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Global use of ultrasound in newborn vascular access: RA. CE. VA: implantation and management of complications

Ferdinando Spagnuolo[1]

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Abstract
The use of ultrasound is advantageous in many respects: pre-procedural vein selection, real-time venipuncture, tip navigation (to verify guidewire or catheter progression) and post-procedural tip location, detection of early (hematoma, pneumothorax, hemothorax) and late complications (cardiac tamponade, fibroblastic sleeve, thrombosis).Such assessment is best performed using a systematic and standardized approach, as the Rapid Central Vein Assessment, described in this study for neonates too.

Abbreviations

CVC	Central venous catheter
Ra.Ce.VA	Rapid central vein assessment
Ra.Pe.VA	Rapid peripheral vein assessment
CICC	Centrally inserted central catheter
FICC	Femoral inserted central catheter
CAJ	Cavoatrial junction
IJV	Internal jugular vein
ICA	Internal carotid artery
TTE	Transthoracic echocardiography
CEUS	Contrast-enhanced ultrasound
PNX	Pneumothorax
CVADs	Central venous access devices, NICU neonatal intensive care unit

Introduction

According to the most recent Wo.Co.VA (World Congress on Vascular Access) classification, a central venous catheter (C.V.C.) is defined as a vascular device made of silicone or polyurethane, whose tip is placed in the region of the cavo-atrial junction. More precisely, depending on the insertion site, CICCs are defined as all central catheters with entry at the level of the deep veins of the supraclavicular and sub-clavicular area, PICCs as those with brachial insertion and FICCs as those with femoral insertion. The use of a CVC allows intermittent or continuous infusion, in critical and/or emergency situations, of hyperosmolar and vesicant, acid or alkaline solutions and drugs, blood products and contrast medium. Catheter diameter dimensions are expressed in French or Gauge. The French expresses the outer diameter (1 French = 0.3 mm) and the Gauge (G) the inner diameter of the lumen. In clinical practice, CVCs whose diameter ranges from 2.7 to 9 F single- or multi-lumen are predominantly used.

Authoritative guidelines [1, 2] state the need to use echo-guided venipuncture in all central venous catheter placements, both in adults and children, in order to optimize the success of the maneuver, reduce the number of punctures and minimize the risk of insertion-related complications.

The use of ultrasound is advantageous in many respects: pre-procedural vein selection, real-time venipuncture, tip navigation (to verify guidewire or catheter progression) and post-procedural tip location, detection of early (hematoma, pneumothorax, hemothorax) and late complications (cardiac tamponade, fibroblastic sleeve, thrombosis).

Using ultrasound for vessel selection

The rational choice of the optimal vein to be cannulated is decisive. According to most authors, deep veins are preferably visualized with Small sectorial probe, 7–8 MHz, Linear “hockey stick” probe 10–14 MHz, Micro-convex probes, 7–8.5 MHz. and suitable for visualizing tissue up to a depth of 3–5 cm. Using B-mode visualization, the image plane can be oriented along the vessel's 'short axis' or along the ‘long axis’ (Fig. 1). Vein and artery have a similar ultrasound appearance, with an anechoic lumen. Arteries have thicker and more hyperechogenic walls than

✉ Ferdinando Spagnuolo
ferdinando.spagnuolo@policliniconapoli.it

[1] Neonatal Intensive Care Unit, A.O.U. Università degli Studi della Campania “Luigi Vanvitelli”, Naples, Italy

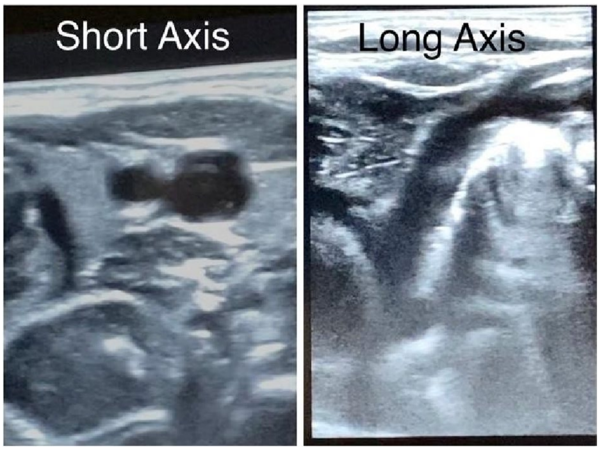

Fig. 1 Using a B-mode display, the image plane can be oriented along the short axis of the vessel “short axis” or along the long axis “long axis”

venous ones and are less compressible. Generally, the ability to compress the vessel with minimal pressure is used to distinguish vein from artery. In doubtful cases, arterial pulsation can be detected for a few seconds in short axis. Color Doppler flow identification can also assist in differentiation. The Doppler scale should be low enough and the color gain increased to detect even flow that is initially not visible. If the patient has normal cardiac contractility, flow in the artery is rhythmically pulsatile, whereas in the venous system it is generally slower non-pulsatile, continuous.

The color of the Doppler only indicates the direction of flow relative to the probe. A non- compressible lumen indicates thrombosis of the vessel.

There is no ideal site for the placement of central venous catheters, but it must be established based on the integration of the preliminary ultrasound examination, the required performance of the catheter and the patient's clinic. The GAVeCeLT group (Italian Group for Venous Access Devices) has developed evaluation protocols for the systematic ultrasound assessment of deep vessels and adnexal structures pre-implantation, including RaCeVa (Rapid Assesment of the Central Veins) and RaPeVa (Rapid Assesment of the Peripheral Veins) [3].The advantages of a pre-implantation ultrasound examination are intuitive, allowing static and dynamic evaluations to be carried out and identifying anatomical variations, the caliber and depth of the vessel, the patency of the entire course and attached structures (nerves, etc.). Anatomical variants of the internal jugular vein (IJV) have been extensively described, showing that it is located anterolateral to the carotid artery in 92%, > 1 cm lateral to the carotid artery in 1%, medially in 2%, and outside the pathway predicted by landmarks in 5.5% of patients [4] (Fig. 2).

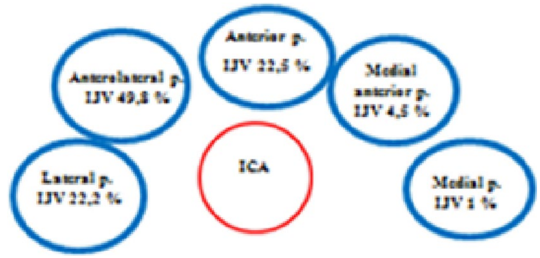

Fig. 2 Anatomical variants of the internal jugular vein (IJV)

The measurement of the vessel diameter can be in transverse or sagittal section and is a determining factor to established the caliber of the catheter to be implanted. Veins whose diameter, assessed without a tourniquet, is at least three times the diameter of the catheter (i.e.: whose diameter in millimeters is equal to or greater than the diameter of the catheter in French) are preferable so as to reduce the risk of CVC-related peripheral venous thrombosis [5].

The RaCeVa is the ultrasound examination of the deep vessels of the supra-subclavicular region, it is performed in 7 steps and carried out on both sides of the patient, it takes only a few minutes to execute, if performed by an experienced operator.

Optimization of the image is a crucial aspect in achieving a clear view of all anatomical structures [6].

Step 1 is performed with the probe in a transverse position from the central anterior region of the neck, perpendicular to the skin, near the cricoid cartilage (the left side of the probe must correspond to the left side of the monitor and the right side of the patient) (Fig. 3) by exploring the internal jugular vein (IJV) and the carotid artery in short axis, assessing its diameter, compressibility and shape (Fig. 4). It is also possible to determine the optimal “gain” value by defining the reference “black” (the anechoic blood within the IJV), “grey” (thyroid parenchyma) and “white” (hyperechogenic posterior wall of the carotid artery). Moving down, still in a transverse position, towards the base of the neck in the suprasternal area (Fig. 5), we move on to step 2 and visualize the lower tract of the IJV and the carotid artery. Posterior to the internal jugular, the subclavian artery in long axis is evident (Fig. 6). The probe tilts from the perpendicular plane to the frontal plane, parallel to the clavicle and lateral to the sternal incisura, in order to move to step 3 and identify the structures of the anterosuperior mediastinum (Fig. 7). In this way, it is possible to follow the course of the IJV as it runs above the subclavian artery and joins the subclavian vein forming the brachiocephalic trunk. This is the ideal position for visualization and puncture of the anonymous vein in long axis, as the mediastinal pleura (hyperechogenic line lateral and parallel to the vessel) is also clearly evident (Fig. 8). Bringing the probe to a frontal plane in the supraclavicular

STEP 1

Fig. 3 The probe in a transverse position from the central anterior region of the neck perpendicular to the skin near the cricoid cartilage (the left side of the probe must correspond to the left of the monitor and the right side of the patient)

STEP 2 Descending, still in transverse position, towards the base of the neck in the suprasternal area

Fig. 4 short-axis exploration of the internal jugular vein (IJV) and carotid artery by assessing diameter, compressibility and shape

area (Fig. 9), in step 4, visualizes the subclavian v. and external jugular in long axis [7]. The external jugular vein appears as a minor vessel that runs parallel posteriorly and above the subclavian vein and merges medially with the brachiocephalic trunk or subclavian vein itself.

This is the ideal position for the echo-guided puncture of the subclavian v. or external jugular v. in long axis (Fig. 10). The probe is then positioned perpendicular to the pectoral groove in short axis under the clavicle (lateral to the third of the clavicle) (Fig. 11). Three vessels are evident: the axillary artery and the axillary vein (medial to the artery) in short axis and the cephalic vein in long axis (small vessel running over the artery and flowing into the axillary vein) (Fig. 12).

This is position 5, which is ideal for puncturing the axillary vein, avoiding the risk of arterial puncture but bearing in mind the possibility of pleural injury if the needle goes beyond the posterior wall of the vein. In step 6, the probe is slowly rotated to get a longitudinal view of the vessels, so that it is longitudinal and perpendicular to the chest wall more or less parallel to the pectoral sulcus, under the clavicle (Fig. 13) and explore the axillary vein, axillary artery and cephalic vein in long axis (Fig. 14). It is possible to puncture the axillary vein without risking injury to the pleura. Finally, in the last step 7, the probe at the third intercostal space on the hemiclavicular bilaterally examines the pleura in the pre-implantation phase to ensure its integrity. The parietal-visceral interface is explored in both B-mode (2D) and M-mode (one-dimensional) to highlight lung sliding (Fig. 15) and the sandy beach appearance.

The RaCeVa is a valuable aid in the pre- implantation decision-making phase of a CICC. In pediatric patients and neonates, the choice of the brachiocephalic vein is increasingly in use, as it presents adequate size and favorable characteristics in its in-plane approach.

In a recent study [8] conducted with ultrasound evaluation of the deep veins of 100 infants with an average EG of 32 ws and an average weight of 1690 g, the anonymous vein always showed a greater caliber of 3 mm on both the right and left, in contrast to the often much smaller femoral vein.

Given that the internal jugular and subclavian v. are generally smaller than the brachiocephalic trunk in any newborn, it is deductive which is the preferred choice for a catheter of at least 3 Fr in caliber.

For this reason, we will not discuss RaPeVa in this article, which is dedicated exclusively to the newborn child.

We will just mention that RaPeVa is the systematic ultrasound examination of the deep veins of the arm aimed at choosing the ideal vessel for implanting a PICC. The deep veins (more than 8 mm from the skin plane) most

STEP 3 The probe tilts from the perpendicular plane to the frontal plane, parallel to the clavicle and lateral to the sternal incisura

Fig. 5 The lower part of the IJV and the carotid artery are visualized

Fig. 6 Posterior to the internal jugular is evident the subclavian artery in long axis

appropriate for ultrasound guided PICC placement are all located at the level of the arm, and are the following (in order of preference):

Fig. 7 It is possible to follow the course of the IJV as it runs above the subclavian artery and joins the subclavian vein forming the brachiocephalic trunk

(a) The basilic vein in its course in the bicipito-humeral fossa (b) the brachial veins within the nerve-vascular bundle of the arm, and (c) the cephalic vein (limited to obese patients) [9, 10].

Principles of ultrasound-guided venipuncture

The technique of finding a central venous access includes percutaneous cannulation of a visible and palpable superficial vein, percutaneous cannulation of a deep vein (using a blind technique and landmark or ultrasound) and surgical venolysis of deep vessels [11]. The use of surface anatomical findings is based on the presumed location of the vessels and blind puncture with needle insertion until blood is drawn into the syringe. The catheter is then inserted on a metal guide using a Seldinger technique. The placement of a CVC, despite being performed by experienced operators, is associated with 60–95% complications (depending on the entry site and type of patient) when performed using a blind technique. The incidence of mechanical complications increases sixfold if more than 3 venipuncture attempts are made by the same operator.

The use of ultrasound during the procedure significantly improves the success rate on the first attempt and reduces complications.

Practical recommendations for the use of ultrasound during venous cannulation are reiterated by guidelines, associations, important consensus and government agencies such as the National Institute for Health and Clinical Excellence and the Agency for Healthcare Research and Quality's evidence report [12, 13]. Ultrasound is used to visualize vessels and attached structures in two- dimensional (2D), sometimes with the aid of color Doppler.

STEP 4 Bringing the probe to a frontal plane in the supraclavicular area

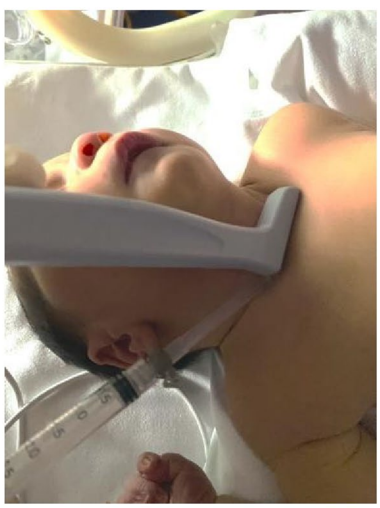

Fig. 8 This is the ideal position for the visualization and puncture of the anonymous vein in long axis, since the mediastinal pleura (hyperechogenic line lateral and parallel to the vessel) is also clearly evident

The operator must acquire knowledge of probe orientation, display image, ultrasound physics, and mechanisms of image generation and artefacts, and be able to interpret two-dimensional images of the vessel lumen and surrounding structures. The venipuncture technique requires the acquisition of two skills in particular: hand–eye coordination and handling of the needle according to the image on the monitor.

The additional use of color Doppler to confirm the presence and direction of flow, requires additional skills. These skills cannot do without manual dexterity to perform the three-dimensional procedure of CVC placement in the vessel lumen while using and interpreting 2D images [14].

Fig. 9 The subclavian v. and external jugular in long axis are displayed

Fig. 10 This is the ideal position for ultrasound-guided puncture of the subclavian v. or external jugular vein in long axis

The vein can be visualized in either short axis (transverse visualization) or long axis (longitudinal visualization) depending on the position of the probe in relation to the vessel. Instead, the puncture can be performed in plane (when the needle trajectory is visible in the plane of the probe), or out of plane (when the trajectory is not in that plane) (Fig. 16).

La venipuncture in plane requires more expertise, but is certainly safer because the needle trajectory is completely under control, avoiding accidental puncture of arteries or pleura. In-plane puncture is preferable when approaching veins of the neck or supraclavicular region (internal and external jugular, anonymous vein, subclavian vein), while the out-of-plane puncture is advantageous for the overall view (arteries, veins, nerves) that is obtained when

STEP 5

Fig. 11 The probe is then placed perpendicular to the pectoral sulcus in short axis under the clavicle (lateral to the third of the clavicle)

STEP 6

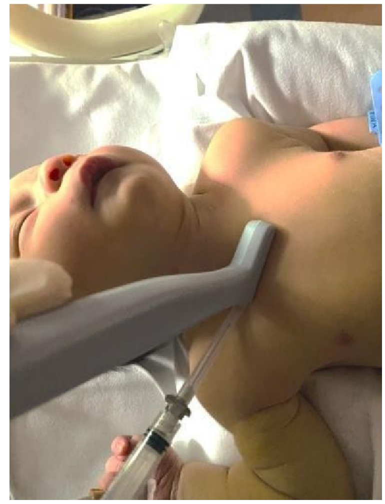

Fig. 13 The probe is slowly rotated to get a longitudinal view of the vessels, so that it is longitudinal and perpendicular to the chest wall more or less parallel to the pectoral groove, below the clavicle

Fig. 12 Three vessels are evident: the axillary artery and the axillary vein (medial to the artery) in short axis and the cephalic vein in long axis (small vessel running on the artery and flowing into the axillary vein)

Fig. 14 The axillary vein, axillary artery and cephalic vein in long axis

puncturing veins of the arm (basilica, brachial) and leg (femoral).

Ultrasound is most effective when used in real time (during needle progression) with sterile technique (sterile gel and probe covers). The needle is highlighted on the screen and simultaneously directed towards the target vessel away from the surrounding structures with an appropriate pathway [15].

The static technique, on the other hand, uses ultrasound to identify the needle entry site in the skin above the vessel of interest and does not require a sterile procedure, performing only a localization of the vein. Both techniques are however superior to the traditional blind approach with simple landmarks.

A single operator can perform real-time ultrasound-guided cannulation. The non-dominant hand holds the probe while the dominant hand handles the needle. The success of the procedure is confirmed by the direct view of the needle entering the vessel and the aspiration of blood into the syringe. The probe is placed on the sterile field and the

STEP 7

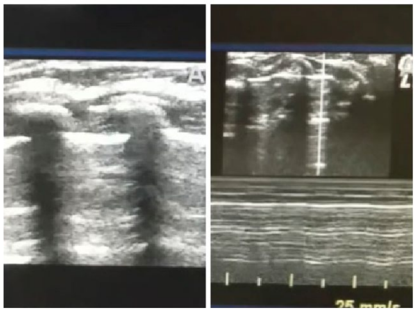

Fig. 15 The parietal-visceral interface is explored in both B-mode (2D) and M-mode (one-dimensional) to highlight lung sliding (and sandy beach appearance

Fig. 16 Instead, the puncture can be performed in plane (when the needle's trajectory is visible in the plane of the probe) or out of plane (when the trajectory is not in that plane)

metal guide on which the catheter or micro-introducer will be inserted, is introduced.

Tip navigation and tip location

Ultrasound should be used to verify the progression of the metal guide and catheter (tip navigation) in the target vessel, to verify its absence in the surrounding structures and to ascertain the central position of the tip (tip location) [16, 17]. The same linear probe that was used to perform the venipuncture, positioned in the supraclavicular, is able to visualize the confluence of the internal jugular, subclavian and anterior jugular, and a microconvex probe, positioned in the right supraclavicular fossa, is able to verify the passage of the catheter up to the superior cava [9]. It is crucial to establish the correct tip location of the catheter in order to avoid complications from misplacement.

The catheter tip must be located near the cavoatrial junction in a safe area. This includes the lower third of the superior cava and the upper portion of the right atrium.

Transthoracic echocardiography (TTE) can be a valuable tool to obtain direct visualization of the tip in the atrium or indirect visualization at the cavoatrial junction with the aid of a convex or microconvex probe and possibly injection of

Fig. 17 The subcostal projection allows good visualization of the inferior vena cava and the terminal portion of the superior vena cava

Fig. 18 The apical 4-chamber allows better identification of the right atrium

ultrasound contrast medium (CEUS) (physiological mixed with air bubbles).

TTE is very difficult, in obese patients, after open abdominal surgery or in cases where the stomach and colon are hyperdistended by gas and requires quite complex training to achieve a high success rate. In pediatric patients and newborn babies, it certainly plays a more decisive role because the anatomical difficulties are less, even though the small caliber of the catheter poses objective limits [18].

The subcostal projection allows a good visualization of the inferior vena cava and the terminal portion of the superior vena cava (Fig. 17), the apical 4-chamber allows a better visualization of the right atrium (Fig. 18), the high parasternal offers a good image of the superior vena cava and its outlet in the right atrium (Fig. 19).

The catheter tip appears as a hyper-echogenic structure with striation artefact with a double-track image.

Fig. 19 The high parasternal offers a good image of the superior vena cava and its outlet in the right atrium

Fig. 20 Microconvex probe in the right supraclavicular location to visualize the passage of the catheter in the superior vena cava in longitudinal view, allowing simultaneous tip navigation and tip location

Using a standard sub-xiphoid projection, showing the superior v. cava, right atrium, right ventricle and tricuspid valve along the same axis, a saline flush can be performed by shaking 5–10 mL of sterile saline and injecting it through the catheter hub, during ultrasound visualization. The shaken saline acts as a contrast and its appearance in the right atrium within 2 s confirms the presence of the catheter tip in the target zone [19].

Recently, Kim et al. proposed the use of the microconvex probe in the right supraclavicular location to visualize the passage of the catheter into the superior vena cava in longitudinal view, allowing simultaneous tip navigation and tip location [20, 21] (Fig. 20) (Fig. 21).

Use of ultrasound in the diagnosis of complications

Ultrasound-guided vein puncture and the use of micro-introduction kits drastically reduce the risk of accidental puncture of the arterial vessels or pleura and hematoma which represent the main and most dreaded early complications. The correct choice of the external diameter of the catheter with respect to the ultrasound-measured diameter of the vein (one third of the diameter of the vein) avoids the risk of late thrombosis. The correct TIP location at the CAJ avoids the risk of cardiac tamponade. Complications associated with CVC placement are largely diagnosable by ultrasound; they may be immediate (hematoma; PNX; hemothorax), related to venipuncture, and late (thrombosis, cardiac tamponade). Ultrasounds of the lungs allows post- procedural control to exclude pleuropulmonary complications. The ultrasound diagnosis of pneumothorax is easy in presence of lung point, in absence of pleural sliding, of B-lines and lunge pulse. Typically, in the adult, the examination is performed in the supine position with a microconvex probe and sometimes linear (in the neonate) or convex depending on the operator's preference.

The probe is positioned longitudinally in the third-fourth intercostal space between the parasternal and the haemiclavicular line perpendicular to or more consecutive ribs [22, 23].

The presence of fluid between the two pleural leaflets can also be easily excluded by ultrasound. The effusion presents as an anechoic fluid mass and in cases of complicated pleural effusions there may be multiple internal echoes. Ultrasound can also determine whether the type of effusion is free, saccate or corpuscular.

Fig. 21 Microconvex probe in the right supraclavicular location to visualize the passage of the catheter in the superior vena cava in longitudinal view, allowing simultaneous tip navigation and tip location

By means of ultrasound, it is possible to identify several findings that may lead to the identification of cardiac tamponade: pericardial effusion, collapse of the right atrium, diastolic collapse of the right ventricle, respiratory changes in mitral and tricuspid valve flow velocities. Cardiac tamponade may be early (procedure-related with bleeding in the pericardial cavity) or late (related to long catheter wall damage).

Conclusions

The systematic ultrasound assessment of deep vessels and adnexal structures pre-implantation, including RaCeVa (Rapid Assesment of the Central Veins) and RaPeVa (Rapid Assesment of the Peripheral Veins) is strongly based on evidence from many published clinical studies. The global use of Ultrasound will have an increasingly important role for CVAD in NICU, considering its many advantages in terms of accuracy, cost-effectiveness and safety.

Some of these ultrasound projections are easy and require only a minimal training, while some others imply a welltrained operator with more than basic knowledge in the field of vascular ultrasound and echocardiography. The literature discusses how the most appropriate training should be structured to acquire the necessary skills of real-time ultrasound for CVAD insertion in newborns.

Current evidence and common sense suggest the new emerging reality is the integrated clinical use of ultrasound in central vascular access placement. It is plausible to hope for a comprehensive 7-step approach that minimizes the risk of the venipuncture procedure while also allowing early detection of complications.

1. Identification of the anatomy of the entry site and location of the vein;
2. Examination of vessel patency;
3. Vein puncture with real time ultrasound technique;
4. Confirmation of needle position in the vein;
5. Tip navigation;
6. Tip location;
7. Ultrasonographic diagnosis of possible complications.

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Declarations

Conflict of interest The author have no relevant financial or non-financial interests to disclose.

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