Ultrasound Guided Central Vascular Access in Neonates, Infants and Children

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Abstract: Ultrasound guided central venous cannulation is rapidly becoming the standard technique for achieving a central line in neonates, infants and children. Older techniques such as surgical cutdown and 'blind' percutaneous venipuncture have many disadvantages: they are time consuming, vein consuming and/or associated with dangerous immediate or late complications. On the other hand, ultrasound has only advantages, giving the operator the possibility of (a) choosing the most appropriate and safest venous access on the basis of ultrasound assessment, (b) performing a 100% safe insertion, (c) ruling out malpositions or pleuro-pulmonary damages, during and after the procedure. Ultrasound guided central venous cannulation has been described in many clinical studies of the last decade, each one showing the higher efficacy and safety of ultrasound guidance in children when compared to the traditional landmark method. Ultrasound can be used for puncturing many different deep veins of the arm, neck, groin and thorax. The vein can be visualized either in short axis or in long axis, while the puncture can be performed 'in-plane' (when the needle trajectory is included in the plane of the ultrasound probe) or 'out-of-plane' (when the needle trajectory is not in that plane). Though, the best clinical results of ultrasound guidance can be achieved - particularly in neonates and infants - only if the operator has been properly trained in this technique through an appropriate curriculum that should include theory lessons, simulation practice and a tutored learning curve.

Keywords: Central venous access, central venous catheters, PICC, ultrasound guidance, venipuncture.

CENTRAL VENOUS ACCESS IN NEONATES, INFANTS AND CHILDREN

Central venous access is often necessary in neonatal and pediatric patients in different settings (emergency room, intensive care units, oncology, pediatric surgery, gastroenterology, etc.) and for different purposes (hemodynamic monitoring, blood withdrawal, dialysis/apheresis procedures, antiblastic chemotherapy, parenteral nutrition, antibiotic drugs, etc.). Central lines are necessary not only to achieve a stable, reliable route of infusion, but also because there are drugs and solutions that require to be infused in a high-flow venous district. Current guidelines [1] recommend to use a central line for infusion of solutions with pH <5 or >9, osmolarity> 600 mOsm/L, as well as for drugs known to be vesicant or potentially associated with endothelial damage [2].

As in adult patients, also in neonates, infants and children a central venous line is defined as a venous catheter whose tip is positioned in proximity of the junction between superior vena cava and right atrium, i.e. in a safe area which include the lower third of the superior vena cava and the upper part of the right atrium [2]. When the catheter tip is located in the inferior vena cava, the line is not properly 'central', though it can be used as 'central' for several purposes (infusion of any type of drug and solution, dialysis, blood sampling etc.), but not for hemodynamic monitoring.

Thus, a central line is defined by the position of the catheter tip, and not by the site of entrance of the catheter into the venous system, which may occur through practically any accessible vein, such as a superficial vein of the scalp or of the limbs, or a deep vein of the arm, or a deep vein of the neck and the thorax, or even the umbilical vein.

Venous access techniques include the percutaneous cannulation of a visible, palpable superficial vein (with or without the aid of a near-infrared technology), or the percutaneous cannulation of a deep vein (located by a 'blind' landmark technique or by ultrasound guidance), or the surgical cutdown of a deep vein, or even the direct cannulation of a patent vein (the umbilical vein at birth).

Table **1** shows a simple classification of central lines in neonatal and pediatric patients, according to the route of access.

ULTRASOUND GUIDED CENTRAL VENOUS ACCESS

In the last century, most central venous catheters in neonates, infants and children were positioned either by the surgical cutdown technique or by the 'blind' percutaneous technique. Though, both techniques have serious limitations: surgical cutdown is time-consuming, vein-consuming, invasive and potentially associated with a high risk of hemorrhage, tissue damage and infection [2]. 'Blind' percutaneous venipuncture is less accurate in children and neonates than in adults (since the landmarks are less defined) and potentially associated with severe complications such as pneumothorax, haemothorax or haemo-mediastinum, secondary to accidental arterial and/or pleural puncture.This explains why the success rate of central access in neonates and children – if

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Table 1. Central Lines

• Umbelical catheters (Umbelical vein)*
• Epicutaneo-caval catheters (Superficial veins of limbs or scalp)*
• Central venous catheters: tunneled, non-tunnelled, ports (central veins of the neck and of the supra/infra-clavicular region)
• PICC, Peripherally Inserted Central Catheters (Deep veins of the arm)
• Inferior Vena Cava catheters (femoral and saphenous vein)

** = only in neonates.*

compared to adults - has always been considered to be lower and the complication rate higher.

This has radically changed in the last decade, after the introduction of ultrasound guided venipuncture in the clinical practice. Clinical experience with ultrasound in children and neonates started almost twenty years ago, somewhat later than in adults, but very quickly it was evident that real-time, ultrasound-guided venous access resulted in a lower technical failure rate (overall and on first attempt), faster access, and a reduction in mechanical complications.

The first experience with ultrasound consisted of the so-called 'ultrasound assistance', which means the ultrasound scan of the vein before the puncture, so to assess its position and patency, while the puncture itself is performed without using the probe. It was rapidly clear that 'ultrasound assistance' (or 'static' technique), though evidently more successful than 'blind' percutaneous venipuncture, was not so effective and safe as 'ultrasound guidance' (or 'dynamic' or 'real-time' technique), which consists in the visualization of the needle entering the vein.

In the last decade, several studies [3-9] and meta-analyses [10-12] have demonstrated the higher efficacy and safety of ultrasound guidance in children when compared to the traditional landmark method. US guidance should be the method of choice and not a second option or a rescue technique in difficult cases. Ultrasound should be used not only in short-term central venous access but also in long-term venous access, such as in the case of tunneled cuffed central catheters [13]. Quicker access time has been observed in several studies, and US guidance is also preferred to the 'blind' technique when the venous access has to be positioned in emergency [14]. Though, further studies are required to evaluate the impact of the use of US guidance when a vascular access is required in an emergency, when compared to the intra-osseous route.

Ultrasound guidance can be used for puncturing many different deep veins of the arm, neck, groin and thorax (see Table **2**). The vein can be visualized either in short axis (so called 'transversal' view) or in long axis ('longitudinal' view), depending on the position of the probe vs. the position of the vein. Regardless of the type of vein visualization, the puncture can be performed 'in-plane' (when the needle trajectory is included in the plane of the ultrasound probe) or 'out-of-plane' (when the needle trajectory is not in that plane).

'In-plane' venipuncture requires more skills but it is definitely safer than 'out-of-plane', since it allows a complete control of the trajectory of the needle, thus avoiding to miss the target or to hit a 'wrong' target (artery, pleura, etc.). In-plane puncture should be preferred when accessing veins of the neck and/or in the supra-clavicular area (internal and external jugular vein, brachio-cephalic vein, subclavian vein). Out-of-plane venipuncture carries the advantage of a 'panoramic view' of all structures (arteries, nerves, veins) and should be preferred when accessing veins at the groin (femoral, saphenous) or at the arm (basilic, brachial).

Table 2. Ultrasound-Guided Venipuncture

• At neck – Internal jugular vein (*out of plane*)
• In the supra-clavicular area – Internal and external jugular, subclavian, brachio-cephalic vein (*in plane*)
• In the infraclavicular area – Axillary, cephalic vein (*out of plane/in plane*)
• At mid-arm – Basilic vein, brachial veins (*out of plane*)
• At the groin – Femoral, saphenous vein (*out of plane*)

The first clinical experiences of ultrasound guided venipuncture in children and neonates were performed on the internal jugular vein, particularly with the 'out-of-plane' technique, with the vein visualized in short axis [15].

As regards neonates, most experts now suggest that ultrasound evaluation and at least static (skin marking) should be routinely performed before internal jugular vein puncture in neonates [16-18]. In these patients, ultrasound guided puncture is usually considered more difficult than in infants and children. Though the internal jugular vein is easily identify by ultrasound, it may be quite small and mobile in the tissues of the neck, so that both the in-plane and the out-of-plane technique require particular experience [19].

In infants and in children, internal jugular vein is easily visualized, usually in short axis, and it can be punctured both in-plane and out-of-plane. Ultrasound allows to evaluate the caliber of the internal jugular vein, its position, its size variations with breathing, and other features. The 'out-of-plane' puncture, the first and most traditional approach to the internal jugular vein, is less safe and less effective than in-plane puncture, for several reasons: (a) the needle often passes through the sterno-mastoid muscle, leaving a catheter located in a very unstable position, and mobile at any movement of the neck (excessive movement of the catheter at the exit site is notoriously associated with increased risk of thrombosis and infection); (b) since the trajectory of the needle is not under complete control, there is a relevant risk that the needle may pass the posterior wall of the internal jugular vein, hitting the subclavian artery which lies behind; (c) for non-tunnelled catheters positioned according to the 'out-of-plane' puncture of the internal jugular vein, the exit site of the catheter is located at mid-neck, i.e. in a position which is associated with difficult securement and uneasy management of the dressing.

On the other hand, 'in-plane' puncture of the internal jugular vein in short axis - i.e., an ultrasound guided Jernigan approach [2]- is associated with no risk of accidental arterial puncture, a high success rate and a relatively comfortable exit site located in the supra-clavicular area.

Since the first reports of ultrasound guided venipuncture of the internal jugular vein, many other 'central' veins have been accessed under ultrasound in pediatric patients [20, 21], such as the subclavian vein, the axillary vein, and – more recently – the brachio-cephalic vein.

US visualization of the subclavian vein and of the brachio-cephalic trunk is possible and relatively easy in all neonates, infants and children, by scanning the supra-clavicular region with the probe parallel to the clavicle and angled so to be almost in a frontal plane. The longitudinal view of these two veins allows a supra-clavicular, in-plane approach where needle tip and shaft can be clearly identified [22, 23]. Since the operator passes above the clavicle, the in-plane needle visualization is perfect and not interrupted by any bony structure. Usually, due to the probe orientation in the supra-clavicular fossa, only the distal end of the subclavian vein and the brachio-cephalic trunk are visualized. Both veins are quite large, stable and unaffected by breathing variations: though, the brachio-cephalic vein may be an easier target, since it is larger (as an average, diameter is at least 3-4 mm even in very small neonates) and it is associated with less risk of accidental puncture of the pleura (which lies laterally to the vein). In small children and neonates, special care should be given to the brachial plexus by visualizing it and avoiding to hit it when entering the medial tract of the subclavian vein. The exit site remains in the supra-clavicular area, which is preferable than the exit site at mid-neck, the latter being associated with poor comfort and high risk of contamination and infection.

An ultrasound-guided infra-clavicular approach to the subclavian vein has also been described [24]. The needle is inserted below the clavicle, as in the traditional 'blind' access to the subclavian vein, but the vein is visualized above the clavicle. This approach offers the advantage of an exit site in the infra-clavicular region (crucial for high comfort and low risk of contamination/infection), but it is not completely safe still implies a short tract of 'blind' progression of the needle, when its trajectory is hidden by the shadowing of the clavicle.

Other options are the axillary vein, the cephalic vein in its final tract, and the external jugular vein close to its confluence into the subclavian vein.

The axillary vein is easily visualized below the lateral third of the clavicle, and can be punctured with an out-of-plane technique in short axis or with an in-plane technique in long axis. It is usually quite small in neonates and in infants, and much more useful in children. Some infants may have a prominently large cephalic vein, which can be visualized and cannulated in its last tract, below the clavicle, soon before its confluence in the axillary vein.

It is important to stress that in neonates and in children, exactly as in adults, the subclavian vein can be visualized by ultrasound exclusively above the clavicle, while the axillary vein can be visualized by ultrasound exclusively below the clavicle. In fact, the transition between axillary vein and subclavian is located over the margin of the first rib, in an area hidden by the clavicle. Since this anatomic feature is often forgotten or dismissed as irrelevant, there have been some ambiguities in the less recent literature dealing with ultrasound approach to the subclavian vein; in some papers, the ultrasound guided infra-clavicular puncture of the axillary vein has been wrongly considered to be an ultrasound guided puncture of the 'subclavian vein'.

In neonates and infants, the deep tract of the external jugular vein can be quite large- even larger than the subclavian vein and safer to puncture, since the external jugular vein has no direct contact with the pleura. The external jugular vein can be visualized in long axis, while the probe is above the clavicle, as a vein located behind, above and parallel to the subclavian vein; it can be easily punctured by the in-plane technique, with a resulting exit site in the supra-clavicular area.

As mentioned above, an exit site of the catheter in the infra-clavicular area (US approach to the axillary vein or cephalic vein) is better, in terms of securement and dressing as well as in terms of comfort and infection rate, than an exit site in the supra-clavicular area (US in-plane approach to the subclavian vein, external jugular vein, internal jugular vein and brachio-cephalic vein) and far better than an exit site at mid-neck (out of plane approach to the internal jugular vein). Though, in neonates, it may be easy to move the exit site in the infra-clavicular area, far from the puncture site, by means of a short tunneling. Such maneuver – relatively easy and fast – may allow to couple the advantage of choosing a large vein, accessed by a safe US guided puncture, with the advantage of an exit site in ideal location.

Ultrasound can be used also to access the femoral vein and the saphenous vein, positioning catheters whose tip is located in the inferior vena cava. Though such lines are not properly 'central' and cannot be used for hemodynamic monitoring (central venous pressure, oxygen saturation of venous mixed blood, etc.) still they can be a safe option in patients with inadequate veins in the supra/infra-clavicular area.

The US-guidance is particularly recommended for femoral venipuncture because it significantly reduces complications secondary to accidental arterial puncture [17, 25-27]. US visualization of the femoral vein is sometimes difficult in neonates and infants. The inguinal region is far less echogenic than the neck region. Doppler and zoom functions may be helpful. The puncture of the femoral vein should be ideally performed close to the inguinal ligament at the level of the common femoral artery. Sharp needles should be used to reduce the incidence of vein transfixion, an event that remains high in neonates. Low abdominal compression can be used to facilitate vein puncture by increasing the femoral vein diameter. If no increase in diameter occurs, iliac vein thrombosis should be suspected.

Care should be used (a) in positioning the tip of the catheter inside the inferior vena cava above the iliac junction and below the renal veins (catheters whose tip is in the iliac veins or close to the hepatic veins are associated with a high risk of thrombosis and/or malfunction); (b) in protecting the exit site at the groin from urine/fecal contamination (this can be achieved by several methods: proper planning of the exit site, tunneling of the catheter upward or downward, and/or use of semipermeable transparent dressing over the exit site).

Peripherally inserted central catheters (PICCs) should also be positioned by ultrasound guidance, by accessing the basilic vein or the brachial veins at mid-arm; such technique can be used only in children with arm veins of appropriate size (diameter 3 mm or more).Ultrasound guided central catheters inserted in the deep vein of the arm (typically, only in children; catheter diameter 3 Fr or more) should not be confused with the 'epicutaneous-caval' catheters inserted in superficial veins of the limbs or of the scalp (exclusively in neonates; diameter 1-3 Fr), whose positioning does not require ultrasound guidance but may benefit of other technologies (such as near-infrared technology, NIR). A reasonable, shared definition of 'superficial' vein includes all veins within 5-7 mm from the skin surface; 'deep' veins are 5-7 mm or more from the skin surface. Visualization by NIR technology appears to be effective only for superficial veins; on the contrary, ultrasound visualization of superficial veins may be difficult since the veins may be compressed by the probe itself. Deep veins can be effectively visualized and cannulated only by ultrasound.

OTHER ADVANTAGES OF ULTRASOUND

Pre-Puncture US Evaluation

In neonates and in children, as well as in adults, much of the benefit of ultrasound during central venous cannulation comes out not only from the act of US-guided puncture, but particularly from the pre-procedural ultrasound evaluation of all the possible venous options. This evaluation may bring a rationale choice of the most appropriate vein to cannulate, considering such factors as vein size, possible pathological abnormalities, and collapse during breathing. Of particular importance is the size of the vein: as for adults, in order to avoid the risk of venous thrombosis, the external diameter of the catheter should not exceed 1/3 of the internal diameter of the vein. Measurement of the size of the vessel is required in order to avoid the insertion of large bore catheters that could impair the flow of the vessel and to avoid the insertion of a J-wire guide that could be larger than the cross-sectional diameter of the vessel [28]. Also, vascular anatomy is different between patients [29-31] and the position of a vessel could be altered: for these reasons it is important to determine the ideal vessel to puncture as well as the ideal site where the vessel could be punctured with the lowest risk for that patient.Recently, different protocols have been proposed for a rationale evaluation of central veins, such as the RaCeVA (Rapid Central Vein Assessment: see below).

US Detection of Malposition

Ultrasound is also useful after the venipuncture, for a real-time assessment of the direction of the guidewire and/or of the catheter itself. For example, after any venipuncture in the infra-clavicular area, the US examination can rule out the presence of the guidewire in the internal jugular vein and confirm its direction towards the brachio-cephalic trunk. In neonates, the guidewire can be easily tracked by ultrasound down to the superior vena cava, so to rule out the possible malposition in the contra-lateral brachio-cephalic vein. In children, when positioning a PICC, the US examination can rule out the accidental entrance of the catheter in the internal jugular vein: a compression of the probe over the internal jugular vein, so to collapse it, may actually facilitate the correct positioning of the catheter into the brachio-cephalic vein and into superior vena cava.

US Detection of Pneumothorax

By using the same linear probe utilized for venipuncture, it is possible to detect the presence/absence of pneumothorax, by positioning the probe in the parasternal region, transversal to the ribs, and observing the so-called 'sliding sign'. The 'sliding sign' indicates the movement of the visceral pleura below the parietal pleura and rule out the presence of air in the intra-pleural space, with an accuracy superior to the standard chest x-ray.

Echocardiographic Verification of Tip Position

When the tip of the catheter has been positioned at the cavo-atrial junction or in the right atrium, it can be easily seen by echocardiography. A tip positioned in the lower part of the superior vena cava can also be seen by echocardiography in selected cases, specially if infusing an echogenic contrast medium (such as colloid solution, or a mixed air/saline solution) into the catheter and detecting the so-called 'cloud bursting' effect in the right atrium.

TECHNIQUE OF ULTRASOUND VENIPUNCTURE

In neonates and infants, ultrasound-guided central venous catheterization is often difficult even for skilled physicians, particularly when the vein is small and/or collapsed or when the guidewire is J-shaped or too thick [28]. Trendelenburg's position may help in some hypovolemic patients by increasing the diameter of the vein, but it appears to be effective only for internal jugular or axillary venipuncture, and not consistently. A 21G echogenic needle should be ideally used. Also, in order to avoid any difficulty in the progression of the guidewire, it is highly recommended to adopt a soft straight tip, non-J, nitinol guidewire, size 0.018". It is often desirable to use a micro-introducer kit and position the catheter by the modified Seldinger method. The introducer-dilator should consist of a dilator at least of the same diameter of the catheter and by an introducer at least half French larger. The ultrasound probe should be a linear one. Frequency between

7 and 10 mHz are appropriate for children, while maneuvers in neonates and infants are preferably performed with 10-14 mHz probes.

The following is the step-by-step description of the technique of central venous cannulation in an infant admitted to a pediatric intensive care unit.

The procedure starts with a US evaluation of all central veins available. According to the RaCeVA protocol, the scan is performed methodically, with the child in supine position, with the head slightly in extension and turned to the opposite site Fig. (**1**), starting with the visualization of the internal jugular in short axis at mid-neck Fig. (**2**, left) and at the basis of the neck Fig. (**2**, right): it is evident the close proximity between the internal jugular vein and the underlying subclavian artery, in long axis. Just above the clavicle, with the probe angled so to be in an almost frontal plane exploring the anterior mediastinum, it is possible to evaluate the brachiocephalic vein in long axis Fig. (**3**, left), and more laterally the transition between the subclavian vein and the brachiocephalic vein, both in long axis Fig. (**3**, right); moving the probe even more laterally behind the clavicle, the external jugular vein becomes evident, in long axis, parallel to the subclavian vein and as much as large in diameter Fig. (**4**, left). Below the clavicle, the axillary vein (in short axis: Fig. (**4**), right) appears to be quite small.

After such evaluation, the vein most likely to be associated with an easy and safe venipuncture is the brachiocephalic vein, by the in-plane technique. Since the diameter of the vein is wider than 4 mm (= 12Fr), a 4Fr catheter can be safely inserted in it.

The operative field is delimited and after proper skin antisepsis the sterile drapes are positioned. The probe is covered with a long sterile sleeve and the vein is visualized again in long axis and punctured by the in-plane technique Fig. (**5**, left). The echogenic needle is easily visualized inside the vein Fig. (**5**, right). The guidewire is threaded into the needle, for a few centimeters, so not to get too deep inside the atrium, where it may cause arrhythmias; for a better control of the length of the guide wire, a marked guidewire is preferable. The ultrasound is used again to visualize the guidewire, after the removal of the needle Fig. (**6**, left). The introducer-dilator is inserted over the guidewire Fig. (**6**, right), and its intravascular position is checked by ultrasound Fig. (**7**, left).

The catheter is inserted at an entry site conveniently located below the clavicle, and then tunneled to the puncture site Fig. (**7**, right). After being trimmed at the desired length (as estimated by landmark measurements), the catheter is inserted into the introducer Fig. (**8**, left). The final position of the tip can be verified during the maneuver by several methods (by fluoroscopy, or by intracavitary EKG, or by echocardiography) [2]. The catheter is secured with a sutureless device. The small incisions at the puncture site and at the entry site are sealed with glue Fig. (**8**, right). The whole area is protected with a semipermeable transparent dressing.

FINAL CONSIDERATIONS

Much evidence as well as common sense show that ultrasound has a major role in central venous access of neonates, infants and children.

Though, in spite of such evidence, ultrasound-guided central cannulation is not yet widely adopted in neonatal and pediatric units, for several reasons: (a) puncture and cannulation of central veins in neonates and children obviously requires more training and a longer learning curve than in adults; (b) clinicians dealing with pediatric patients tend to be quite conservative and suspicious of new techniques; (c) there is an overall lack of a sufficient number of prospective randomized clinical trials in neonates and children.

Fig. (1). US evaluation of all central veins available. According to the RaCeVA protocol, the scan is performed methodically, with the child in supine position, with the head slightly in extension and turned to the opposite site.

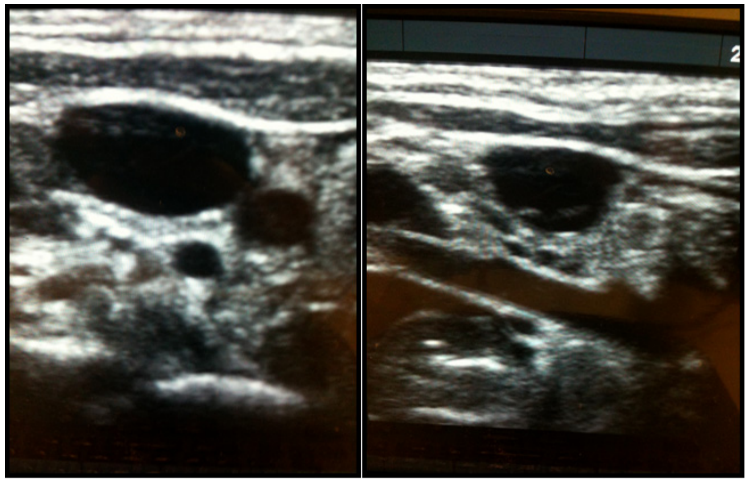

Fig. (2). Visualization of the internal jugular in short axis at mid-neck (left) and at the basis of the neck (right).

Fig. (3). Just above the clavicle, with the probe angled so to be in an almost frontal plane exploring the anterior mediastinum, it is possible to evaluate the brachio-cephalic vein in long axis (left), and more laterally the transition between the subclavian vein and the brachio-cephalic vein, both in long axis (right).

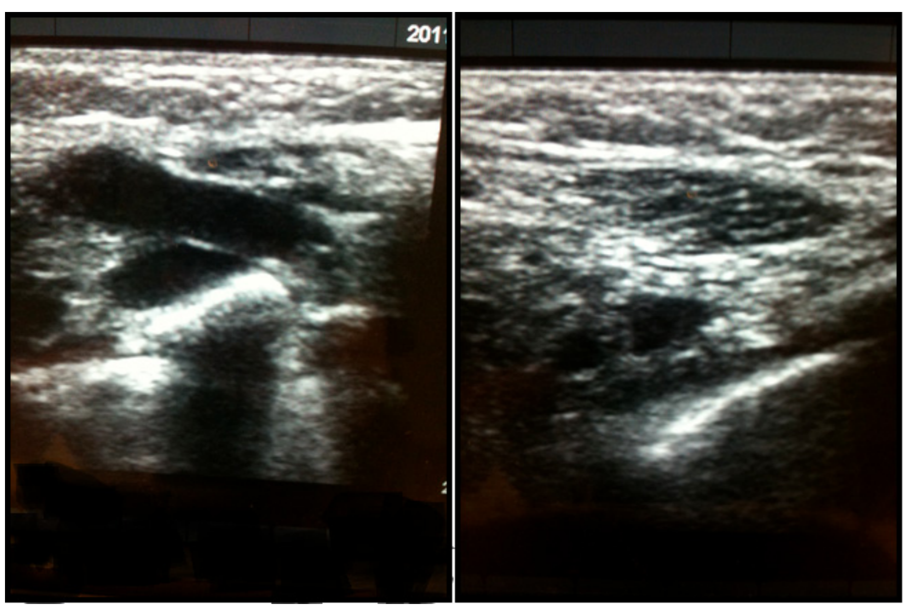

Fig. (4). Moving the probe even more laterally behind the clavicle, the external jugular vein becomes evident, in long axis, parallel to the subclavian vein and as much as large in diameter (left). Below the clavicle, the axillary vein (right) appears to be quite small.

Fig. (5). US-guided venipuncture of the brachio-cephalic vein, by the in-plane technique. The operative field is delimited and after proper skin antisepsis the sterile drapes are positioned (left). The echogenic needle is easily visualized inside the vein (right).

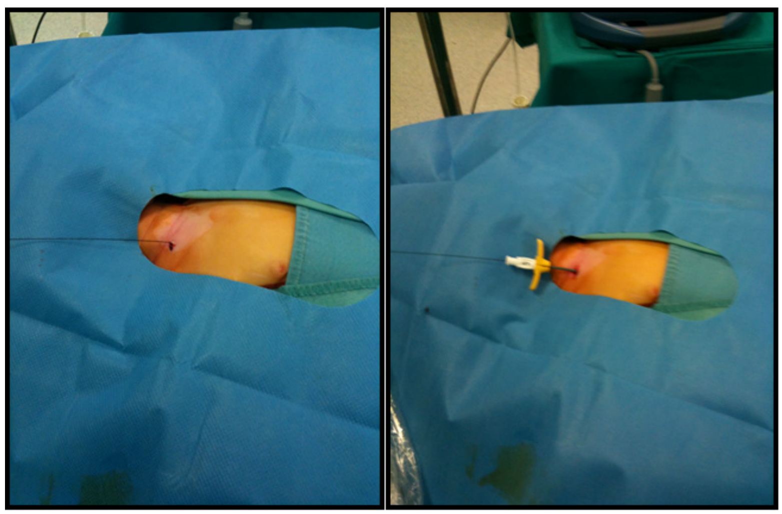

Fig. (6). The introducer-dilator is inserted over the guidewire.

Fig. (7). The intravascular position of the introducer-dilator is checked by ultrasound (left) and the catheter is inserted and then tunneled to the puncture site (right).

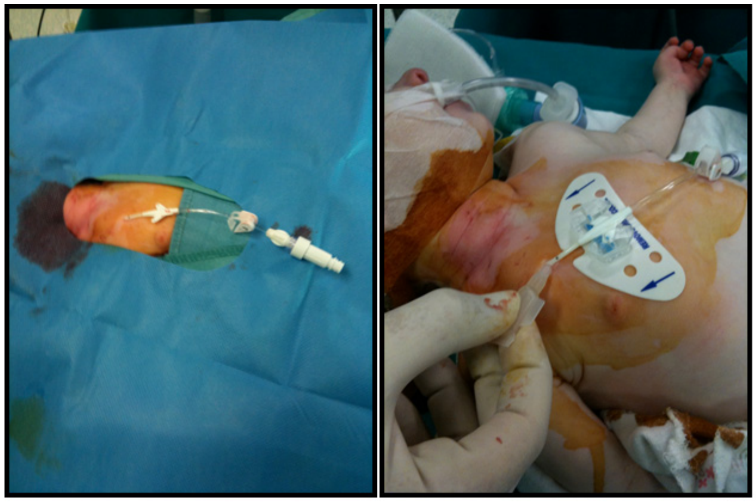

Fig. (8). After being trimmed at the desired length, the catheter is inserted into the introducer (left). The small incisions at the puncture site and at the entry site are sealed with glue (right).

Little can be done to change the clinicians' aptitude; also, there are objective difficulties in producing prospective, controlled randomized studies in this kind of patients. On the other hand, operator training certainly plays a major role and something can be done to improve the quality of training and the confidence of the operator [32]. There are a few studies in the literature [33] that failed to show a significant advantage of ultrasound guidance if compared to the 'blind' technique: it is quite likely that such trials were biased by the poor training of the operator in mastering the ultrasound technique [34]. Studies demonstrating the advantages of ultrasound guidance were carried out mostly by young operators who were specifically trained and dedicated to the use of ultrasound, whereas studies reporting negative outcomes were usually performed by older operators with little experience with ultrasound. The use of the ultrasound probe in a very limited space such as the neck of a neonate, the weight of the ultrasound probe itself, the easy compressibility of the veins etc. are all elements which make the procedure quite difficult in not properly trained hands. Proper ultrasound training (which should include theoretical lessons, practice on simulators, and an appropriate tutored learning curve) is essential before using this technique in infants and children.

CONFLICT OF INTEREST

Declared none.

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Declared none.

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