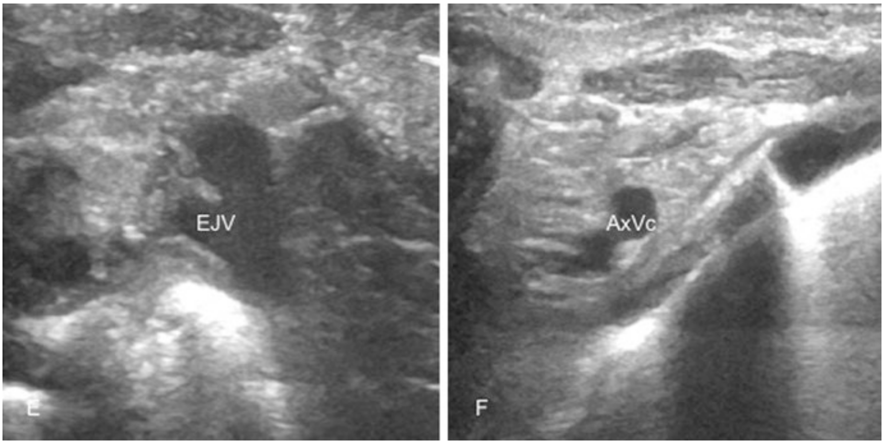

Fig. 12.3 Ultrasound imaging of two central veins rarely used for CICCs in neonates: EJV = external jugular vein; AxVc = axillary vein (in its thoracic tract)

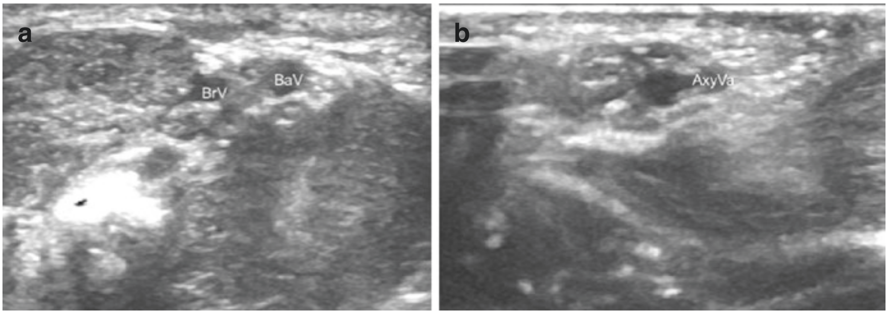

Fig. 12.4 Ultrasound imaging of deep veins at the arm: BrV = brachial vein and BaV = basilic vein (**a**); AxyVa = axillary vein (at axilla) (**b**)

In most cases, the BCV will be the largest vein available, and the easiest to puncture by ultrasound. The small caliber of the vessels, and the immaturity of the thrombolytic system make neonates particularly susceptible to catheter-related thrombosis. Therefore, it is of paramount importance to measure the size of the targeted vein by ultrasound prior to its cannulation: the outer diameter of the catheter should be equal or smaller than one third of the vessel lumen.

12.5 Material

Single, double, and triple lumen, 2–3-4 Fr catheters to be inserted via the direct Seldinger technique are available on the market and specifically designed for the use in neonates. Though, their use is not recommended for several reasons: (a) even

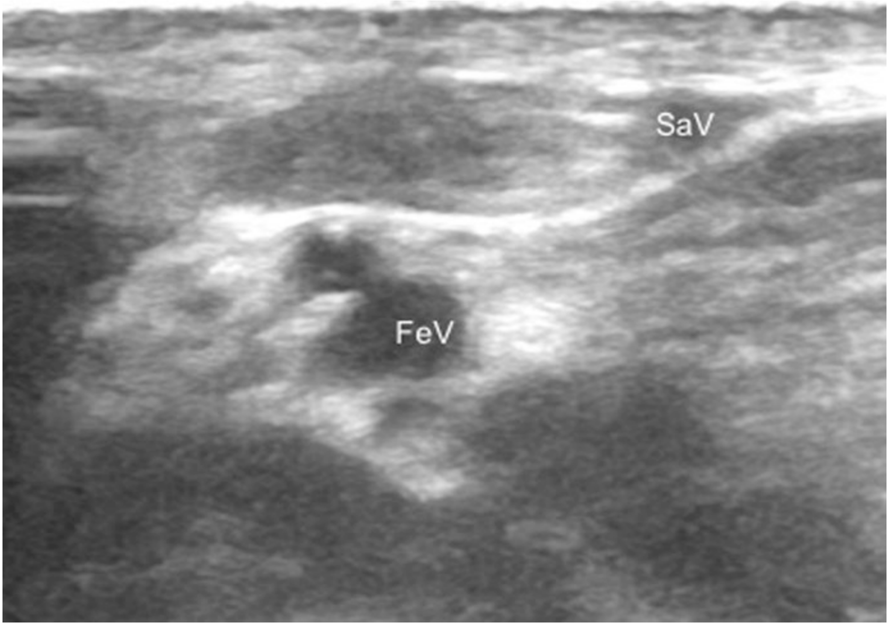

Fig. 12.5 Ultrasound imaging of the veins at the groin: FeV = common femoral vein; SaV = saphenous vein

when made in polyurethane, these catheters are not power injectable and so their flow performance is poor; (b) most of these catheters are provided in kits including large needles (20–19G) and J-shaped guidewires, which are unsuitable for neonates; (c) the direct Seldinger technique is not ideal in neonates, since it may be quite traumatic and does not allow tunnelling; (d) all of these catheters are not trimmable, so that a specific catheter of specific length must be chosen case by case.

On the contrary, we recommend the 'off-label' use of central venous catheters marketed as peripherally inserted central catheters (PICCs) for children and adults. Figure 12.6 shows a 3Fr single lumen catheter and Fig. 12.7 a double lumen 4 Fr catheter: both are PICCs used 'off label' as CICCs. These catheters have many advantages:

- They are of new generation, high quality polyurethane
- They are power injectable, so that even a 3Fr catheter will allow high flow (1 ml/sec)
- They are provided with a state-of-the-art high quality micro-insertion kit including echogenic 21G needle, soft straight tip 0.018-inch nitinol micro-guidewire, and 3.5–4.5Fr micro-introducer-dilator
- Because of the insertion by modified Seldinger technique, they can be easily tunneled
- They are available as single lumen 3Fr or 4Fr and as double lumen 4Fr, covering most requirements of critically ill neonates

Fig. 12.6 3Fr single lumen polyurethane power injectable PICC used as tunneled CICC in a neonate

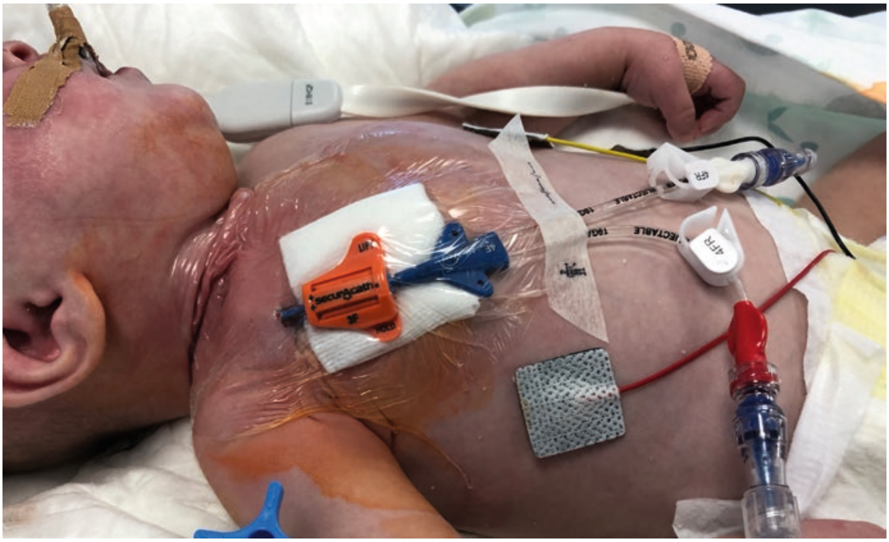

Fig. 12.7 4Fr double lumen polyurethane power injectable PICC used as tunneled CICC in a neonate

- Their length can be adjusted taking into consideration the site of insertion, the length of tunneling and the planned extravascular tract
- They can be secured by subcutaneous anchorage.

The same catheters can be used 'off label' as FICCs (Fig. 12.8). Their only limit is that the smallest caliber available is 3Fr (1 mm of external diameter: approximately 20G as internal area). This implies that if a BCV or a CFV is smaller than 3Fr, 22G or 24G should be used (Fig. 12.9). This can be done by off-label use of short peripheral venous cannulas or short peripheral arterial cannulas (available in polyurethane and in poly-ether-bloc-amide).

Fig. 12.8 3Fr single lumen polyurethane power injectable PICC used as FICC in a neonate

Fig. 12.9 Short venous cannula used as CICC in a neonate

Also, high quality ultrasound machines are needed. Linear transducers with high resolution (10–13 MHz) and short footprint (26 mm) must be used for ultrasound-guided puncture and cannulation of the vein. A ‘hockey stick’ shape will be particularly useful when accessing the BCV, so to facilitate the tilting of the probe. Tip location will require a micro-sectorial probe or a micro-convex probe.

12.6 Pre-Procedural Maneuvers

In order to avoid pain-response related movements of the neonate, CICCs and FICCs are inserted under general anesthesia or deep sedation. Hypovolemia should be corrected before the procedure, as feasible.

Before the preparation of the sterile field, a proper ultrasound examination of the local veins should be performed, using a systematic standardized protocol as the RaCeVA (before CICC insertion) or the RaFeVA (before FICC insertion), so to carefully choose the vein and the site to be punctured. The need for tunneling will be based on the RAVESTO protocol: in most elective punctures of the BCV, a tunnel to the infraclavicular area is strongly recommended, so to achieve an ideal exit site in terms of management; in most elective FICCs, a tunneling to mid-thigh will be useful, so to move the exit site away to the groin area.

Sterile precautions are mandatory, including hand hygiene (preferably using alcohol-based gel rub), proper skin antisepsis with 2% chlorhexidine in alcohol and maximal barrier precautions (cap, mask, sterile gown, sterile gloves, wide sterile drapes all over the patient and sterile cover for the ultrasound probe).

A towel roll is preferably placed under the shoulder of the baby and the head turned to the contralateral side, whenever a CICC must be placed. In FICC placement, the lower limb is fixed in extension and slight abduction.

The operator is always standing on one side of the patient, while the display of the ultrasound device is placed contralaterally.

12.7 Ultrasound-Guided Venipuncture

Any ultrasound-guided puncture can be defined describing (a) the spatial relationship between the vein and the probe (short axis, oblique axis, or long axis) and (b) the spatial relationship between the needle and the probe (in-plane, out-of-plane). In-plane techniques are safer and should be preferred for CICC insertion: their major advantage is the visibility of the advancing needle over the entire distance, so that the surrounding structures and their relation to the needle can be easily recognized. Though, the in-plane technique is not easy, since it requires an exact alignment of probe, vessel, and needle. Optimal hand-eye coordination is mandatory. The out-of-plane technique is easier and gives a good anatomical overview. However, the major disadvantage is the poor visibility of the needle tip, so that there is risk of accidental perforation of the vessel and injuries to underlying structure. For this reason, the out-of-plane approach should not be adopted for CICC insertion.

12.8 Tip Navigation

Soon after venipuncture and after insertion of the micro-guidewire, the intravascular location of the wire and its direction should be checked, using the same linear probe utilized for venipuncture. In the case of CICC insertion, the guidewire must be seen entering the SVC (visualized in long axis, placing the probe in the supraclavicular region, and tilting so to visualize the mediastinum). In the case of FICC insertion, the wire should be visualized inside the external iliac vein (visualized in long axis). The maneuver can be repeated—if needed—so to also visualize the micro-introducer and the catheter itself, after insertion. Ultrasound-based tip navigation will allow to immediately detect wrong direction of the wire (for example, into the contralateral BCV).

12.9 Tip Location

Ideally, the tip of a CICC should be located at the junction between RA and SVC, while the tip of a FICC may be located either in the IVC or in the RA, depending on the indication for central venous access (need for hemodynamic monitoring will imply a tip inside the RA). The easiest, safest, and most cost-effective methods of tip location are ultrasound and intracavitary electrocardiography (IC-ECG), which also have the great advantage of being intraprocedural. The old-fashioned method of 'blind' guess of the length of the catheter during the procedure, followed by a post-procedural chest x-ray should be abandoned. Radiological tip location (a) it is less accurate than either ultrasound or IC-ECG, particularly in neonates; (b) it is unsafe, since it implies x-ray exposure; (c) it is expensive; (d) being post-procedural, it may be associated with the necessity of repositioning the catheter (performing a new procedure and—what is worst—a new anesthesia/sedation of the neonate).

Intracavitary ECG (IC-ECG), though not recommended for UVC and ECC, because of some logistic problems, is particularly easy and rapid with CICC and FICC with caliber 3Fr or larger. It only requires a sterile cable for the connection between the catheter and the ECG monitor (see Chap. 6). Decades of clinical studies have demonstrated that IC-ECG is highly accurate and almost 100% applicable and feasible in neonates and children.

Ultrasound-based tip location is also easy and rapid in neonates, with almost 100% applicability and feasibility in neonates. A 7–8 MHz small sectorial probe placed in the subcostal area will allow to visualize the SVC, the IVC and the RA; when the catheter cannot be directly visualized, a rapid injection of a small amount of saline (0.5–1 ml) will enhance its visualization (so called 'bubble test').

As both methods are easy and inexpensive, the most reasonable strategy is to use both together. Considering that both methods are more accurate than radiology, a post-procedural chest-x-ray will be useless. In the rare case of suspected pleura-pulmonary damage, ultrasound scan of the pleura will be far more accurate and more cost-effective than radiological control (see Chap. 7).

12.10 Options for Venous Access

CICC can be inserted by ultrasound-guided approach of several veins of the supraclavicular area (IJV, EJV, SV, BCV) and of the infraclavicular area (AxV). In clinical practice, the easiest and safest approach is the BCV.

The IJV has been the most popular vein because it is relatively large and easy to scan; though, due to its compressibility, it may not be easy to puncture; also, the progression of the catheter inside the vein before entering the BCV may be difficult. The EJV is punctured by ultrasound-guidance only in its distal tract, where it runs parallel, posterior, and superior to the SV; it is a rather easy and safe vein to cannulate, but its main limit is the small caliber. The SV can be punctured by a supraclavicular approach or by a mixed infra-supraclavicular approach (see below); it is not compressible, but its puncture and cannulation is less safe than other accesses, due to its intimate contact with the pleura. On the other hand, the supraclavicular approach to the BCV will rapidly become the first choice for ultrasound-guided central venous access in neonates. The BCV is relatively large, easy to scan and non-compressible as is the SV; however, as opposed to the SV, the full visualization of the BCV is easier. The ultrasound-guided infraclavicular approach to the AxV has never been described in neonates, mostly because of its compressibility and the very small caliber in this age group (Fig. 12.10).

FICC can be inserted by ultrasound-guided approach of the common femoral vein (CFV), the external iliac vein, the superficial femoral vein, and the saphenous vein. In clinical practice, most FICCs in the neonate are inserted puncturing the CFV.

12.10.1 Internal Jugular Vein

The highly unpredictable and variable course of the IJV and its relationship to the carotid artery are not issues any more when using ultrasound (US). A short axis/out-of-plane approach is potentially dangerous (perforation of the posterior wall of the IJV, with resulting injury to the underlying subclavian vein). A short-axis/in-plane or an oblique axis/in-plane approach should be preferred. In either case, the IJV should be visualized and punctured as low as possible, close to its confluence with the BCV. The US probe is placed perpendicular to the skin so to visualize the IJV in short-axis or slight oblique-axis. The needle enters the skin laterally to the probe, so to be visualized in all its trajectory. As the needle is visualized inside the vein, the micro-guidewire is threaded inside the vein. An oblique-axis approach may facilitate the progression of the wire, if compared to the short-axis.

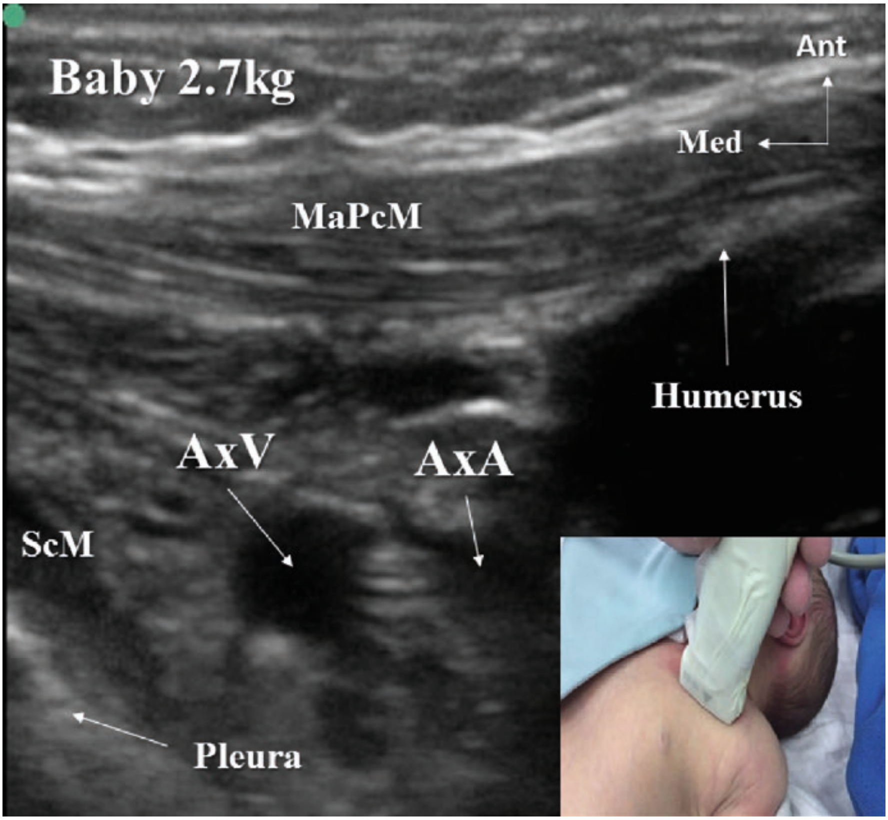

Fig. 12.10 Infraclavicular region in a neonate: AxV = axillary vein; AxA = axillary artery; MaPcM = major pectoral muscle; ScM = scalene muscle

12.10.2 Brachio-Cephalic Vein

The BCV is relatively large (the largest vein that can be accessed by ultrasound in the neonate) and fixed to surrounding tissue structures, so that it is non-compressible and patent even in hypovolemic patients. A short 10–14 MHz linear probe is used, preferably with 'hockey stick' shape. The BCV is localized using the RaCeVA protocol: by placing the ultrasound probe perpendicular to the skin at the level of the cricoid cartilage, a short-axis view of the IJV is obtained initially (RaCeVA, position 1); the probe is then moved caudally following the IJV until it crosses the subclavian artery (RaCeVA, position 2). The probe is then turned slightly medially and tilted behind the clavicle until the optimum sonographic long-axis view of the BCV is obtained (RaCeVA, position 3) (Fig. 12.11). The trajectory of the right BCV is

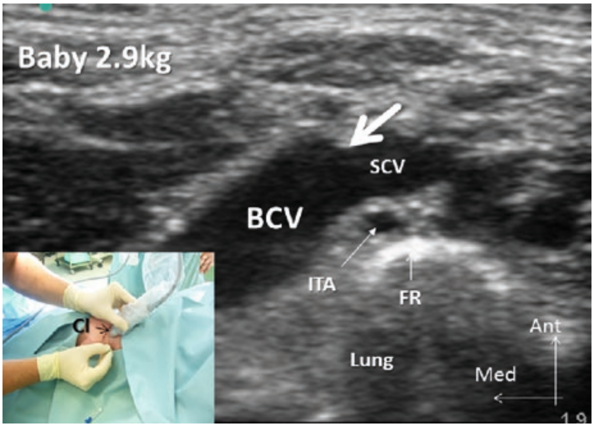

Fig. 12.11 Ultrasound imaging of the left brachio-cephalic vein (BCV) and of the subclavian vein (SCV), both in long axis

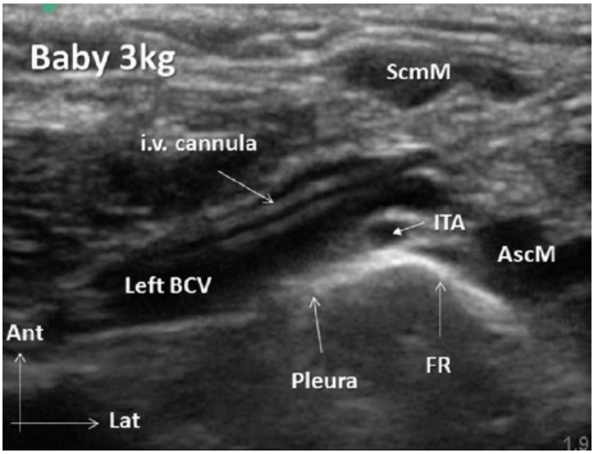

Fig. 12.12 Intravenous cannula entering the left brachio-cephalic vein (BCV)

vertical or oblique, while the left BCV is more horizontal; nonetheless, on both sides, the BCV is easily visualized in long axis in any neonate.

Using the in-plane approach, the echogenic needle is then advanced from lateral to medial, strictly under the long axis of the ultrasound probe until visualized on the ultrasound screen. The tip of the needle is then guided under real-time ultrasound control into the BCV (Fig. 12.12). When then needle is visualized inside the vein, the micro-guidewire is threaded into the needle.

The left BCV may be easier to cannulate because of its horizontal orientation. Though, when threading the catheter into the vasculature, some difficulty may be encountered when the confluence between left and right BCV is T-shaped; in these situations, the access to the right BCV (Fig. 12.13) allows an easier progression of the catheter from the BCV to the SVC.

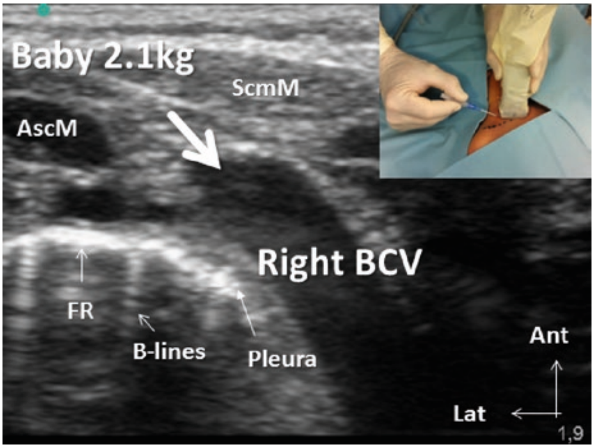

Fig. 12.13 Ultrasound imaging of the right brachio-cephalic vein (BCV) in long axis

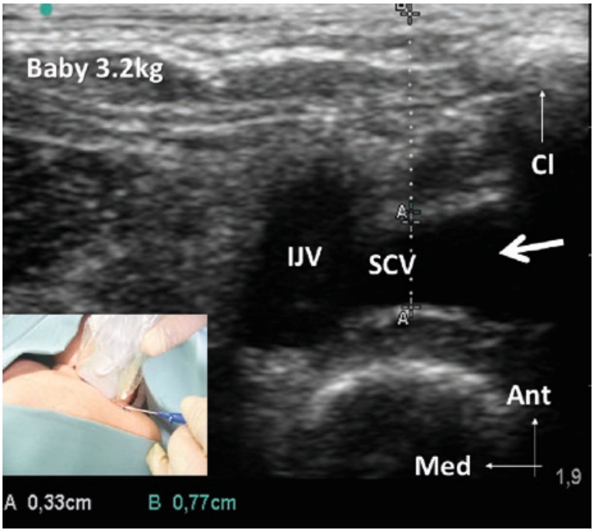

Fig. 12.14 Ultrasound access to the left subclavian vein (SCV), close to its confluence into the internal jugular vein (IJV)

12.10.3 Subclavian Vein

Like the BCV, the SV is also fixed to the surrounding tissue making it likewise non-compressible, and patent in hypovolemia. However, the SCV is much smaller than the BCV. Also, the risk of accidental injury to the pleura is higher.

Two different in-plane approaches have been described. The first is a completely supraclavicular approach, like the BCV approach but with the needle entering more laterally (care must be adopted to avoid any damage to the subclavian artery and to the pleura) (Fig. 12.14). The second is a combined infra/supraclavicular approach: the probe is placed over the clavicle, and it follows the needle while it enters the AxV/SV, visualized in long-axis in the infraclavicular area. When the clavicle is still echo-transparent, as in very small neonates, the maneuver is relatively safe.

Nonetheless, the main reason for not puncturing the SV is related to its smaller caliber if compared to the BCV. When the goal is to insert a catheter of good performance (3Fr, power injectable), a vein of at least 3 mm should be chosen, so to minimize the thrombotic risk. While most neonates >500 g may have a BCV of 3 mm, this does not occur for the SV.

12.10.4 Common Femoral Vein

The CFV is usually accessed with a short-axis/out-of-plane approach since a potential perforation of the posterior wall of the vein is not associated with relevant damages. Also, the short-axis approach allows a panoramic view of the surrounding structures and allows to avoid accidental arterial injury. After the puncture, though, a long axis visualization of the CFV and of the external iliac vein is useful for the proper visualization of the guidewire (ultrasound-based tip navigation). In fact, as the angle between CFV and external iliac vein is quite sharp, there is some risk that the needle (or the guidewire) may damage the anterior wall of the external iliac vein, placing the catheter in the pelvic space in extravascular position.

12.11 Tunneling

As already mentioned, according to the RAVESTO protocol, the choice of the ideal puncture site should be completed by the choice of the exit site. The two most common puncture sites for CICCs and FICCs in neonates (the supraclavicular area and the groin) cannot be regarded as optimal as exit site, because of the high risk of contamination. For this reason, tunneling is almost always recommended. When accessing the BCV, the catheter is tunneled caudally, so to get the exit site in the infraclavicular area (Fig. 12.15). When puncturing the CFV, the catheter is tunneled so to locate the exit site at mid-thigh. The rationale and the technique of tunnelling are discussed in Chap. 8.

Tunneling is always technically feasible for 3–4Fr polyurethane catheters inserted by modified Seldinger technique. It may be difficult or impossible for catheters inserted by simple Seldinger technique.

Fig. 12.15 CICC inserted into the brachio-cephalic vein and then tunneled to the infraclavicular area

Fig. 12.16 Tunneled CICC secured with subcutaneous anchorage

12.12 Securement

As for other central venous access devices, the cornerstone of catheter securement and protection of the exit site are cyanoacrylate glue, sutureless devices and transparent membranes. The great advantage of using 3–4Fr polyurethane catheters is that they can be secured with the best securement method currently available, subcutaneous anchorage (Fig. 12.16). On the contrary, catheter <3Fr can only be secured by skin adhesive sutureless systems, which are less effective (see Chap. 8).

12.13 Complications

12.13.1 Immediate Complications

Puncture-related complications, such as pneumothorax, hemothorax and accidental arterial puncture have been described during ‘blind’ insertion of CICC and FICC, but they are apparently very rare or exceptional using ultrasound guidance. The best methods of prevention are (a) pre-procedural correction of hypovolemia, (b) optimal sedation/anesthesia, (c) choice of the largest and easiest vein (the BCV, in most cases), (c) use of appropriate material (ultrasound device, needles, guidewires, catheters, etc.), and—finally—(d) proper training of the operator. All puncture-related complications can be ruled out or detected early by ultrasound (see Chap. 7).

12.13.2 Early Complications

Late cardiac tamponade and pleural effusions due to vessel perforation have been described for ECC but not for CICC and FICC. As these complications are often secondary to primary or secondary malposition, the best prevention strategies are (a) the use of a proper intraprocedural method of tip location (IC-ECG or ultrasound) and (b) proper securement of the catheter.

12.13.3 Late Complications

The most frequent late complications include infection, venous thrombosis and lumen occlusion.

The risk of a catheter-related infection in neonates is inversely proportional to gestational age and directly proportional to the duration of catheterization. Other risk factors include the use of parenteral nutrition, catheter type, and altered integrity of skin and gastrointestinal barriers. The best prevention strategies are a proper protection of the exit site (tunneling, glue, subcutaneous anchorage, transparent membranes) and an appropriate protocol of maintenance of the infusion line (frequent saline flushes, use of needle free connectors with disinfecting caps, etc.).

Lumen occlusion is frequent with ECC, but less frequent with power injectable CICCs and FICCs; prevention consists in proper maintenance of the line (see above).

Venous thrombosis seems to be quite rare for CICCs and FICCs, as long as the proper match between catheter caliber and vein diameter is adopted, and a proper intraprocedural method of tip location (ultrasound and/or IC-ECG) is used.

12.14 Conclusion

Ultrasound guided CICCs and FICCs are the ideal central venous access in critically ill neonates requiring surgery, intensive care treatments, transfusions, frequent blood sampling and hemodynamic monitoring.

For minimizing complications, an appropriate insertion bundle should be adopted:

1. Preprocedural ultrasound examination of the venous patrimony (RaCeVA, RaFeVA)

2. Determination of the size of the targeted vessel via ultrasound
3. Proper planning of the puncture site and of the exit site
4. Hand hygiene, skin antisepsis with 2% chlorhexidine and maximal barrier precautions
5. Puncture/cannulation of the vessel under real-time ultrasound guidance, ruling out immediate puncture-related complications by ultrasound
6. Tip navigation = ultrasound control of the course of the guidewire and of the catheter
7. Intraprocedural tip location by ultrasound and/or intra-cavitary ECG
8. Tunneling, as required
9. Protection of the exit site with cyanoacrylate glue
10. Catheter securement with sutureless devices (preferably, subcutaneously anchored)
11. Coverage of the exit site with transparent membranes with high permeability

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