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Ultrasound-guided vascular access in adults and children : beyond the Internal Jugular Vein puncture

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Abstract : Based on our clinical experience and a review of the current literature, this paper describes a large variety of ultrasound-guided vascular puncture techniques used in adults and children far beyond the well described puncture of the internal jugular vein. This includes low or posterior approaches of the internal jugular vein, puncture of the subclavian vein and its variant in children, infraclavicular access to the axillary vein and also more peripheral punctures of the basilic, brachial and cephalic veins. Arterial line placement in the radial, humeral, axillary or femoral are also described as well as the aid of ultrasonography for peripheral insertion of central catheters (PICC Lines). Additional information on ultrasonographic assessment of potentially related complications, like pneumothorax or hemopericardium, will complete this review.

INTRODUCTION

The benefit of ultrasonography seems even more important for vascular access than for peripheral nerve blockades. Nerve stimulators can always be used for nerve blocks while only palpation can orientate traditional vascular access. Moreover, while nerve blocks can be avoided by a well balanced intravenous anesthesia and analgesia, invasive vascular puncture can't be avoided and are live saving in some situation.

Based on our clinical experience and a review of the current literature, this paper describes a large variety of ultrasound (US)-guided vascular puncture techniques used in adults and children far beyond the well described puncture of the internal jugular vein (IJV). This includes low or posterior approaches of the IJV, puncture of the subclavian vein (SCV) and its variant in children, infraclavicular access to the axillary vein (AxV) and also more peripheral puncture of the basilic, brachial and cephalic veins. Arterial line placement in the radial, humeral, axillary or femoral region is also described as well as the aid of ultrasonography for peripheral insertion of central catheters (PICC Lines).

Additional information on ultrasonographic assessment of potentially related complications, like pneumothorax or hemopericardium, will complete this review.

ADVANTAGE OF US-GUIDANCE

Prepuncture US examination of the region of interest offers some additional information compared to clinical examination :

- Position of the vessel (anatomic variation)
- Patency of the vessel (partial or complete thrombosis) (Fig. 1)
- Size of the vessel (left-right asymmetry, hypovolemia)
- Stenosis or hematoma (previous attempts)

In chronic patients, central venous lines (CVL)-related thrombosis are in fact frequent, underestimated and the cause of many difficulties during blind punctures. There in good evidence in adults and children that direct US needle guidance results in :

- Higher success rate
- Fewer mechanical complications
- Higher "first pass" success rate

, all of which improves patient care and comfort (1-4). The result of meta-analyses led to different national recommendation advocating the use of US for CVL placement in adults and children (5, 6).

LIMITATION OF US-GUIDANCE

The three main limitations for US application in regard to vascular access are :

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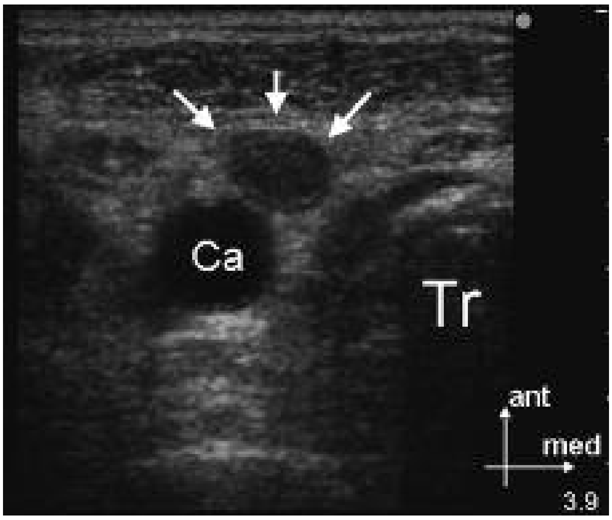

Fig. 1. — Usefulness of prepuncture US screening. In this case the left internal jugular vein (white arrows) is thrombosed and located medially to the carotid artery. A blind puncture would inevitably have failed and probably lead to an accidental carotid puncture.

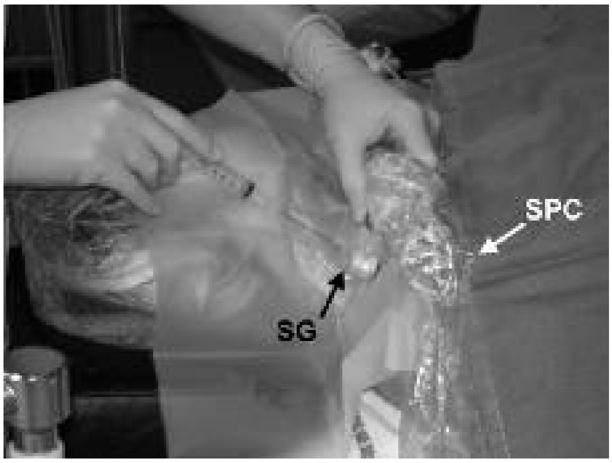

Fig. 2. — A strict sterile setting, including sterile gel (SG) and sterile probe cover (SPC), is required for the placement of central venous catheters. With this setting no increases in infection rate are described in the literature.

- the need for a special equipment and its price
- US physics and their incompatibility
- and learning curve.

US machines devoted to peripheral nerve blocks are perfect for vascular access. A lower image quality (a cheaper machine...) is even sufficient in many cases but can be cumbersome for small peripheral vessels or central vessels in infants. Doppler function seems mandatory for flow examination and thrombosis analysis. Differentiation between artery and vein is usually made without Doppler function by looking for compressibility and pulsatility. A large linear high frequency probe (6-13 MHz) is used in most situation while a smaller linear "pediatric" or "Hockey-Stick" probe is compulsory for invasive procedures in young children. Some authors advocate the use of curvilinear probes (7). These probes have a divergent US beam allowing visualization of the needle in a wider range of insertion angles in the in-plane approach. With the appearance of real-time compound imaging technology the difference with linear probes is reduced and linear probe still have the advantage to offer higher quality (higher frequency ranges) in a non-distorted image. To the cost of this equipment should be added the cost for sterile disposables like sterile gel and probe covers (Fig. 2). However US guided puncture appears cost effective over classical techniques when all the factors, including theater time and cost, failed punctures, and cost of complication care, are taken into account (8).

US physics do not allow visualization through bone or air. For these reasons, the presence of the clavicles or even worse subcutaneous emphysema causes difficulties in the application of some techniques. Because the image depicted on the screen is not the real anatomy but a mirror of it, anesthesiologists should have basic knowledge of "sono-anatomy" to be able to recognize artifacts, to differentiate vessels, cysts and ganglion (9), and to detect technical problems (10).

The learning curve to guide the needle with precision is highly variable depending on hand-eyes coordination capacities (11, 12). Vessels can be imaged in two different planes :

- in short axis (SAX), giving a cross-sectional view (circle) of the vein
- in long axis (LAX), giving a longitudinal view (tube) of the vein.

Needle approach can be performed by two different techniques in regard with needle-probe alignment (13, 14) :

- out of plane (OOP), the needle is inserted perpendicular to the US beam and will be seen as a white dot when the tip pierce this US beam.
- In plane (IP), the needle is inserted parallel and strictly into the US beam and can be seen as a white line.

Three combinations are used in clinical practice depending on the puncture to be performed, the age of the patient, the vessel size or the anesthesiologist's preference (Fig. 3). Needle visualization and

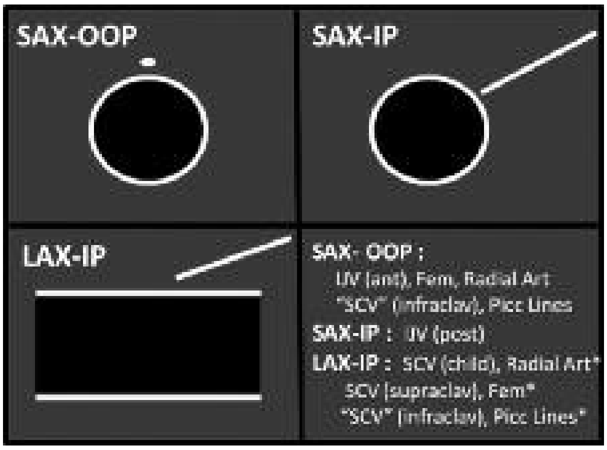

Fig. 3. — Three different ways to perform US-guided vascular punctures and there indications. Short axis (SAX) view of the vessel and Out-Of-Plane (OOP) needle approach (white dot). SAX view of the vessel In-Plane (IP) needle approach (white line). Longitudinal view of the vessel and IP needle approach. IJV : internal jugular vein, Fem : femoral vein or artery, SCV : subclavian vein, "SCV" : axillary vein below the clavicle. (*) : second choice.

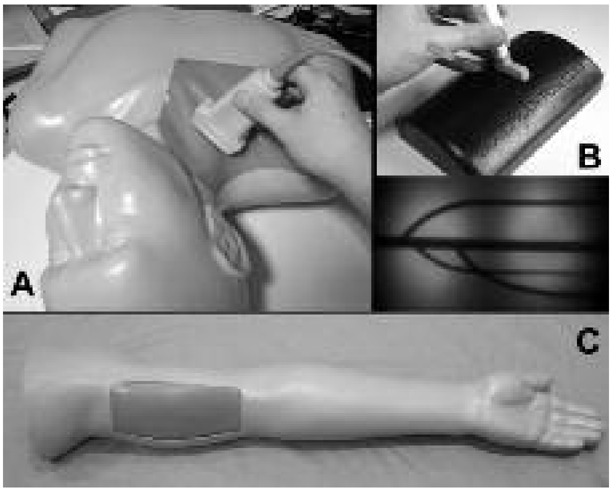

Fig. 4. — US needle guidance training is mandatory before puncturing patients. How to handle both the needle and the probe can be learned on different models. (A) "Head and Torso" model with two vessels in the neck and one vessels going under the clavicule. (B) "Pediatric Vessels" model with vessels from 5 to 2 mm width. (C) "Arm" model with different veins simulating the puncture of the basilic and cephalic vein.

precise needle guidance should be learned on "phantoms", not on patients. Different models can be used : water bad, jelly cubes, piece of meat (15), cheap homemade models (16) or more expansive professional models (Fig. 4). One hour training on these models (with the aid of an experienced US user) is usually sufficient to learn the different tricks to track the needle tip in both approaches.

Central venous catheterization

The Internal Jugular Vein

The IJV is probably the most common site for CVL placement. Reasons for failure to cannulate the vein with external landmarks are rapidly highlighted by US : visualization of the vessel, showing its position, its patency or the presence of residual thrombosis or narrowing due to prior attempts (17, 18). CVL-related thrombosis are frequent but underestimated because often asymptomatic and not systematically screened (19). Thrombosis appears as a hypoechoic structure into the anechoic vessel's lumen, reducing its compressibility. For these reasons, *US screening* alone offers already a huge advantage compared to the blind technique, with a minimal learning curve (20). Different diagnostics will also incidentally be made by the anesthesiologist (carotid stenosis or major atheromatosis, thyroid gland cysts or multinodular goiter...) offering sometimes new information to colleagues and increasing patient care (21). There is now good evidence that the use of *US guidance* for IJV CVL placement results in higher success rate, fewer mechanical complications and a high "first-pass" success rate, all of which improve patient's comfort. Anatomic variations are detected and easily punctured (22), thrombosed veins are avoided, all this with a relative short learning curve and without any increase in infection problems if a sterile setting is used (23). US imaging is thus recommended is all patients and should at least always be considered in conditions of coagulopathy, neck abnormally (obesity), anatomical deviation due to masses (goiter) or previous vein cannulation and neck surgery.

The two different approaches used in blind IJV cannulation can be used during US guidance :

- In the anterior approach, the probe is place transversally to the neck offering a cross section view of the vessels (SAX). With an OOP approach the needle tip is tracked in the subcutaneous tissues and introduced in the center of the IJV avoiding any contact with the common carotid artery (Fig. 5).
- In the posterior approach, the probe is slightly turned oblique to allow needle insertion posterior to the clavicular branch of the sternoclavicular muscle. The slightly oval SAX view of the vein is this time punctured with an IP approach (Fig. 6). This approach is interesting if the vein is collapsed and located just above the carotid

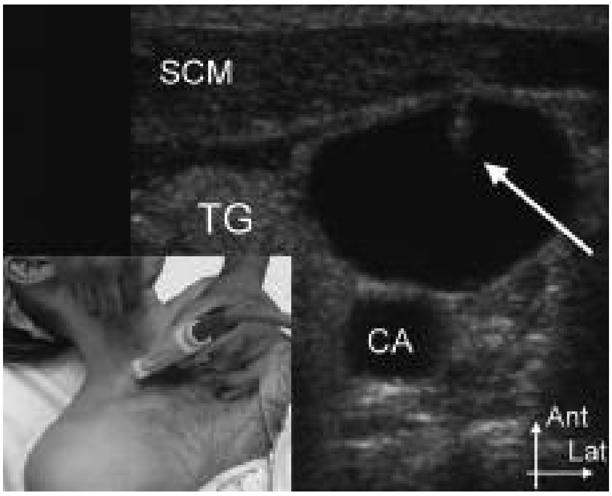

Fig. 5. — Anterior puncture of the right IJV (SAX-OOP). The needle tip is seen as a hyperechoic dot (white arrow). SCM : sternocleidomastoide muscle, TG : thyroid gland, CA : common carotid artery.

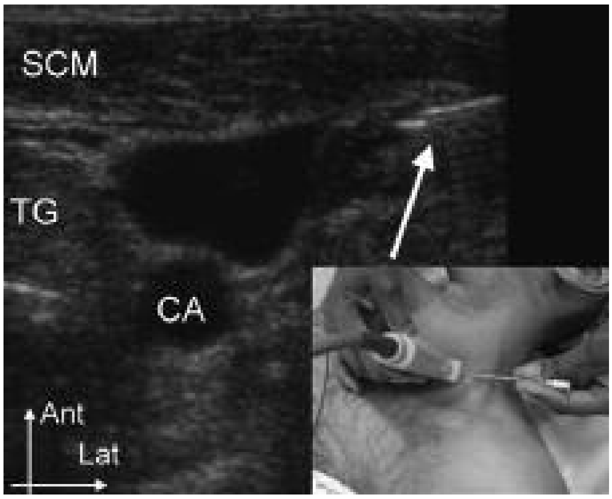

Fig. 6. — Posterior puncture of the left IJV (SAX-IP). The needle shaft and tip are seen as a hyperechoic line (white arrow). SCM : sternocleidomastoide muscle, TG : thyroid gland, CA : common carotid artery.

artery (risk of carotid puncture with the anterior approach).

The use of US for IJV cannulation in children and infants has the same advantages as in adults (24-29). The benefit is even more important in this age category because extreme head rotation is often used (placing the IJV above the artery) (30), the incidence of accidental carotid puncture is higher (11 to 25% vs 6-10%) and carotid puncture can be difficult to diagnose (lower blood pressure, polycythemia and low SPO^2 in congenital cardiopathy). *US screening* can be used with any high frequency probe, while smaller pediatric or “Hockey Stick” probes will be needed for *US puncture* below 5 years of age. In infants below 10 kg, some difficulties are however often encountered :

– the puncture is often transfixiant (if the vessel is hit in its center, blood flow is usually sufficient during needle withdrawal)
– the IJV is very mobile, slipping away from the needle
– the size of the IJV is often close to the needle size in infants

For these reasons, but also for the comfort of the infants and the nurses, subclavian access is more often used in young children (31) (see below).

The Subclavian Vein

The subclavian vein (SCV) can be visualized in the supra or retroclavicular area. By following the IJV distally the first vessel coming for lateral to medial will be the subclavian artery (quite deep and reaching the common carotid artery at the right side and coming close to it at the left side) ; more caudally a second vessel reaches the IJV at the jugulo-subclavian confluent to form the brachiocephalic vein.

In adult, the technique is almost similar to the posterior approach of the IJV, but lower. The SCV (LAX view) is catheterized with an IP needle approach from lateral to medial (Fig. 7). This quite superficial puncture offers nice needle visualization. Needle advancement is however directed to the mediastinum and should therefore be monitored continuously. If large catheters are place in this area, problematic withdrawal should be foreseen (bleeding, difficulty to apply compression...).

In children and especially in infants another technique is possible (32). The principle of this technique is to place the US probe at the supraclavicular level to obtain a longitudinal view of the SCV (like in the adult), but to gain access to the vein via the usual infraclavicular route. In infants, the 2.5 cm long US “Hockey-Stick” probe allows simultaneous visualization of the entire SCV and of the needle passing under the clavicle (Fig. 8). In older children this is not possible anymore : the ultrasonic view is focused on the SCV and the needle is advanced under the clavicle in order to pass strictly under the US probe. Although three dimensional orientation is less easy the procedure is not more difficult because the target to hit is larger. In all cases, the needle is seen passing through the anterior wall of the SCV which can be catheterized under direct vision in the direction of its confluence

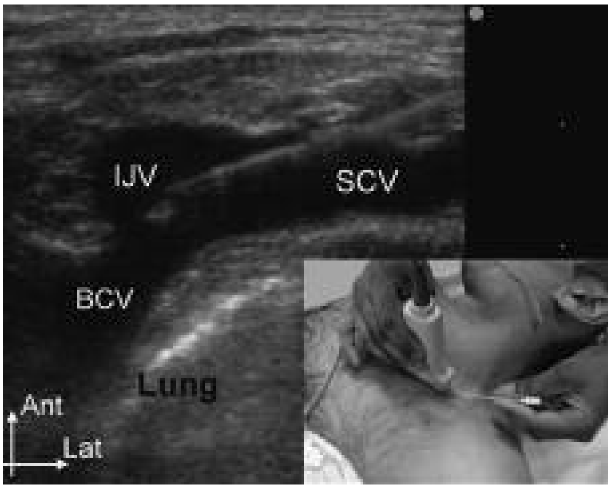

Fig. 7. — Supraclavicular puncture of the left SCV (LAX-IP). An US probe placement just above the clavicle offers a nice view of the subclavian vein (SCV), its junction with the homolateral internal jugular vein (IJV) and the brachiocephalic vein (BCV). The needle is inserted into the jugulo-ssubclavian confluent above the lung top (Lung).

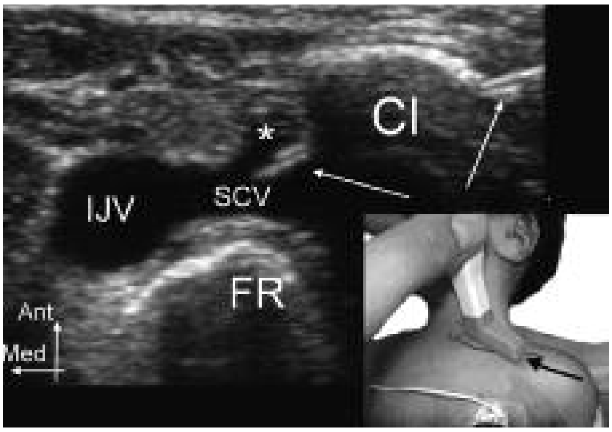

Fig. 8. — Infraclavicular puncture of the left SCV in an infant (LAX-IP). The 25 mm "Hockey-Stick" probe allows visualization of the all region from infraclavicular to the jugulo-subclavian confluent. The needle (white arrow) passes under the clavicle (Cl), punctures the subclavian vein (SCV) and is catheterized almost till the internal jugular vein (IJV). FR : first rib, * : end of the external jugular vein.

with the homolateral IJV. This US-guided approach of the SCV offers a new possibility for central venous catheterization in children. This technique, used in our institution for more than 2 years, seems promising for children less than 10 kg and probably also for older children. It provides good quality needle guidance and allows to check the vessel patency before puncture.

The Axillary Vein

US-guided "subclavian" vascular punctures are usually described by an approach below the clavicle. At this infraclavicular level, the vein visualized is not the subclavian vein but still the axillary vein (AxV), which name will change when it passes the outer border of the first rib. Till now there are no real comparative studies in the literature but those techniques are used by some experienced centers with very good results (33-36). AxV and artery are very close to each other at the infraclavicular level and can be distinguished by these characteristics :

– the vein is more caudal and superficial
– valves can be seen into the vein
– the cephalic vein reaches the SCV just before the clavicle
– the diameter of the vein variates with the respiration (inspiration test in awake patient)
– the artery is pulsating and has a arterial flow (Pulse Doppler)

The AxV will be puncture under direct US guidance before it passes under the clavicle.

This more lateral approach has some advantages over the blind technique : reduction of accidental arterial punctures, no contact with the periostium of the clavicle (less discomfort), insertion of the catheter into the vein before it passes the costoclavicular space or pinch (less risk for catheter transection), especially important for long term catheter, like chest port systems (37). The inconvenient is that, in this US technique, the needle is directed to the lung making needle visualization absolutely mandatory and requiring a larger experience. It is also advised to hit the vein close to the clavicle to use its attachment to a bony structure to prevent the anterior wall to collapse during the puncture.

Two different approaches are possible depending on the patient's anatomy, the level of dehydration and the practitioner's preferences :

– Cross sectional view of the vessel and Out-Of-Plane needle approach (SAX-OOP) (Fig. 9).
– Longitudinal view of the vessel and In-Plane needle approach (LAX-IP) (Fig. 10).

After catheterization, the homolateral distal jugular vein is screened to detect wrong guidewire migration (38). If the guidewire is seen into the IJV, the US probe is use to guide its correct placement, if needed, by compressing the IJV.

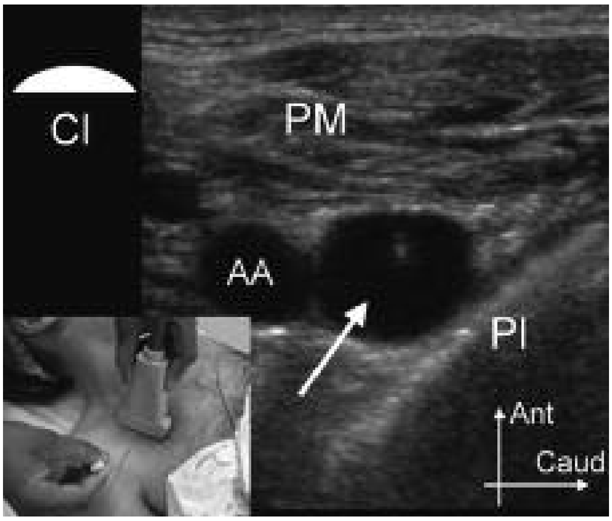

Fig. 9. — Infraclavicular puncture of the right AxV (SAX-OOP). Sagital US scan below the clavicle (Cl). Cross section view of the vessels before they pass under the clavicle. The needle tip is seen in the axillary vein (AxV). PM : pectoral muscles, AA : axillary artery, Pl : pleura.

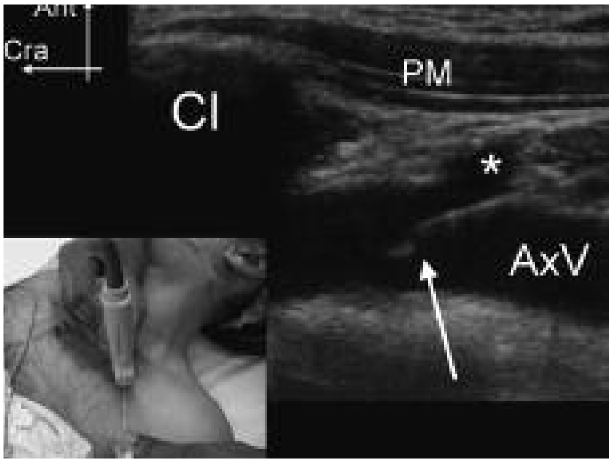

Fig. 10. — Infraclavicular puncture of the left AxV (LAX-IP). Longitudinal view of the axillary vein (AxV) below the clavicle (Cl). White arrow : needle tip, PM : pectoral muscles, * : cephalic vein.

The Femoral Vein

US guidance for femoral vein puncture is also interesting because, like for the IJV, it reduces the incidence of accidental arterial puncture, reduces the number of attempts and increases first pass success rate and patient comfort (39-40). The same results are found in children and infant (41) (Fig. 11), where arterial hematoma significantly impairs venous puncture afterwards. Two complementary maneuvers are used to improve US-guided puncture :

– External leg rotation : reposition the vein beside the artery when this was initially located under it.
– Valsalva or abdominal compression (in children) : increase the size of the vein by checking the iliac vein patency.

Peripherally Inserted Central Catheters placement (PICC lines)

Since a few years, new catheters have been designed in silicone or polyurethane. The insertion of these long catheters (up to 60 cm) in the arm allows drug administration into the vena cava superior which is mandatory for phlebogenic solutions. In our experience, a combination of different factors offers the best comfort to the patient :

– Mid-arm puncture : bigger vein – less phlebitis and thrombosis, more comfort, but *requires US-guidance*.
– Puncture with small needles and a Seldinger technique (compared to big needles with a peel-off introducer) : easier insertion – less bleeding – clean dressing.
– External length adjustment after insertion (compared to length reduction before insertion) : precise positioning of the extremity of the catheter by fluoroscopy.
– Presence of an anti-reflux valve at the end of the catheter (Groshong™ Bard®) : prevents occlusion even in coughing patients (cystic fibrosis).

Different veins can be visualized and catheterized under US guidance at the mid-arm level. The first choice is the basilic vein (4 to 8 mm width, 3 to 15 mm deep, close to the ulnar nerve) (Fig. 12). If not present, one of the brachial veins (deeper, close to the medial nerve and the brachial artery) or the cephalic vein (small, even more superficial but the passage to the axillary vein is sometimes tricky) can be used.

Arterial access

US guidance is useful in patients with faint pulse due to hypovolemia, low cardiac output or vasospasm secondary to multiple cannulation attempts. Different studies in adults (42) and children (43) described that the use of US made the puncture quicker, increased success rate and reduced the number of attempts compared to the palpation method.

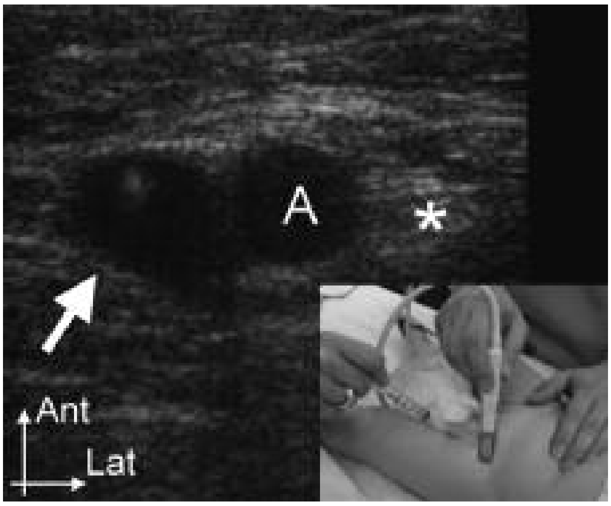

Fig. 11. — Puncture of the right femoral vein in an infant (SAX-OOP). The femoral artery (A) is seen in the middle of the screen. On its left (medial) side, the needle tip is seen in the femoral vein (white arrow). Note that in infant, abdominal pressure is used to increase the size of the vein just before puncture. * : femoral nerve.

The radial artery has two accompanying veins on its sides. Application of mild pressure with the transducer collapses these veins and makes the pulsation of the artery more prominent. The image of the radial artery is usually obtained in a transverse view (SAX) of the wrist. An OOP approach is then used to puncture the vessel (Fig. 13). Alternatively the probe can be rotated by 90° allowing a longitudinal image of the artery (LAX) and an IP needle approach. If the radial artery is already in spasm, it can be imaged and cannulated at more proximal locations underneath the brachioradialis muscle at the mid-forearm (palpation is made extremely difficult at this region by the lack of bony structure under the artery) (44).

Similarly the brachial artery can be catheterized in the antecubital fossa using US and avoiding lesion of the medial nerve. In complex cases a transpectoral approach of the axillary artery has been described (45). The technique is similar to the infraclavicular puncture of the AxV used in adult patients.

The catheterization of the femoral artery is similar to the technique used for CVL placement in the femoral vein (see CVC) (46). Atheromatosis should be ruled out before puncture or avoided by performing the needle insertion in a clear region. The use of US for femoral arterial puncture is advised in infants or in case of difficult pulse palpation (obesity, low cardiaque output, hypothermia...).

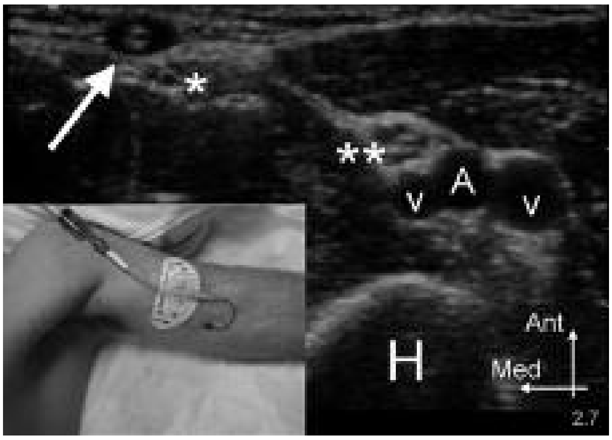

Fig. 12. — Catheterization of the left basilic vein at the mid-arm for PICC lines insertion (SAX-OOP). The first choice for catheter insertion is the basilic vein (white arrow), the second would be one of the brachial veins (V). * : ulnar nerve, ** : medial nerve, A : brachial artery, H : humerus.

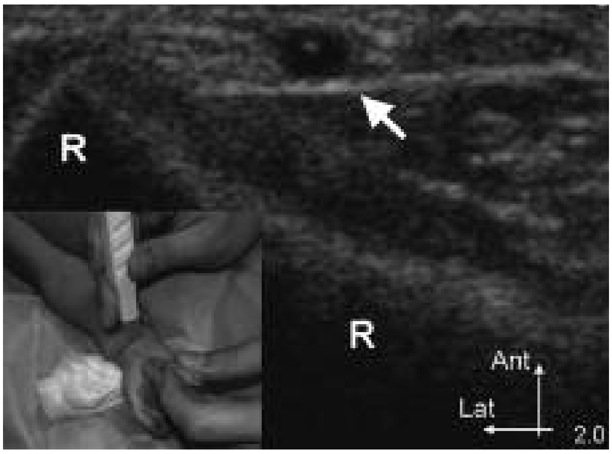

Fig. 13. — Puncture of the right radial artery in a child (SAX-OOP). White arrow : needle tip within the artery (centered in the image), R : radius.

PERIPHERAL VENOUS ACCESS

Dehydration, chronic illness, obesity or drug abuse makes peripheral venous access very difficult in some patients. Different veins can be imaged and cannulated using US guidance either on the dorsum of the hand, at the forearm, the antecubital fossa or higher in the arm (47, 48). The basilic, the brachial or the cephalic are the preferred sites because easily visualized (bigger diameter) (49, 50). Classical intravenous cannula can be used but are often too short. If catheterization length is less than 2.5 cm, dislodgment often occurs after a few hours. Therefore longer catheters like AngioCath®, Flextip® or MidLines® (15 to 20 cm) (51) or even PICC lines (up to 60 cm) can be inserted through a

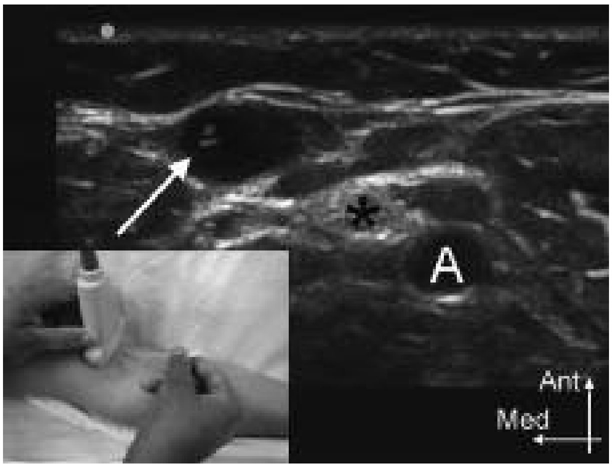

Fig. 14. — Cannulation of the basilic vein at the antecubital fossa for difficult peripheral access (SAX-OOP). White arrow : IV cannula into the vein, * : medial nerve, A : brachial artery.

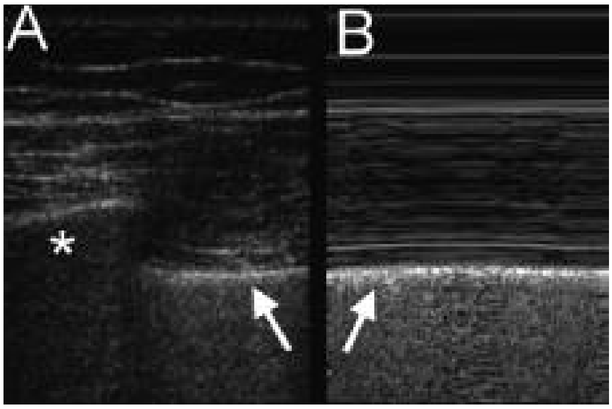

Fig. 15. — US screening to detect a pneumothorax. (A), US scan of the anterior thoracic wall, in real-time imaging detection of the movement of the visceral pleura (white arrow), positive "lung sliding sign" excluding a pneumothorax. * : rib. (B), US M-Mode image of the same region, the "seashore sign" with a granular pattern below the pleural line (white arrow) excludes the presence of a pneumothorax.

large cannula or even better with a Seldinger technique.

In children or even in the adult patient the saphenous vein near the internal malleolus can be used at the lower limb.

Usually a transverse view of the view (SAX) is used with an OOP approach (Fig. 14). Alternatively, like for arterial cannulation, the probe can be rotated by 90° allowing a longitudinal image of the artery (LAX) and an IP needle approach.

Postprocedural assessment of potential complications

Pneumothorax

In the absence of previous pleural disease, the visceral pleura move against the parietal pleura during normal spontaneous breathing or mechanical ventilation. This physiological movement can be detected by US, forming in real time examination the pleural "sliding sign". When a pneumothorax is present, the pleura's are separated by air, which hampers the transmission of the ultrasound beam to the visceral pleura and thus the visualization of the "sliding sign". A clear and rapid visualization of the "sliding sign" is important in acute patient because it is linked with the absence of pneumothorax (52) (Fig. 15A).

Usually if doubt still persists, a time-motion analyze (M-Mode) of the lung surface is performed. In this mode, an obvious difference should appear on either side of the pleural line imaged as the "seashore sign" : the motionless parietal structures above the pleural line generating the horizontal lines (the sea) and lung dynamics of the visceral pleura creating an heterogeneous granular pattern below the pleural line (the sand) (Fig. 15B).

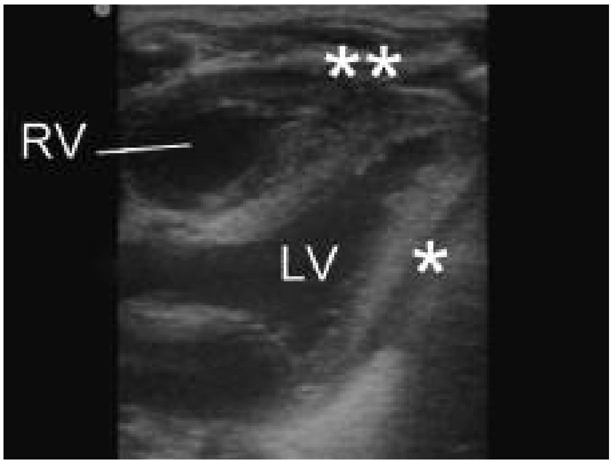

Fig. 16. — Parasternal long-axis view of the heart to assess the pericardial space for fluid. No effusion is seen in this child. * : usual location of posterior effusions, ** : location of anterior and thus circumferential effusions. RV : right ventricule, LV : left ventricule.

In supine patients an anterior pneumothorax is often radiographically "occult" but easily detected by ultrasonography (53). The extent of the pneumothorax can also be ultrasonographically determined (by scanning the entire thoracic wall) with accuracy close to the CT scanning (54).

Hemopericardium

While a complete echocardiographic examination requires a 2 years specific training, some simple information's like global contractility, ventricular filling and presence of pericardial fluid can be learned much quicker (55, 56). Focussed assessment of trauma patient (FAST) by noncardiologist is already widely used and includes the search for pericardial effusion. In case of hemodynamic instability after difficult CVL placement, US should be used to exclude pericardial effusion (Fig. 16) and, if present, could assist needle guidance for drainage (57).

Conclusion

Central and peripheral vascular access remains challenging in some adult or pediatric patients, even in experienced hands. High resolution ultrasonography allows for the first time the anesthesiologists to see under the skin, to screen the anatomy of each of their patients, to adapt their technique and to guide their needles with precision. US guided vascular puncture usually requires a lower image quality (cheaper machine) and a shorter learning curve. US guidance is already used by many centers as a rescue method when conventional techniques fail. Let us hope, for the comfort and the safety of our patients, that ultrasonography will be widely used as a primary technique in a near future.

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