Chapter 11
Epicutaneo-Cava Catheters

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11.1 Introduction

Central venous access devices are often required in neonates, particularly in preterm babies or in newborns who are candidate to intensive care procedures, surgery, or parenteral nutrition. A venous access device is 'central' when its tip is located in the superior vena cava (SVC) or in the right atrium (RA) or in the inferior vena cava (IVC). According to the terminology adopted by the WoCoVA Foundation (WoCoVA = World Congress on Vascular Access), central venous access devices in neonates should be classified as follows:

- Umbilical venous catheter (UVC)—inserted in the umbilical vein, tip at the junction between RA and IVC.
- Epicutaneo-cava catheters (ECC)—inserted in superficial veins of the limb or the scalp, tip in the SVC or at the junction between RA and SVC
- Centrally Inserted Central Catheters (CICC)—inserted by ultrasound guidance in deep veins of the supra/infraclavicular area, tip at the junction between RA and SVC
- Femorally Inserted Central Catheters (FICC)—inserted by ultrasound guidance in deep veins of the groin and the thigh, tip in the IVC or at the junction between RA and SVC.

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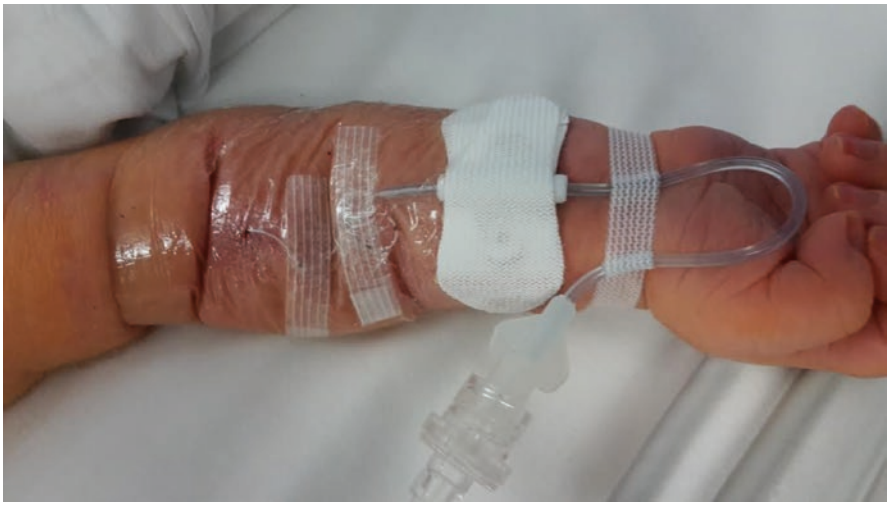

Fig. 11.1 Epicutaneo-cava catheter inserted in the upper limb of a neonate

In this chapter, we will discuss the indications, technique of insertion and complications of epicutaneo-cava catheters (ECC) (Fig. 11.1). These central venous access devices have been often called 'PICCs' (peripherally inserted central catheters). Though this term is correct, it may yield confusion, since PICC is also the term commonly used for indicating central catheters inserted by ultrasound-guided puncture and cannulation of the deep veins of the arm in children and adults. ECCs and PICCs are completely different central devices: ECCs are small bore catheters (1–2.7Fr), made of silicone or old generation polyurethane, inserted via superficial veins of the limbs or scalp using direct vein visualization. PICCs are larger catheters (3Fr and more), made of new generation polyurethane, usually power-injectable, inserted into the deep veins of the arm (brachial, basilic, axillary) using ultrasound guidance.

There is a huge technological leap between these two devices, which translates in different performances: PICCs are appropriate for blood sampling, for high flow infusion (up to 1 ml/sec vs 1 ml/min of ECC), for hemodynamic monitoring (central venous pressure, central venous sampling for oxygen saturation in mixed venous blood, etc.) and for infusion of blood products; they have extended dwell time (even months); they can be secured with subcutaneously anchored sutureless systems, thus abolishing the risk of dislocation; their tip can be safely located using intracavitary ECG (difficult to use for ECC); an accurate diagnosis of PICC colonization or infection is consistently possible by the DTP method (Differential Time to Positivity), which is not applicable to ECC; and so on.

11.2 Indications

The most frequent indication of ECC in neonates are based on the type of infusion (solutions with pH <5 or > 9, emulsions with high osmolarity, such as parenteral nutrition, or irritant/vesicant solutions that might be associated—by different mechanisms—with endothelial damage), or on the expected duration of venous access (more than 6 days but less than 14 days), or on the venous patrimony of the neonate (difficult venous access).

The ECC, as any other central venous access, should be promptly removed as soon as a central line is not required any longer. Though there is uncertainty regarding the actual duration of an ECC, several reports show that—at least in preterm neonates—the risk of infective and mechanical complications of ECCs increases enormously after 14 days. Therefore, in many NICUs these devices are routinely replaced by new ones after two weeks. When the expected duration of intravenous infusion is beyond 2–3 weeks, a more appropriate option of central venous access is the placement of large bore polyurethane catheters (3-4Fr) by ultrasound-guided percutaneous puncture and cannulation of the internal jugular vein, of the brachiocephalic vein (CICC) or of the femoral vein (FICC).

11.3 Materials

ECCs are available in different caliber (from 1 to 2.7 Fr), single lumen or double lumen. Small ECC (1Fr) are more frequently used in preterm weighing less than 1000 g, while 2Fr catheters are used in neonates weighing >1000 g. According to the commonly accepted strategies of thrombosis prevention, the vein cannulated by the ECC should have an inner diameter at least three times the caliber of the catheter. In the case of ECC, this is not always possible, since often the superficial veins of the upper and lower limb have a diameter below 1 mm; this might explain the high incidence of thrombosis/phlebitis of ECC, particularly in the tract of the vein close to the exit site.

ECCs are available both in silicon and in polyurethane, though the latter are becoming more and more popular and should be preferred. Polyurethane ECCs are less fragile and associated with higher flow performances if compared to silicon ECCs. A new type of antimicrobial ECC coated with rifampicin (antibiotic) and miconazole (antifungal) is now available on the market. Randomized controlled trials are currently evaluating its effectiveness in reducing the risk of central line associated blood stream infection.

11.4 Choice of the Cannulation Site

The choice of the vein most suitable for the insertion of an ECC often relies upon an empiric decision, depending usually on the operator's preference and experience, after a non-systematic assessment of the main superficial veins (Fig. 11.2). This is not an optimal strategy, as it may be associated with an uncontrolled exploitation of the venous patrimony of the neonate. We strongly recommend adopting a protocol of systematic evaluation of all peripheral veins, such as the RaSuVA protocol (Rapid Superficial Veins Assessment), already described in Chap. 9. The RaSuVA consists

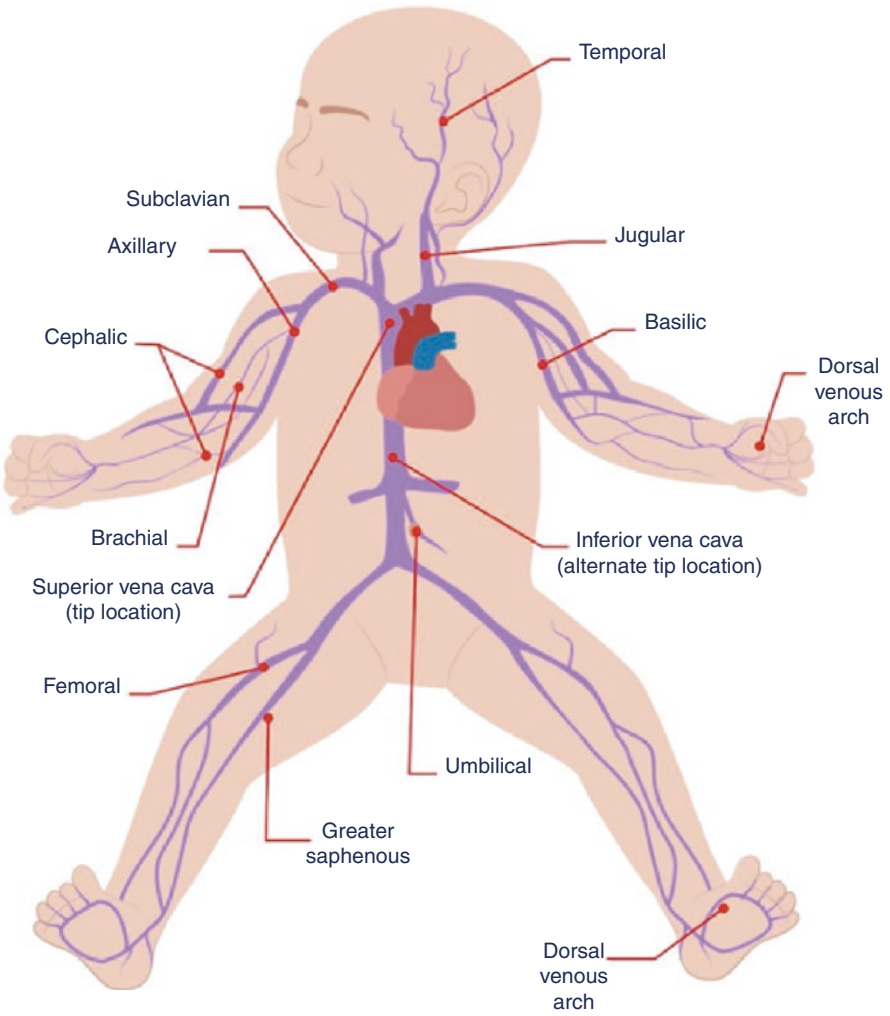

Fig. 11.2 Main veins that can be accessed for ECC insertion

in the sequential assessment of seven potential ECC sites, exploring the veins of the neonates 'from foot to head', first on the right and then on the left side: (1) medial malleolus, (2) lateral malleolus, (3) popliteal fossa, (4) back of the hand and wrist, (5) antecubital fossa, (6) anterior scalp veins, (7) posterior scalp veins. The exploration can be performed with direct eye visualization of the superficial veins, or by using NIR technology (see Chap. 5).

RaSuVA is an easy tool designed to build a detailed and complete map of the superficial veins of the neonate, through a rational and systematic approach, so to choose the best vein for cannulation and avoid unnecessary multiple venous punctures. Using the data derived from RaSuVA, it is possible to define a list of preferred veins in each patient, depending on the type of the venous device to insert (peripheral or central). For example, the insertion of peripheral cannulas is preferably performed in the lower limbs (excluding the saphenous vein) as a first option, or on the back of the hand and at the wrist as a second option. The insertion of an ECC is usually performed at the antecubital fossa (first option) or at the saphenous vein at the medial malleolus (second option). The puncture/cannulation of scalp veins is taken into consideration only in very selected cases.

11.5 Technique of Insertion

After choosing the cannulation site, the neonate is prepared to the procedure (proper immobilization, comfort-care, and sedation).

The next pre-procedural step is the estimation of the required length of the ECC, depending on the cannulation site and on the size of the patient (Fig. 11.3).

For cannulation site at the upper limb (Fig. 11.4) or on the scalp, length estimation is calculated as the distance from puncture site to the right sternoclavicular notch + the distance from the sternoclavicular notch to the third intercostal space.

For cannulation site at the lower limb, length estimation is calculated as the distance from puncture site to the groin + the distance between groin and navel + the distance between navel and xyphoid process.

Figure 11.2 summarizes the length estimation.

The procedure follows these steps:

- Hygiene of the hands (alcohol gel rub, as first option)
- Maximal barrier precautions (cap, mask, sterile gown, sterile gloves)
- Check of the content of the insertion pack (sterile drapes, sterile gauze, forceps, scissors, syringes, tourniquet, centimeter tape, etc.) and check of materials usually not included in the pack (saline, cyanoacrylate glue, chlorhexidine swab, etc.)
- Check of the content of the catheter kit: catheter (to be filled with saline) and introducer (usually, 20-24G breakable needle, or micro-introducer for modified Seldinger)
- Skin antisepsis with 2% chlorhexidine in alcohol, avoiding excessive amounts of antiseptic solution and friction movements (Fig. 11.5)

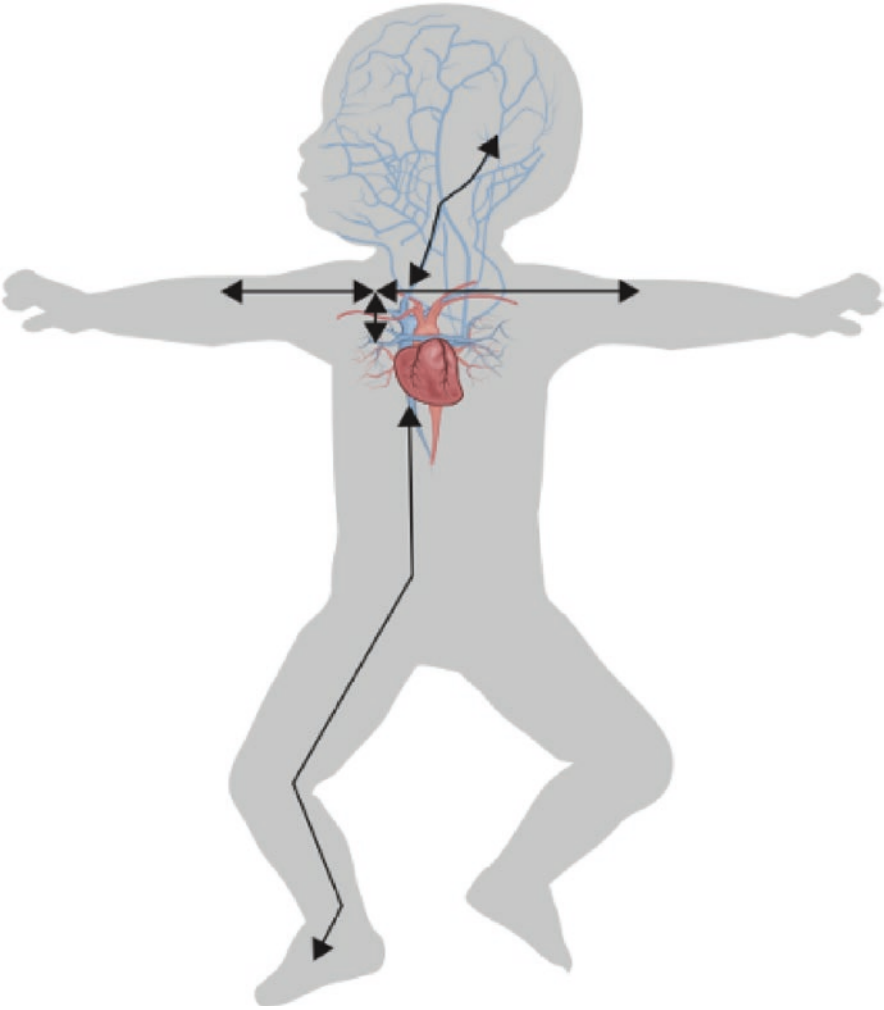

Fig. 11.3 Graphic representation of the methods for estimating the length of the ECC

- the antiseptic needs 30 seconds for reaching the maximal activity; after 30 seconds, the area is rinsed with saline
- wide sterile field, using fenestrated drapes (Fig. 11.6)
- placement of tourniquet (if cannulation site is on the limbs)
- direct puncture of the vein (Fig. 11.7), checking blood return (Fig. 11.8); the visualization, puncture and visualization of the vein may be facilitated by NIR devices (see Chap. 5)
- removal of the tourniquet
- insertion of the catheter through the needle or through the introducer

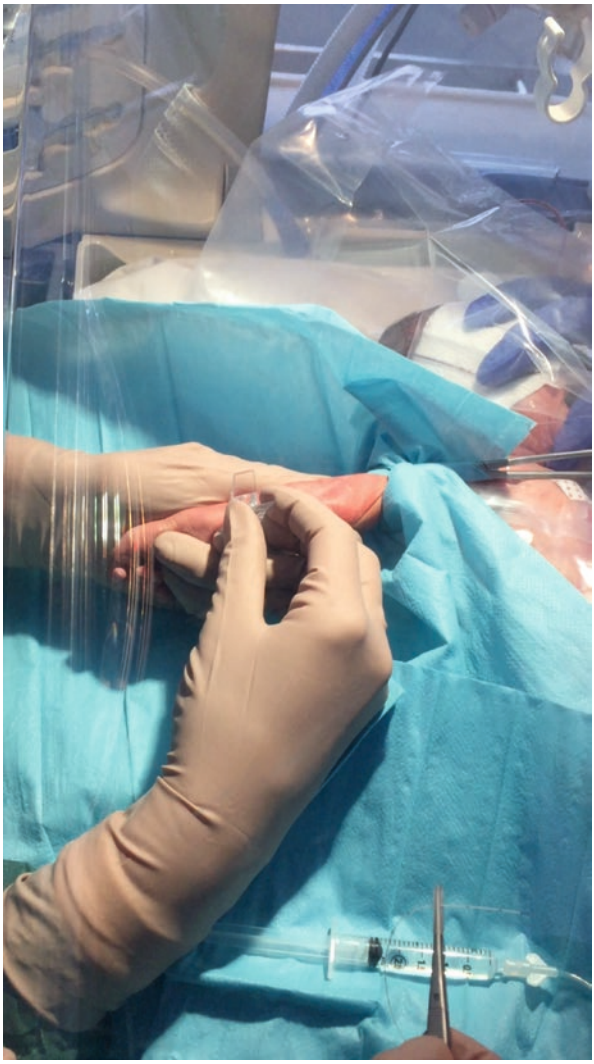

Fig. 11.4 Puncture at the upper limb

- as the catheter is inserted for the estimated length, the position of the tip is checked by real time ultrasound (see below)
- after checking the blood return by aspirating through the ECC, the needle/introducer is removed

the exit site is sealed with a minimal amount (< 0.25 ml) of cyanoacrylate glue; cyanoacrylate glue is safe, inexpensive, and easy to apply, and it yields the additional advantage of being very effective in preventing any bleeding/oozing at the puncture site; removal of cyanoacrylate glue is also consistently easy and harmless

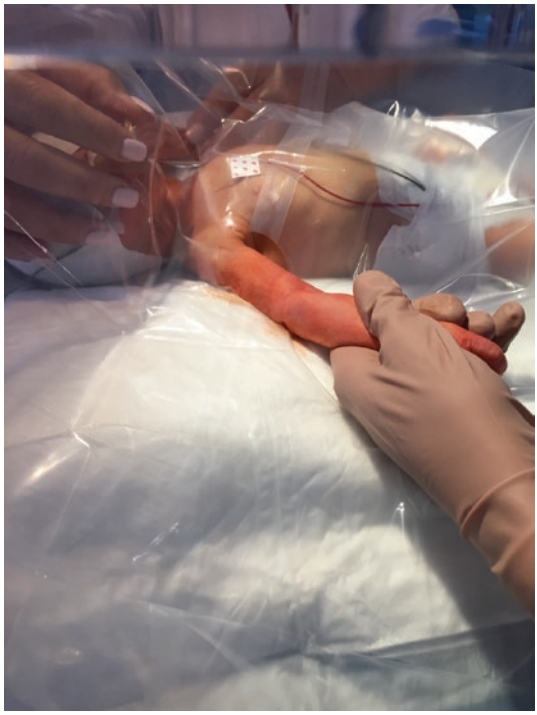

Fig. 11.5 Skin antisepsis with 2% chlorhexidine in alcohol

Fig. 11.6 Wide sterile field

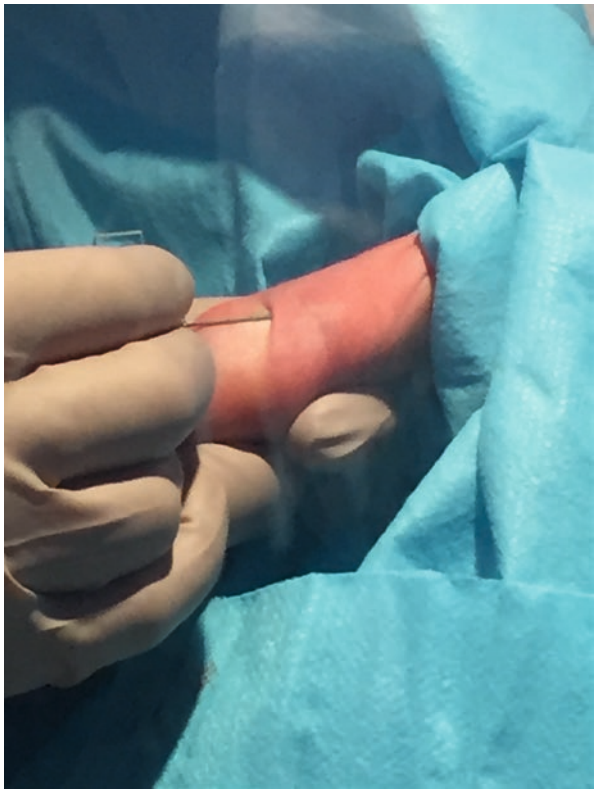

Fig. 11.7 Venipuncture

- if additional sterile strips are used, they should block the catheter on the skin at no less than 1 cm of distance from the exit site
- after cleaning the skin with saline, the area is wiped and then covered with semi-permeable transparent membranes with high permeability (high MVTR). (Fig. 11.9)

11.6 Insertion Complications

The most frequent complication during insertion is difficulty in the progression of the ECC, due to extravascular placement of the catheter or vascular abnormalities. When this happens, several maneuvers are used: changing the position of the limbs or the head, flushing the catheter with small amount of saline, etc.

The catheter should be left in place only after confirmation of the appropriate position of the tip by ultrasound and after verification of blood return.

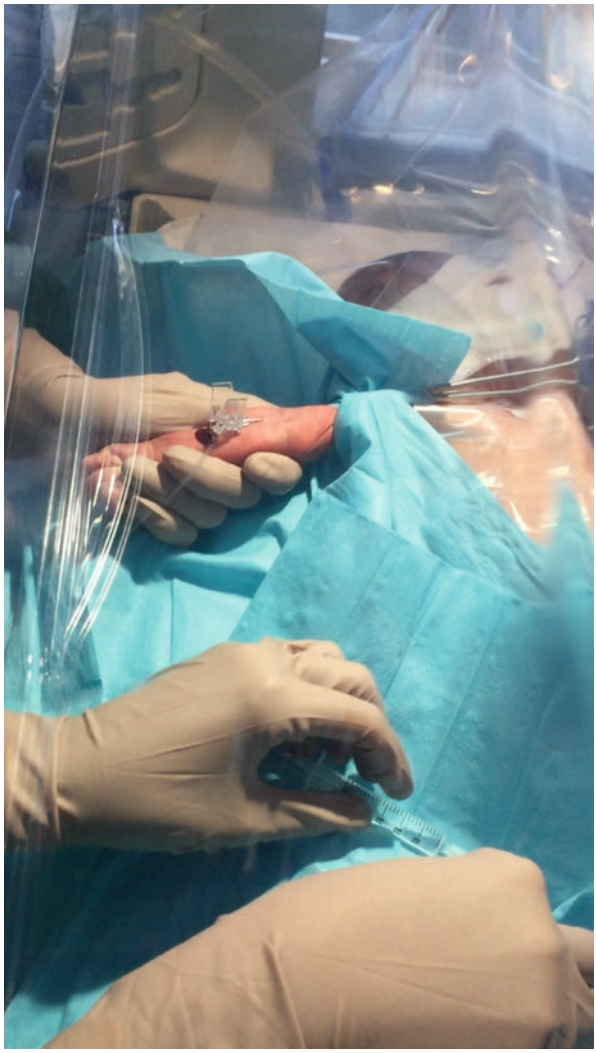

Fig. 11.8 Blood return from the needle

11.7 Tip Location

The old strategy for ECC placement, which unfortunately is still very popular, consists in the 'blind' placement of the catheter, based on the length estimation by surface landmarks, followed by a post-procedural radiological control by a chest/abdomen x-ray. Traditionally, an ECC inserted at the upper limb or on the scalp should have its tip radiologically projected at the level of the body of the fourth thoracic vertebra (T4), which corresponds, very approximately, to the SVC/RA junction; an ECC inserted at the lower limb should have its tip radiologically projected at the level of the body of the ninth thoracic vertebra (T9), which corresponds, very approximately, to the IVC/RA junction (Fig. 11.10). When the catheter

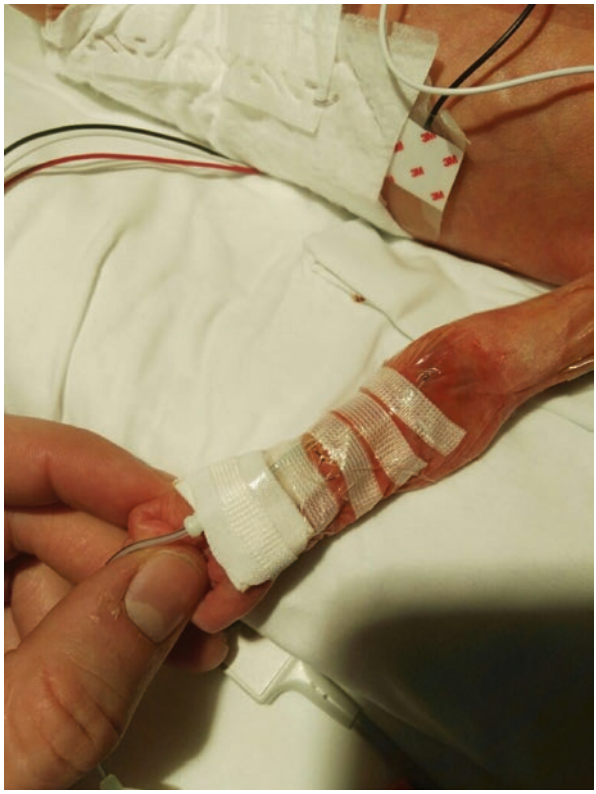

Fig. 11.9 Final dressing: cyanoacrylate glue, sutureless securement, sterile strips and transparent membrane with high permeability

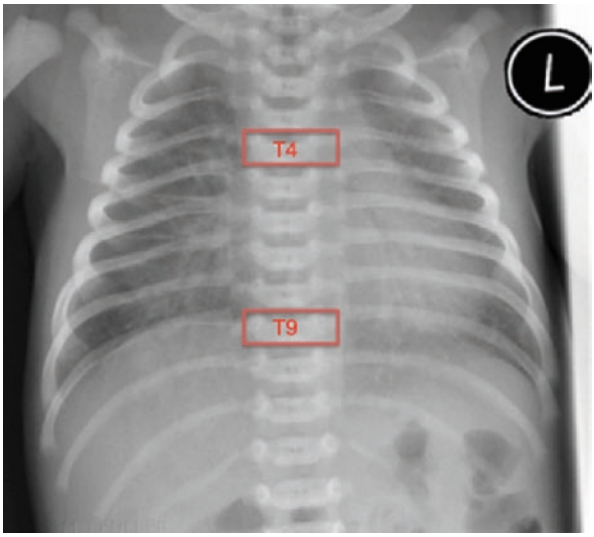

Fig. 11.10 Chest x-ray showing the fourth vertebral body (T4) and the ninth vertebral body (T9)

is difficult to visualize on x-ray, a small amount of contrast medium (0.3–0.5 ml) has been used to enhance visualization. This radiological method of tip location has many disadvantages: (a) it is quite inaccurate, since the SVC/RA junction and the IVC/RA junction are not directly seen on x-ray, but their location is indirectly inferred by radiological landmarks; (b) it is post-procedural, so that—if the tip position is not correct—it may be necessary to reposition the ECC; (c) it is not safe, since it implies x-ray exposure.

For these reasons, the method of tip location currently recommended is based on ultrasound: it is accurate, since both the catheter and the vascular structures can be easily visualized in the neonate; it is intraprocedural, so that the final position of the ECC can be verified immediately and the catheter can be secured immediately; it is safe, since exposure to ultrasound is harmless. Ultrasound has a role not only during the maneuver of placement, as a real-time method of verification of the correct direction of the catheter inside the vasculature (tip navigation) and of the final position of the tip (tip location), but also as an accurate and non-invasive post-procedural tool for the periodic verification of the position of the ECC, so to detect any secondary malposition or other catheter-related complications.

The use of ultrasound for tip navigation and tip location is described in detail in the Neo-ECHOTIP paper (see Bibliography). In short, when the ECC is inserted via veins of the scalp or the upper limbs, tip navigation is performed using a 10–14 MHz linear probe and assessing the progression of the catheter into the superior vena cava by a simple supraclavicular view (as the one described in the RaCeVA). When the ECC is inserted via the veins of the lower limbs, tip navigation is performed following the catheter inside the femoral vein and the external iliac vein, using a linear probe. In any case, tip location is performed using a subcostal longitudinal view that allows visualization of the right cavities of the heart, and/or a subcostal bi-caval view (Fig. 11.11) that allows visualization of SVC, RA and IVC (Fig. 11.12). The tip of the catheter is visualized directly, or indirectly by injecting a small flush of saline (0.5–1 ml).

In adults and in children, intracavitary ECG is nowadays the gold standard for the intra-procedural tip location, due to its great accuracy and feasibility. So far, few studies have investigated ECC placement with intracavitary ECG in neonates. The small number of patients enrolled and the poor quality of the signal, probably related to the small diameter of the catheter, make it impossible to draw a definite conclusion about the feasibility of this technique in the neonatal population. Though, this is an interesting field of research and in the next future intracavitary ECG may be an aid in tip location, together with ultrasound.

11.8 Maintenance

As for any vascular device, the adoption of proper strategies of maintenance of the ECC plays a pivotal role in minimizing complications and prolonging the life of the catheter. The implementation of dedicated teams for the management of central venous access is proven to be associated with successful clinical outcomes.

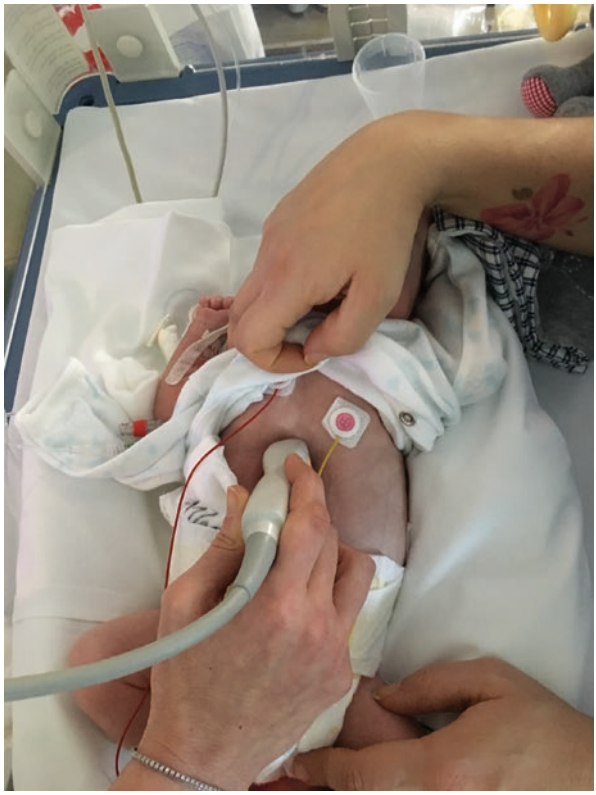

Fig. 11.11 Probe placed in the subcostal space

The most important recommendations are the following:

- proper hand hygiene before and after any procedure performed on the ECC
- sterile handling of the infusion lines and of the hubs
- maintenance of a constant flow (at least 0.5–1 ml/h for ECC < 2Fr) so to keep the lumen patent
- bolus infusions should be administered using 10 ml syringes, that exert low pressure (approximately 50 PSI), since no ECC is power injectable. Smaller syringes may be associated with higher pressure (100 PSI for 5 ml syringes and 200 PSI for 2 ml syringes) and risk of catheter rupture
- dressing change should be focused on the necessity of avoiding bacterial contamination of the exit site and catheter dislodgment and should be performed only in case of local problems (detachment of the membrane, bleeding, etc.). The cornerstones of a proper dressing of ECC are cyanoacrylate glue and semipermeable transparent dressings with high permeability (high MVTR—'moisture vapor transfer rate') (Fig. 11.13)

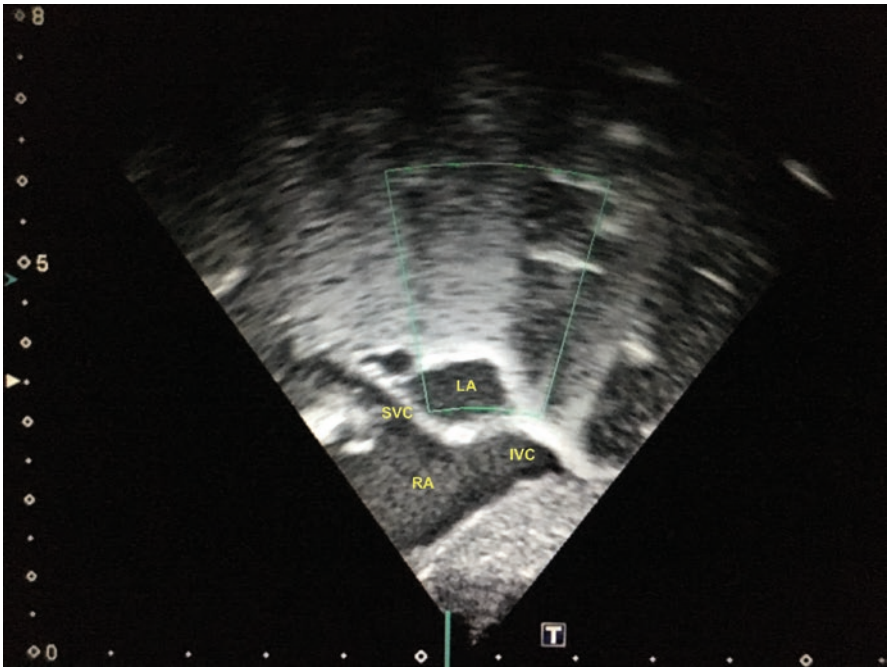

Fig. 11.12 Subcostal bi-caval view, showing right atrium (RA), superior vena cava (SVC) and inferior vena cava (IVC)

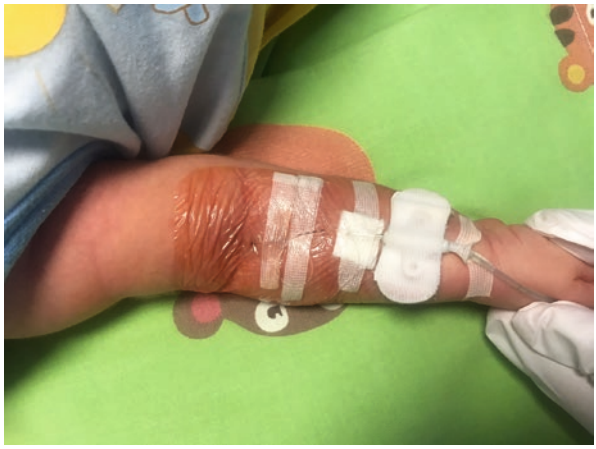

Fig. 11.13 Exit site of epicutaneo-cava catheter protected with glue and transparent membrane

11.9 Removal

The removal of ECC must be done with sterile gloves and after proper skin antisepsis. The catheter should be removed very slowly. ECCs are fragile, even if in polyurethane, and minimal adhesions of the catheter to the vein wall (typically because of fibroblastic sleeve or phlebitis around the ECC) may offer resistance, and the catheter may fracture spontaneously. At the end of the procedure, the length of the catheter should be assessed, so to verify that no fragments have been lost in the vasculature.

When the catheter does not come away easily, several maneuvers are usually attempted, even if most of them are not expected to be effective. Probably, gentle slow traction, rotation of the catheter, and waiting are the best strategies. In some rare cases (catheter stuck inside a vein with phlebitis, or catheter rupture) surgery may be required.

11.10 Complications

11.10.1 Infection

The diagnosis of catheter-related blood stream infection (CRBSI) is not practical with ECCs, since the method of Differential Time to Positivity (DTP) cannot be applied since blood culture from an ECC is often impossible. Thus, the only feasible diagnosis is central line associated blood stream infection (CLABSI), which inevitably include not only ECC-related blood stream infections, but also blood stream infections secondary to other non-evident sources. The diagnosis of CLABSI implies a positive peripheral culture, with systemic signs of infection, in a neonate who had a central line for 48 h or more, in absence of other evident sources of infection. CLABSI is often the effect of a prolonged stay of the ECC (more than two weeks) and/or breakthrough of the aseptic technique during the maneuvers of insertion/maintenance. If CLABSI occurs, the ECC should be removed immediately, and proper antibiotic treatment started. An attempt at saving the central access might be considered only when (a) proper antibiotic treatment has begun, (b) the infection is not caused by S. Aureus, Candida, or Gram-negative germs, and (c) a second blood culture performed 48–72 h later is negative. After ECC removal because of infection, a new central access should not be inserted in the following 2–3 days.

11.10.2 Catheter Malfunction

Malfunction can be secondary to intraluminal obstruction (clots, drug precipitates, lipid aggregates, etc.) or extraluminal factors (catheter kinking, tip malposition, fibroblastic sleeve, venous thrombosis around the tip, etc.). If an intraluminal obstruction is suspected, the ECC should be flushed gently. The cause of the extraluminal obstruction can be assessed by ultrasound examination. Many of these causes eventually lead to ECC removal.

11.10.3 Catheter Dislodgment

This complication is usually secondary to accidental traction of the catheter during dressing change or general neonatal care. Few millimeters may not be clinically relevant but dislodgment of 1 cm or more are likely to be associated with important secondary malposition of the tip, so that the catheter cannot be considered central anymore. Assessment of the tip location can be easily performed by ultrasound. If tip malposition is detected, the options are (a) use of the catheter as peripheral line, or (b) removal.

11.10.4 Tip Migration

The tip of the ECC can migrate inside the vasculature even without any dislodgment of the catheter at the exit site, for instance because of variation of the intrathoracic pressure. The new location of the tip should be assessed by ultrasound. Treatment may include partial withdrawal of the catheter, or removal.

11.10.5 Local Phlebitis

Several factors may cause a local thrombophlebitis of the vein that has been cannulated for ECC insertion: mismatch between vein diameter and catheter caliber, trauma of the vein wall during cannulation, bacterial contamination due to poor skin antisepsis, chemical irritation of the vein caused by the powder inside the gloves, and so on. If the phlebitis does not recede in 48 h, the ECC must be removed.

11.10.6 Catheter-Related Venous Thrombosis

It is usually associated with an incorrect position of the tip. The diagnosis requires proper ultrasound exploration of the vasculature where the tip of the catheter appears to be located. Severe obstruction of the SVC or the IVC may require thrombolysis using alteplase (rTPA) or urokinase, preferably administered through the catheter, especially if the thrombosis is around the tip. Anticoagulant treatment should be started. When the thrombosis is associated with catheter malfunction and/or tip malposition, the ECC should be removed after a proper period of anticoagulant therapy (3–7 days).

11.10.7 Edema of the Limb

It is often secondary to a dressing that is too tight. Ultrasound should be used, so to assess that the edema is not secondary to catheter-related venous thrombosis.

11.10.8 Secondary Erosion of the Pericardium or of the Pleura

ECCs—if very thin, and/or very mobile, and/or if the tip is not properly located at the RA/SVC junction—may rarely cause an erosion of the vein wall with entrance of the tip of the catheter into the pleural space or into the pericardial space. In the first case, a pleural effusion occurs with respiratory distress; in the second case, a pericardial effusion with cardiac tamponade. Ultrasound plays a central role in the prevention of this complication (periodical assessment of tip location), in its diagnosis (detection of effusion by chest ultrasonography and echocardiography) and in its treatment (ultrasound-guided thoracentesis or pericardiocentesis) (Fig. 11.14).

11.11 Limitations of the ECCs

ECCs are extremely important in the management of the newborns: as central lines, they can be used for delivery of parenteral nutrition and of any solutions, even if irritant or vesicant to the vein wall. Though, they have many limitations:

- the flow is very slow (maximal flow 1 ml/min), so that may not be appropriate for critically ill neonates requiring transfusions or volume repletion
- as no ECC is power injectable, this venous access is particularly fragile and prone to rupture

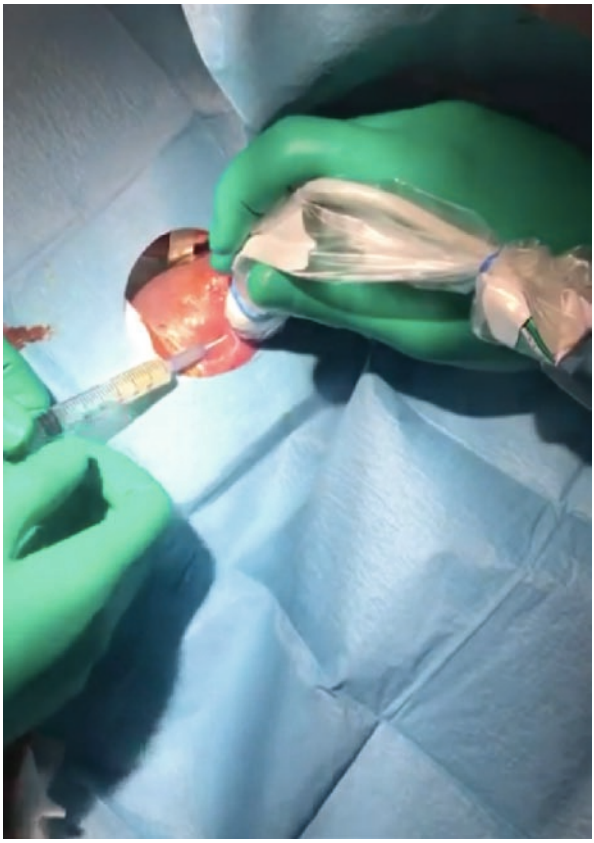

Fig. 11.14 Ultrasound-guided aspiration of pleural fluid effusion

- as blood withdrawal is difficult or impossible, blood samples must be obtained by additional punctures of peripheral veins; also, diagnosis of CRBSI by DTP is not possible, and measurement of oxygen saturation in mixed venous blood cannot be obtained
- due to the small caliber, measurement of central pressure is not possible
- their expected dwelling time is limited to few weeks (even less in preterm babies), because of the frequent complications.

This explains why ECCs may be appropriate in uncomplicated stable neonates requiring only hydration and parenteral nutrition, but not in critically ill neonates requiring surgery or aggressive intensive care treatments. In these latter cases, an ultrasound guided CICC will be more appropriate. Many papers of the last few years have suggested that ultrasound guided CICCs are feasible and safe even in very small neonates, with a high percentage of success and minimal risk, in experienced hands. CICCs and FICCs offer several advantages not only in term of performance (high flow, blood withdrawal, etc.) but also it is likely that they are associated with lower risk of complications (occlusion, secondary malposition, venous thrombosis, mechanical rupture, infection) if compared to ECC.

Bibliography

1. Barone G, D'Andrea V, Vento G, et al. A systematic ultrasound evaluation of the diameter of deep veins in the newborn: results and implications for clinical practice. Neonatology. 2019;115:335–40.
2. Barone G, Pittiruti M. Epicutaneo-caval catheters in neonates: new insights and new suggestions from the recent literature. J Vasc Access 2020 Nov;21(6):805–809. https://doi.org/10.1177/1129729819891546. Epub 2019 Dec 5. PMID: 31804149.
3. Brissaud O, Harper L, Lamireau D, et al. Sonography-guided positioning of intravenous long lines in neonates. Eur J Radiol. 2010;73:e18–21.
4. Çağlar S, Büyükyılmaz F, Bakoğlu İ, İnal S, Salihoğlu Ö. Efficacy of vein visualization devices for peripheral intravenous catheter placement in preterm infants: a randomized clinical trial. J Perinat Neonatal Nurs. 2019;33:61–7.
5. Capasso A, Mastroianni R, Passariello A, et al. The intra- cavitary electrocardiography method for positioning the tip of epicutaneous cava catheter in neonates: pilot study. J Vasc Access. 2018;19:542–7.
6. Costa P, Kimura AF, Brandon DH, et al. Predictors of nonelective removal of peripherally inserted central catheters in infants biological research for. Nursing. 2016;18(2):173–80.
7. Costa P, Kimura AF, Brandon DH, et al. The development of a risk score for unplanned removal of peripherally inserted central catheter in newborns. Rev Latino-Am Enfermagem. 2015;23(3):475–82.
8. D'Andrea V, Pezza L, Barone G, Prontera G, Pittiruti M, Vento G. Use of cyanoacrylate glue for the sutureless securement of epicutaneo-caval catheters in neonates. J Vasc Access 2021 Apr 8:11297298211008103. https://doi.org/10.1177/11297298211008103. Epub ahead of print. PMID: 33827329.
9. Erhard DM, Nguyen S, Guy KJ, et al. Dwell times and risk of non-elective removal of 1-French peripherally inserted central catheters according to catheter tip position in very preterm infants. Eur J Pediatr. 2017;176:407–11.
10. Escourrou G, De Luca D. Lung ultrasound decreased radiation exposure in preterm infants in a neonatal intensive care unit. Acta Paediatr. 2016;105:e237–9.
11. Gorski L, Hadaway L, Hagle ME, et al. Infusion therapy standards of practice. J Infus Nurs. 2016;39:S1–S159.
12. Mertens L, Seri I, Marek J, et al. Targeted neonatal echocardiography in the neonatal intensive care unit: practice guidelines and recommendations for training: writing group of the American Society of Echocardiography (ASE) in collaboration with the European association of echocardiography. Eur J Echocardiogr. 2011;45:131.
13. Gupta R, Drendel AL, Hoffmann RG, et al. Migration of central venous catheters in neonates: a radiographic assessment. Am J Perinatol. 2016;33:600–4.
14. Jain A, Deshpande P, Shah P. Peripherally inserted central catheter tip position and risk of associated complications in neonates. J Perinatol. 2013;33:307–12.
15. Jain A, McNamara PJ, Ng E, et al. The use of targeted neo- natal echocardiography to confirm placement of peripher-ally inserted central catheters in neonates. Am J Perinatol. 2012;29:101–6.
16. Katheria AC, Fleming SE, Kim JH. A randomized controlled trial of ultrasound-guided peripherally inserted central catheters compared with standard radiograph in neonates. J Perinatol. 2013;33:791–4.
17. Lamperti M, Pittiruti M II. Difficult peripheral veins: turn on the lights. Br J Anaesth. 2013;110:888–91.
18. Masilamani K, van der Voort J. The management of acute hyperkalemia in neonates and children. Arch Dis Child. 2012;97:376–80.
19. McCay AS, Cassady C. PICC placement in the neonate. N Engl J Med 2014 May 29;370(22):2154. https://doi.org/10.1056/NEJMc1404381. PMID: 24869737.

20. Mermel LA, Allon M, Bouza E, Craven DE, Flynn P, O'Grady NP, et al. Clinical practice guidelines for the diagnosis and management of intravascular catheter-related infection: 2009 update by the Infectious Diseases Society of America. Clin Infect Dis. 2009;49:1–45.
21. Milstone AM, Reich NG, Advani S, et al. Catheter dwell time and CLABSIs in neonates with PICCs: a multicenter cohort study. Pediatrics. 2013;132:e1609–15.
22. Nifong TP, McDevitt TJ. The effect of catheter to vein ratio on blood flow rates in a simulated model of peripherally inserted central venous catheters. Chest. 2011;140:48–53.
23. Ohki Y, Tabata M, Kuwashima M, et al. Ultrasonographic detection of very thin percutaneous central venous catheter in neonates. Acta Paediatr. 2010;89:1381–4.
24. Pettit J. Assessment of infants with peripherally inserted central catheters: part 2. Detecting less frequently occurring complications. Adv Neonatal Care. 2003;3:14–26.
25. Pettit J. Assessment of infants with peripherally inserted central catheters: part 1. Detecting the most frequently occurring complications. Adv Neonatal Care. 2002;2:304–15.
26. Phipps K, Modic A, O'Riordan MA, Walsh M. A randomized trial of the vein viewer versus standard technique for placement of peripherally inserted central catheters (PICCs) in neonates. J Perinatol. 2012;32:498–501.
27. Pittiruti M, Scoppettuolo G. Manuale Gavecelt Dei PICC E Dei Midline. 1st ed. Milan: EDRA S.p.A; 2016.
28. Pittiruti M. Central venous catheters in neonates: old territory, new frontiers. J Vasc Access. 2013;14:318–9.
29. Pittiruti M. The 'off-label' use of PICCs. In: Sandrucci S, Mussa B, editors. Peripherally inserted central venous catheters. Milan: Springer; 2014. p. 127–44.
30. Pittiruti M. Ultrasound guided central vascular access in neonates, infants and children. Curr Drug Targets. 2012;13:961–9.
31. Racadio JM, Doellman DA, Johnson ND, et al. Pediatric peripherally inserted central catheters: complication rates related to catheter tip location. Pediatrics. 2004;107:E28.
32. Sengupta A, Lehmann C, Diener-West M, et al. Catheter duration and risk of CLA-BSI in neonates with PICCs. Pediatrics. 2010;125:648–53.
33. Sharpe E, Pettit J, Ellsbury DL. A national survey of neonatal peripherally inserted central catheter (PICC) practices. Adv Neonatal Care. 2013;13:55–74.
34. Shekelle PG, Pronovost PJ, Wachter RM, et al. The top patient safety strategies that can be encouraged for adoption now. Ann Intern Med. 2013;158:365–8.
35. Spencer TR, Pittiruti M. Rapid central vein assessment (RaCeVA): a systematic, standardized approach for ultra- sound assessment before central venous catheterization. J Vasc Access. 2018;20:239–49.
36. Tauzin L, Sigur N, Joubert C, et al. Echocardiography allows more accurate placement of peripherally inserted central catheters in low birthweight infants. Acta Paediatr. 2013;102:703–6.
37. van den Berg J, Lööf Åström J, Olofsson J, et al. Peripherally inserted central catheter in extremely preterm infants: characteristics and influencing factors. J Neonatal Perinatal Med. 2017;10:63–70.
38. Wrightson DD. Peripherally inserted central catheter complications in neonates with upper versus lower extremity insertion sites. Adv Neonatal Care. 2013;13:198–204.
39. Zhou L, Xu H, Liang J, et al. Effectiveness of intracavitary electrocardiogram guidance in peripherally inserted central catheter tip placement in neonates. J Perinat Neonatal Nurs. 2017;31:E2.
40. Zhou LJ, Xua HZ, Xu MF, et al. An accuracy study of the intracavitary electrocardiogram (IC-ECG) guided peripherally inserted central catheter tip placement among neonates. Open Med. 2017;12:125–30.