SciMedCentral Archives of Emergency Medicine and Critical Care

Review Article

Ultrasound Guided Vascular Access Practical Issues (Pictorial Essay)

Daniel Wastl[1]*, Christoph F. Dietrich[2], Susanne Morf[3], Fiona Crossey[1], Michael Blaivas[4], and Xaver Brachtendorf[5]

[1]Medizinische Klinik, Medizinische Intensivstation Krankenhaus Nordwest, Germany
[2]Department of Allgemeine Innere Medizin (DAIM), Kliniken Hirslanden Beau Site, Switzerland
[3]Intensivmedizin Center da sandà Val Müstair, Switzerland
[4]University of South Carolina School of Medicine, USA
[5]Agaplesion Bethanien Krankenhaus, Germany

***Corresponding author**
Daniel Wastl, Medizinische Klinik, Medizinische Intensivstation Krankenhaus Nordwest, Frankfurt/Main Germany

Submitted: 20 November 2023
Accepted: 13 December 2023
Published: 15 December 2023
ISSN: 2476-2016

Keywords
- Ultrasound Guided Vascular Access
- Critical care medicine
- Best practice suggestions

Abstract

Ultrasound-guided vascular access is rapidly becoming a more critical topic as critical care medicine systems struggle with an increasing number of patients with vascular access problems. Depending on the situation up to 50% of the patients may have no peripheral vascular access sites or access is very difficult to obtain, which can lead to many complications such as bleeding, pneumothorax or prolonged procedure. Aggravating factors are the increase in obesity, longer lifespan in the case of chronic diseases and the increasing use of corrosive drugs that contain chemotherapeutic agents. The ability to utilize ultrasound guidance for vascular access is an important skill and like in many procedures, such as securing an airway or relocating a dislocated joint, a toolkit of options is often required as multiple sites may need to be checked in order to find a feasible site for cannulation. In this pictorial essay, we describe multiple ultrasound-guided vascular access approaches along with best practice suggestions.

INTRODUCTION

Evidence-based recommendations on ultrasound-guided vascular access procedures have recently been published by the EFSUMB (European Federation of Societies for Ultrasound in Medicine and Biology) [1], as have literature reviews and comments on indications and contraindications [2]. We also refer to the current EFSUMB guidelines on interventional ultrasound (INVUS) [(1, 3-6)], contrast enhanced ultrasound [7-10], elastography [11-14], and comment on the guidelines [15-22].

Ultrasound guidance is used to identify target vessels and their topography through direct visualization [23] in order to increase the success rate and performance speed, to minimize the number of attempts and reduce complications to < 2 %. [24]. Ultrasound guidance has been shown to reduce complication rates compared to landmark techniques [(25-29)] and leads to shorter access time and fewer puncture attempts [2,30-35]. The two most significant benefits associated with ultrasound-guided (USG) techniques versus landmark techniques are lower risks of accidental artery puncture and of local hematoma [36,37]. A lower pneumothorax rate is also significant in terms of morbidity and costs. USG benefits have been demonstrated in a variety of clinical settings including hemodynamics [(31, 32)], critically ill patients [38,39], parental nutrition [36], ventilated [40], and oncological patients [41- 45]. Establishing a central venous access is fundamental for emergency physicians in order to monitor hemodynamics, central venous pressure (CVP) and pulse contour cardiac output (PiCCO), to administer vasoactive drugs, hyperosmolar fluids and volume resuscitation [30]. However, many central line placements and the associated potential complications can be obviated by ultrasound-guided peripheral venous cannulation [46]. This is particularly common in the emergency department and with critically ill patients.

Ultrasound guidance increases the first-attempt success rate of central venous catheter placement [31,47]. A decision on the best approach for US-guidance (direct, indirect, freehand, mechanical guidance, Doppler) should be made by the operator according to the patient's characteristics, the equipment used and his own expertise [48]. USG for central venous catheter placement has been endorsed as a key safety measure by both the Agency for Healthcare Quality and Research in the United States and the National Institute for Health and Care Excellence (NICE) in the UK [1,24,49-56]. USG for central venous access was listed as one of the primary applications for emergency US in the guidelines published by the American College of Emergency Physicians [57]. Here we illustrate ultrasound-guided (USG) vascular access procedures to provide practical advice and to illustrate the procedures with practical tips and tricks.

PROCEDURE PREPARATION

Indications, contraindications and the rules of patient-informed consent [58,59], should be systematically checked each time, as should other recently discussed variables [2].

Sonographic Vessel Screening

An ultrasound vessel pre-screening of the target vessels should be performed to determine the most suitable anatomical site and the optimal patient position for central vascular access [1]. Knowledge of surrounding structures is of utmost importance. Possible anatomical variations of the veins occur in a substantial number of cases [60-64], and can be identified by means of ultrasound. If possible, in case of venous catheterization, no arterial vessel should be located in front, closely lateral, behind the target or in any other close relation. In the case of a central venous cannulation of the internal jugular vein (IJV), head rotation of 30-40° affects vessel orientation and optimizes IJV contact while reducing the likelihood of inadvertent contact with the common carotid artery, but unfortunately cannot be performed on all patients. Changing the relationship of arterial and venous vessels is more difficult in subclavian and femoral approaches.

Hygienic Procedures (antiseptics, sterile cover, hand disinfection)

Using a prevention bundle is the most effective measure to avoid central line-associated bloodstream infection. Such a bundle includes hand hygiene, full barrier precautions, sterile gloves, covering the examiner and the ultrasound transducer, disinfection with e.g., antiseptic alcoholic octenidinhydrochlorid, avoiding femoral access and removing the catheter as soon as possible. Recent studies as well as work at the German Robert-Koch-institute (RKI) show controversial results concerning the infection rate of the femoral puncture site [65-67]. Recently published surveys attempt to answer the feasibility of these bundles and show decreased infection rates; however, it remains unclear whether one location is superior to the other concerning infection control [68,69]. Due to established guidelines, a sterile cover of the ultrasound probe is mandatory to complete these antiseptic conditions. An assistant, if available, helps tremendously in facilitating sterile coverage of the ultrasound transducer. After preparing the transducer with a sufficient amount of ultrasound gel, the assistant, who does not have to be sterile, carefully places the probe into the sterile ultrasound sleeve and extends it away from the operator along the length of the probe cable. In order to secure the sleeve, use sterile adhesive tape. For better acoustic coupling, we either recommend the use of sterile ultrasound gel or intermittent application of antiseptic alcoholic disinfection. Some ultrasound machines allow for the transducer to be positioned higher and slightly away from the machine, thus enabling one operator to apply the sterile sheath to a transducer, albeit with great care and some difficulty (Figure 1).

Local Anaesthesia and Sedation

In our opinion, local anesthesia with e.g., Mepivacaine is necessary for conscious patients to avoid pain and to improve comfort for everybody involved. If the patient expresses procedure anxiety or is agitated, sedation with midazolam or propofol should be considered. Mechanically ventilated patients should receive local anesthetics as well, since sedation in mechanically ventilated ICU patients is often minimized [70,71]. In general, inadequate sedation can result in stress and patient discomfort during invasive procedures and should be avoided in any case.

Best Patient Positioning

The relative position of arterial and venous vessels may change during movements of the head. Choose the most appropriate head position in order to locate the target vein lateral to the artery. Changes in head position may influence the vein diameter and the relative position of the surrounding vessels [62,72,73]. Especially in hypovolemic patients, intravenous fluid prior to the puncture can be helpful. Another tool to improve intravenous filling is placing the patient in a Trendelenburg position. Also try to improve the position of the examiner and the ultrasound device in relation to the puncture site (aim for a comfortable working environment for the interventionalist). In the author's opinion, a comfortable working space is essential in

Figure 1 Sterile cover (with assistance): Extending the sterile ultrasound sleeve along the length of the transducer wire.

order to reduce misalignments and possible complications. We strongly recommend placing the screen of the ultrasound device and the needle insertion in the same field of view to minimize head rotation of the operator [51] (Figure 2).

How to Improve the ultrasound Equipment?

The ultrasound device should allow good near-field resolution. Special presets, e.g., for cervical, brachial and femoral vessels, are helpful. Check the equipment and its function during preparation. High frequency (5 – 17 MHz, in practice 7 – 12 MHz) linear transducers with a relatively small aperture of less than 4 – 6 cm are recommended for superficial anatomical structures. In deeper locations (e.g., femoral vessels), particularly in obese or edematous patients, the use of a curved array abdominal probe may be the right choice.

Transducers may offer vendor-dependent needle guides, but only a limited number of transducers are useful and most punctures are done freehand.

How to Train the operators' skill?

Adequate teaching, education and training are necessary for a successful procedure, since the level of US experience has a significant impact on complication rates [37,74]. However, it has also been shown that the use of ultrasound-guided technology can reduce the frequency of complications, even when the cannulation is performed by inexperienced operators. Simulation-based skill training is more effective than traditional bedside teaching [75-78], including the number of needle passes to achieve central venous access and the frequency of pneumothorax [79, 80]. Other author's recommend a fixed sequence of labartory training as well as a theoretical and practical teaching on a simulator followed by a clinical training. They recommend at least 30 successful procedures within one year [(81)] [European Society of Anaesthesiology guidelines on peri-operative use of ultrasound-guided for vascular access (PERSEUS vascular access)]

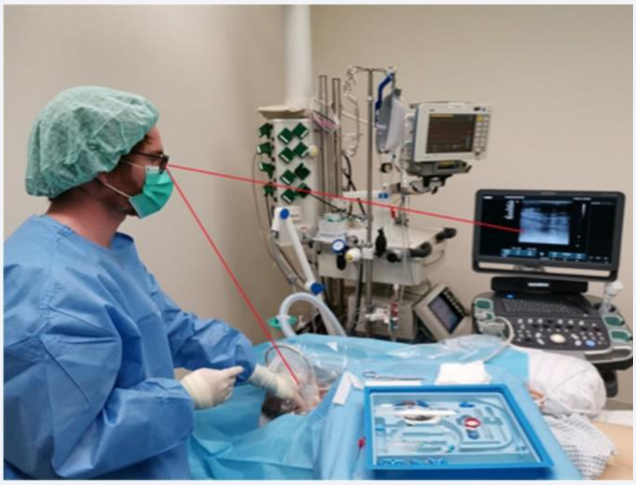

Figure 2 The position of the interventionalist allows aligning the puncture site and the screen of the ultrasound machine in field of vision. We recommend holding the ultrasound probe with the nondominant hand while inserting the needle with the dominant hand.

Ultrasound guiding techniques

The "direct" technique implies needle placement under permanent USG [48]. Other methods("indirect", ultrasound assisted, fixed needle trajectory) have been described to guide and visualize the needle [48, 82-84], but are not part of this practical guide.

The USG techniques can be divided into three different approaches, the longitudinal (in- plane), transverse (out-of-plane) and oblique techniques, which have been described in detail and demonstrated conflicting published evidence in favour of each approach [3,85-92].

Longitudinal Technique (in plane long axis)

Advantages: In the longitudinal and in-plane technique, using adapted angulation, the complete course of the needle [87], and the target vessel, including the posterior wall [86,93], as well as the complete process of insertion and advancement of the needle can be easily guided in real- time (Figure 3).

Disadvantages: From a theoretical point of view, there are no disadvantages of this technique. In some anatomical situations it may be difficult to properly position the transducer and view the full course of the target vessel. Therefore, this technique requires greater levels of hand-eye coordination and can be challenging for beginners with little training.

Transverse technique (out of plane short axis)

With the transversal and out-of-plane technique, the puncture site is exactly in the middle of the probe at an angle of approximately 45° to the skin. Tilting the probe during insertion continuously tracks the needle tip (Figure 4).

Advantages: The advantage of this technique is the reliable positioning of the needle tip according to the course of the vessel, which prevents a deviation from the vessel axis to the right or left. The transversal and out-of-plane technique is useful in anatomical areas with limited access space and for cannulation of smaller vessels. This technique can provide inexperienced users with a steeper learning curve and more self-confidence.

Disadvantages: A disadvantage is the possible loss of control over the needle tip with the risk of posterior wall penetration [(94)]. Also, it may be difficult to determine the most appropriate angle for insertion.

The solution, the oblique technique

With the oblique approach, the needle is seen in plane and during the entire course of its path. The vessel is seen obliquely and is only partially visible. It combines better visualization of the anatomical structures via a short-axis view and better needle tip visualization via an in-plane needle visualization approach [95].

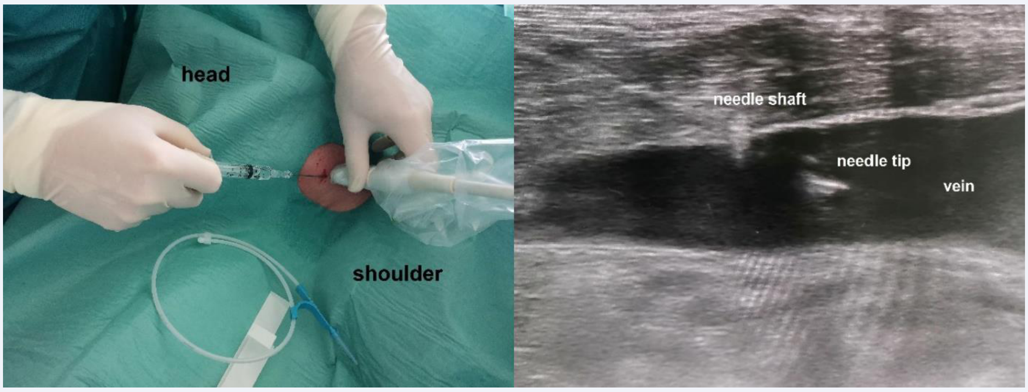

Figure 3 *Longitudinal technique (in plane long axis)*. The transducer is placed parallel to the vessel and the needle at the greatest anterior-posterior diameter of the targeted vessel. The puncture of the skin has to be close to one end of the transducer under an angle of approximately 30° from the skin surface depending on the skin- vessel distance.

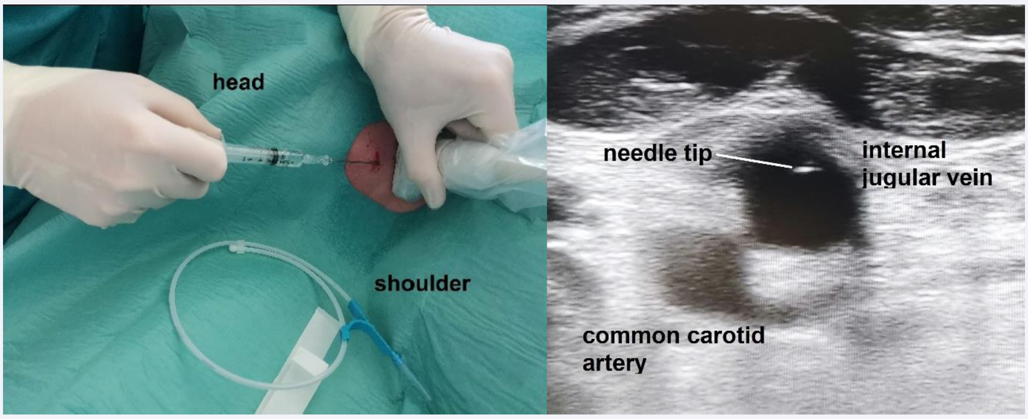

Figure 4 *Transversal technique (out of plane short axis)*. Placing the ultrasound probe transversal to the vessel and inserting the needle in the middle of the probe. By shifting and tilting follow the tip of the needle until successfully puncturing the targeted vessel.

Access Ways

Jugular access: The internal jugular vein (IJV) is the easiest central vein to puncture.

Anatomy, topography and puncture site: The internal jugular vein (IJV) is usually anterior and slightly lateral to the carotid artery and usually has a larger diameter [62]. Due to its superficial location and the simple ultrasound display, it can be regarded as the access site of choice for a central venous cannulation. In addition, an accidental posterior wall puncture is less likely to lead to the development of a pneumothorax. Another advantage is the straight transition of the right jugular vein into the superior vena cava [96].

USG internal jugular vein catheterization with RTUS-guidance can be performed faster, with a higher success rate [97,98], and with fewer complications [40], than the traditional landmark technique. The two heads of the sternocleidomastoid muscle and the clavicle form a triangle on the anterior neck. The internal jugular vein is accessible within this triangle about 2 to 3 cm above the collarbone (Figure 5).

Subclavian access: SV access is associated with the lowest infection rate [99]. However, a survey of intensivists from November 2014 to January 2015 showed that subclavian access was used in 31 % of cases. While those who chose jugular vein-access used ultrasound in 99 %, ultrasound for subclavian access was used in only 31 %, real-time ultrasound even in 28 % (73 % for jugular access) of cases. The main reason was that the operator felt uncomfortable with using real- time ultrasound [100]. The 2012 guideline for performing ultrasound-guided vascular cannulation does not recommend the use of ultrasound for subclavian access [52]. Puncturing the subclavian vein can be difficult in critically ill patients, for example in cases of septic shock or hypovolemia. Ultrasound visualization should help perform subclavian catheterization and make it safer. Based

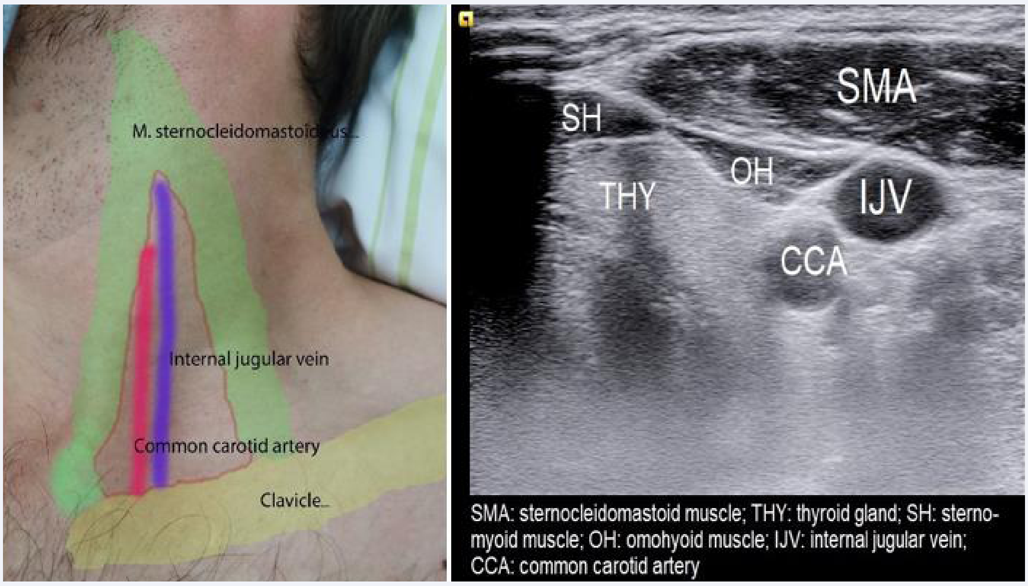

Figure 5 Anatomical landmarks internal jugular vein. SMA = sternocleidomastoid muscle; THY = thyreoid gland; SH = sternomyoid muscle; OH = omohyoid muscle; CCA = common carotid artery; IJV = internal jugular vein

on this reasoning, ultrasound-guided infraclavicular axillary vein catheterization could be an interesting alternative. With this technique, the performer focuses on the transition point of axillary to subclavian vein. After preparation as mentioned above, the vein is punctured with an in-plane needle guidance approach.

Anatomy, topography and puncture site: The subclavicular location of the axillary/subclavian vein and the close relation to the lung apex [101], the subclavian artery and the brachial plexus [48], can make vascular access difficult [102]. Cannulation should be performed by inserting the needle below the collarbone and proximal to the first rib. The cutaneous puncture site should be at the medial point of the collarbone [96] (Figure 6).

Axillary Access: The less frequently used axillary access can be used for safe central venous catheter placement in adult [103-105] and paediatric patients [106]. It is more frequently used in patients with severe burns to the face, neck, and/or proximal shoulders [48,107]. The "axillary access" [108,109], is also possible in patients with a cervical collar or neck trauma [48]. An advantage of the axillary and subclavian vein access is the lower infection rate compared to the internal and especially femoral vein cannulation. Metanalyses show no significant difference between those three puncture sites [110]. In the past, the axillary venous access has not gained popularity because of the difficult identification of landmarks [109]. Since the era of ultrasound-guided vascular access, axillary access has gained popularity due to a number of advantages. These advantages include a fundamental fact: the axillary vein in the upper arm is easier to map and more accessible than in the chest. This vascular access has the anatomical advantage of being further away from the chest wall, the pleura as well as the artery [111]. Therefore, a lower risk of arterial, pleural and nerve damage can be assumed [112].

Anatomy and topography: The axillary vein is the continuation of the basilic vein after passing the proximal border of the teres major muscle and becomes the subclavian vein after passing the lateral edge of the first rib under the clavicle [*108*]. Because the subclavian vein is difficult to visualize, lateral access under ultrasound guidance is easier (Figure 7).

Femoral access: The femoral approach has been discussed previously [25,113-115]. It is favoured especially in cases of resuscitation and interventions such as cardiac compressions or endotracheal intubation, when safe access to the subclavian or internal jugular vein is limited [96].

As mentioned before, femoral access is controversial in the face of catheter infections [65- 67,110,116].

Anatomy, topography and ideal puncture site: The cutaneous puncture should be performed in the anterior superior thigh approximately 3 cm below the inguinal ligament. The ligament extends from the pubic tubercle to the anterior superior iliac spine and is generally intersected by the femoral artery, which is located lateral to the femoral vein [96] (Figure 8).

The Seldinger Procedure

For the initial puncture a needle with attached syringe, half filled with sterile fluid, is used. As soon as the needle passes caudally underneath the transducer, the needle can be detected directly or by soft-tissue tenting. In addition, small "tapping" movements may help to visualize the tip of the needle [117].

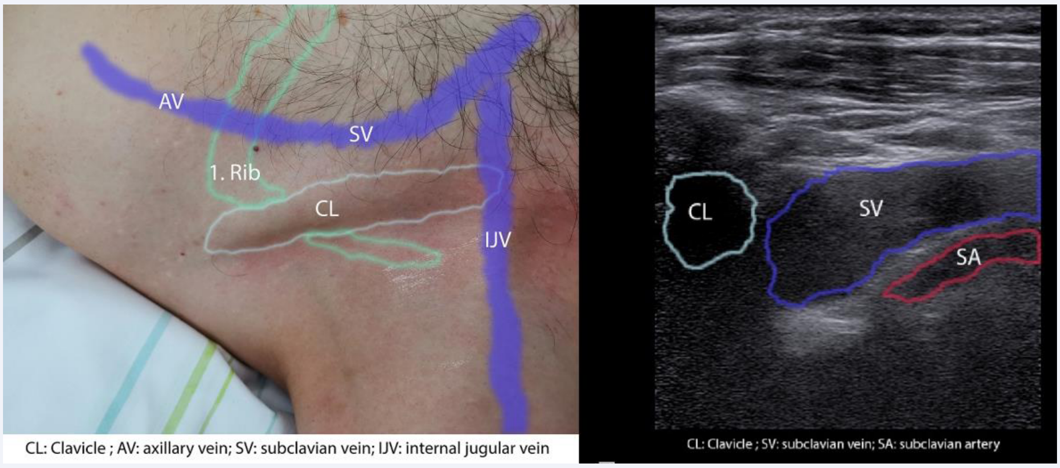

Figure 6 Anatomical landmarks subclavian vein. SV = subclavian vein; AS = subclavian artery; CL = clavicula

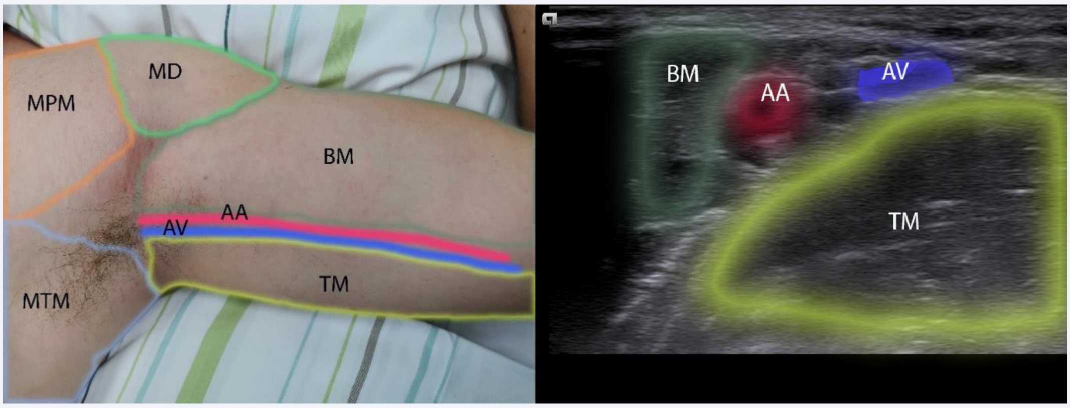

Figure 7 Anatomical landmarks axillary vein: TM: triceps muscle; BM: biceps muscle; AA: axillary artery; AV: axillary vein, MPM: M. pectoralis major; MD: M. deltoideus; MTM: M. teres major

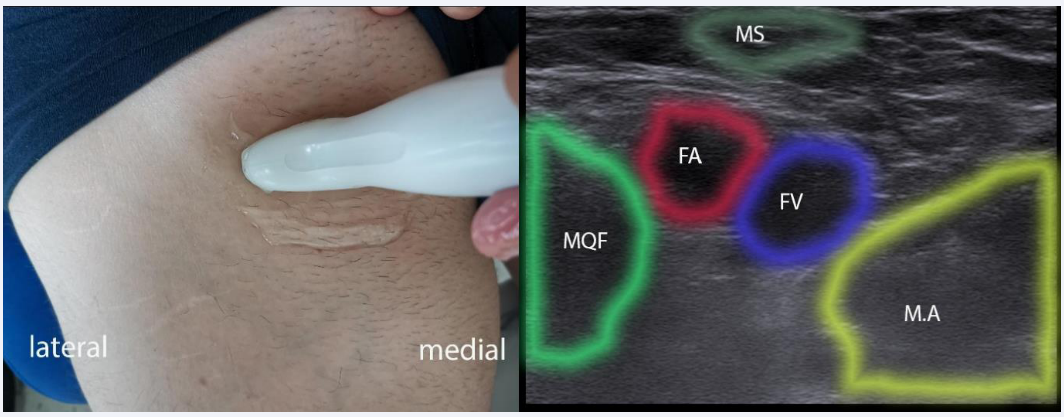

Figure 8 Anatomical landmarks femoral vein: MQF: quadriceps femoral muscle; FA: femoral artery; FV: femoral vein; MA: Musculus adductor; MS: Musculus Sartorius

SciMedCentral

After blood aspiration using the Seldinger technique, a guide wire is introduced under USG. Good coordination is required to perform the puncture with one hand whilst manipulating the US probe with the other. Before removing the guide wire, the correct position of the catheter should be verified by using ultrasonography [117]. Transthoracic echocardiography, particularly with contrast enhancement has proven to be a valid method for the detection of the tip of the catheter in the right atrium [51] (Figure 9 and Figure 10).

Special Situations

Coagulopathy (DIC, thrombocytopenia): A systematic review by Nasr-Esfahani, Mohammad et al., showed that in coagulopathic patients no cases of serious life-threatening bleeding or complications occurred and that the severity of coagulopathy does not correlate with the bleeding risk [118,119]. But van de Weerdt et al., also showed that there seems to be no correlation between severe thrombocytopenia and minor bleeding complications as oozing or a superficial hematoma. A correction of hemostatic effects before CVC placement is still a matter of debate [119]. Nasr- Esfahani, Mohammad et al., concluded, that a correction of coagulation parameters is not necessary for all CVC placements. Additionally, the use of ultrasound guidance resulted in a decreased number of punctures attempts as well as complication rates [118, 119]. A review of Peris et al., showed a significant decrease of hematoma after the use of ultrasound guidance [120].

Since most current national and international guidelines are still based on the landmark technique and thus correlate with a higher risk of complications, there is still a recommendation for the correction of coagulopathy, e.g. thrombocytopenia or INR [121- 123].

In the German cross-sectional guidelines for therapy with blood components and plasma derivatives it is suggested that a central venous catheter can be inserted uncritically in patients with no tendency to diathesis and thrombocytopenia > 10.000/µl. It is also recommended to correct the coagulopathy in patients

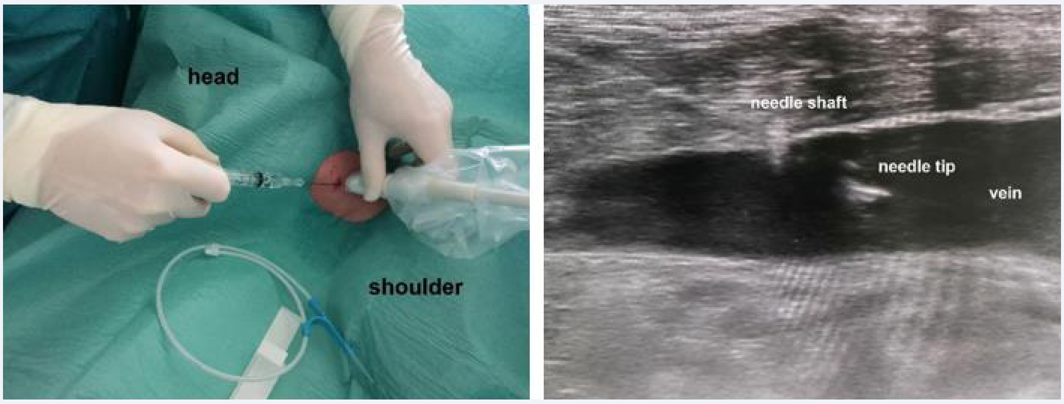

Figure 9 Seldinger procedure: First step - Inserting the needle by visualizing in the longitudinal technique.

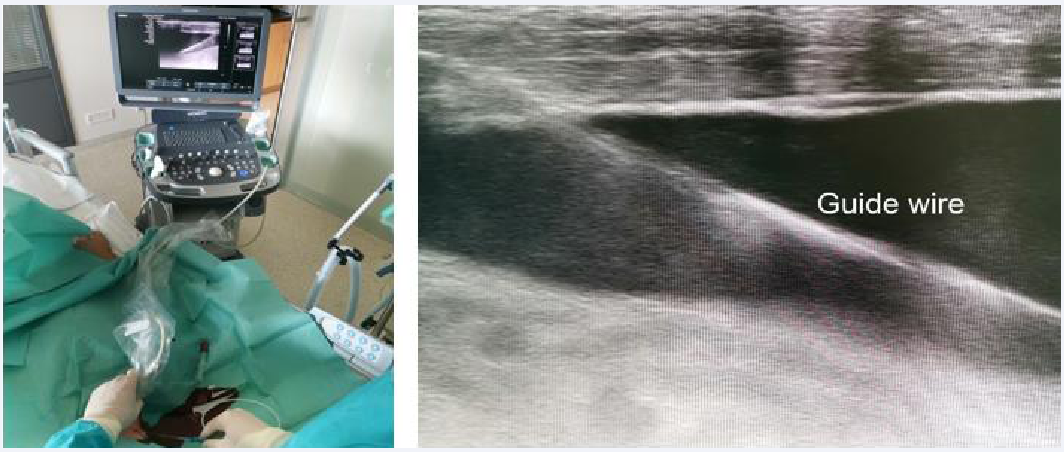

Figure 10 Seldinger procedure: Second step - Introducing the guide wire under permanent ultrasound guidance

with diathesis and platelet counts < 20.000/µl. These guidelines also point out that in patients with liver dysfunction and coagulopathy there is a lack of indication for prophylactic plasma administration prior to liver biopsy, paracentesis, thoracentesis or central venous cannulation [124]. In the author`s opinion, a correction of coagulopathy should be carried out individually, depending on the patient`s constitution, but still in accordance with the current guidelines.

The very obese patient: There is a paucity of literature on central venous catheterization in obese patients, making it difficult to recommend specific procedures or adjustments. Since obesity limits the visualization of the clavicle [125], alternative insertion sites should be considered. Catheterization of the internal jugular vein or femoral vein can also be difficult due to a short neck and a massive subcutaneous fat layer, so that, for example, the brachial access point for catheterization of the artery or vein can be considered. As our hospital is a designated bariatric surgery center and deductive for severely obese patients, we occasionally need to look for different insertion sites (Figure 11).

For severely obese patients with a massive subcutaneous fat layer we use an extra-long puncture needle (18G, 140mm, S-Sharped, e.g. B/Braun Melsungen AG). Due to the length of the needle, it bends when inserted. We therefore recommend guiding the needle close to the tip for a better and firmer grip. Connecting a syringe allows the operator to avoid air aspiration. A long dilatator may be required in these cases.

Other Peripheral Veins: Many clinical situations call for rapid vascular access in order to accomplish patient resuscitation, blood transfusion and antibiotic or other medical administration. As the patient with challenging vascular access becomes more common in many clinical settings, and patients with virtually no options left for venous cannulation appear more frequently, other approaches to vascular access should not be overlooked. These include basilic and cephalic veins in the upper arm, the antecubital fossa and forearm. The great and the small saphenous vein in the leg can also be a potential site if access is critical. The antecubital fossa is often overlooked by vascular access providers (Figure 12). This makes sense since nurses and phlebotomists have typically tapped this area and with no palpable and even possibly scarred antecubital regions, ultrasonography appears to be of little use. However, searching slightly more proximal to the antecubital fossa can reveal access options in a surprising number of patients as these deeper locations are not palpable or visible and are therefore inaccessible to providers using blind technique. Figure 13 shows a large vein in the proximal antecubital region which was neither visible nor palpable upon inspection by an experienced nurse. However, under ultrasound it was easily discovered and cannulated.

The cephalic vein appears surprisingly accessible and large enough in approximately a third of the patients with challenging vascular access. Figure 14 shows a cephalic vein in the lateral lower third of a chronically ill, obese patient's upper arm. Many peripheral venous catheters can be guided to their target vessel

Figure 11 Using a brachial access point in case of a very obese patient with gangrenous groins

Figure 12 Figure Shows a "used up" antecubital fossa in a vascular access challenge patient. Multiple attempts by nursing to palpate any vessels failed and blind stick attempts failed as well. The long blue line shows the approximate location of a cephalic vein which could have been cannulated. The short blue line shows the antecubital fossa vein which was cannulated under ultrasound.

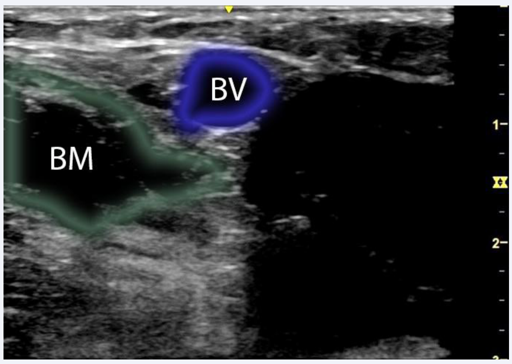

Figure 13 A "used up" antecubital fossa in a vascular access challenge patient shows a large vein missed on palpation and visual inspection. BM: biceps muscle; BV: basilica.

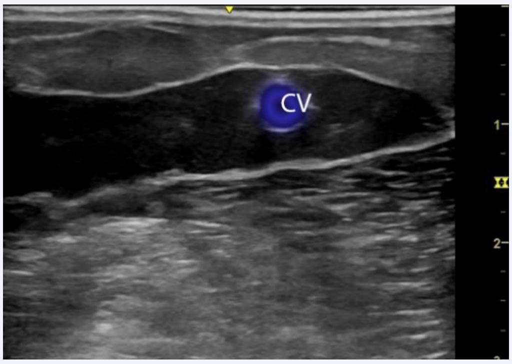

Figure 14 A cephalic vein (CV) is identified on the lateral aspect of a morbidly obese patient's upper arm. While smaller than the typical basilica vein, this was the only available option and successfully cannulated.

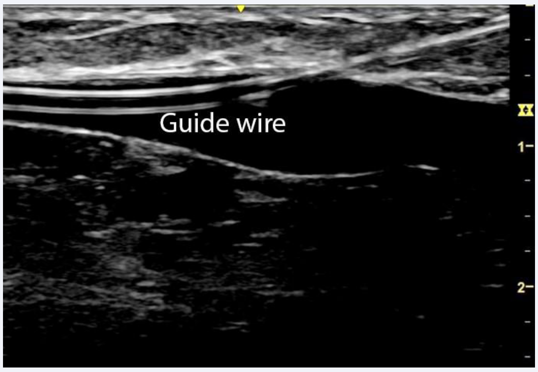

Figure 15 Figure shows an example of in-plane visualization technique with one hand holding the transducer and the other driving the venous cannula. Using one finger, the operator pushes off the catheter from the cannulating needle and is able to watch it feed into the vessel in real time, confirming proper catheter placement directly.

and the catheter "pushed off" into the vein with the same hand while visualizing the procedure using ultrasound (Figure 15). This ensures proper placement and should allay any concerns by nursing staff that the catheter has been misplaced, if blood does not pull back right away or as easily as expected. The vein shown was found to be the only one suitable for cannulation and was easily accessible under ultrasound guidance. In such cases, modified peripheral intravenous catheters like midline catheters, are often useful. Ranging from 10 to 20 cm in length, they are often passed over wire in one combined cannulation process and can remain in place for 3 weeks or longer, a fact much appreciated by general practitioners and other services who may have these patients for weeks at a time in hospital.

Complications

Complications can be divided into mechanical, infectious and thrombotic complications. Mechanical and procedure-related complications include injuries to surrounding nerves and structures, vascular damage particularly arterial puncture leading to fistula formation, pseudo aneurysm, major bleeding and hematoma. The use of a subclavian approach carries a higher risk of pneumothorax or hemothorax than the insertion into the internal jugular vein [126]. Since ultrasound decreases complication rates, all cannulations should be performed using ultrasound guidance. When using the real-time ultrasound technique, the constant visualization of the needle tip and its surroundings leads to a lower risk of mechanical complications [126]. The risk of a mechanical complication increases with the number of insertion attempts. After three or more attempts, the complication rate is six times higher than it is after one attempt [127]. Despite US-guidance, posterior vessel wall puncture may occur as a complication of venous catheterization [94,128]. Factors influencing the risk of posterior wall penetration are the particular access technique (transverse vs. longitudinal approach), the speed of needle insertion, the distance between needle entry and transducer and the angle of insertion [87]. Infectious complications are mainly caused by infection of the puncture site and can lead, via migration along the catheter surface, to intraluminal colonization and hematogenous distribution of the pathogen [126]. Due to the possible emergence of antibiotic-resistant organisms, a prophylactic application of antibiotics is not generally recommended. Scheduled catheter changes are not advised, as replacement via guide wire is associated with an increased rate of infections and a scheduled exchange with a new catheter at a new site is associated with a higher risk of mechanical complications during insertion [129,130]. The most urgent measure against infectious complications are a short dwell time of the catheter, since the probability of catheter-related infections increases gradually [131,132], as well as a proper antiseptic procedure prior to catheter insertion. Another important prophylactic measure is a daily examination of the puncture site. Signs of erythema, entry-site-infection or purulence should lead to a new insertion at a different site. In cases of sepsis or septic shock McGee et al., recommend starting empiric antibiotic therapy to treat possible infections with Staphylococcus epidermidis or Staphylococcus aureus [126].

Even optimal efforts do not guarantee the avoidance of infectious complications, so that all patients with signs and symptoms of infection and no other confirmed focus should be suspected of having a central venous catheter infection. In such a case, blood cultures should be collected from the CVC as well as from peripheral sites (two blood samples each) [126]. A negative culture from a catheter site makes a catheter-related bloodstream infection unlikely [126].

Central venous catheterization also leads to a significant risk of catheter-related thrombosis, and the risk associated with internal jugular insertion is four times higher than the risk of subclavian catheterization [133]. A thrombosis, including the contralateral veins, should be ruled out prior to any vascular access. Excluding neoplastic vein thrombosis is important in oncological patients [44,134]. Ultrasound examination is most helpful for the detection of vascular complications of venous and arterial access, in particular of the thrombosis of the target vessel [135,136], of arterial pseudoaneurysm and of arteriovenous fistula [137-141]. The sonographic signs of the respective complications have been described elsewhere and are not part of this practical guide [51]. Thrombosis, arteriovenous fistulas and pseudoaneurysms represent possible mid-/long-term complications of central venous catheter placement and can be identified sonographically [135-141]. If detected, an effective treatment may be available with para-aneurysmatic US-controlled injection of saline or a US-controlled intrapseudoaneurysmal thrombin injection. These treatments can be combined with manual compression [142]. Correct placement of the catheter is important due to a correlation of perforation of the cardiac cavity and the placement of the tip of the CVC in the right atrium [143]. In some cases, the CVC tip can be detected by ultrasound using a subxiphoidal approach [144-150]. Pneumo- and haemothorax are rare if central venous puncture is performed under USG [33,34]. Catheter displacement is recognized by US at the time of intervention [143-152]. Due to a possible rapid progression of a pneumothorax, especially in ventilated patients, rapid detection of a postprocedural pneumothorax is critical. This can be achieved by using thoracic ultrasound and by systematically searching for specific sonographic signs such as "lung sliding", "lung pulsation" as well as searching for the "lung point" [143]. Ultrasound technology is more sensitive and specific in the diagnosis of occult pneumothorax than thoracic radiography and has the advantage of quick availability. USG should not only be used to guide central venous access, but also to check correct placement of the line and to rule out complications [1, 153-155].

REFERENCES

1. Jenssen C, Brkljacic B, Hocke M, Ignee A, Piscaglia F, Radzina M, Sidhu P, et al. Erratum: EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part VI - Ultrasound-Guided Vascular Interventions. Ultraschall Med. 2016; 37: e1.

2. Hind D, Calvert N, McWilliams R, Davidson A, Paisley S, Beverley C, Thomas S. Ultrasonic locating devices for central venous cannulation: meta-analysis. BMJ. 2003; 327: 361.

3. Lorentzen T, Nolsoe C, Ewertsen C, Nielsen M, Leen E, Havre R, Gritzmann N, et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part I. General Aspects (Short Version). Ultraschall Med. 2015; 36: 464-472.

4. Sidhu P, Brabrand K, Cantisani V, Correas J, Cui X, D'Onofrio M, Essig M, et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part II. Diagnostic Ultrasound-Guided Interventional Procedures (Long Version). Ultraschall Med. 2015; 36: E15-35.

5. Dietrich C, Lorentzen T, Appelbaum L, Buscarini E, Cantisani V, Correas J, Cui X, et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part III - Abdominal Treatment Procedures (Long Version). Ultraschall Med. 2016; 37: E1-E32.

6. Fusaroli P, Jenssen C, Hocke M, Burmester E, Buscarini E, Havre R, Ignee A, et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part V. Ultraschall Med. 2016; 37: 77- 99.

7. Claudon M, Dietrich C, Choi B, Cosgrove D, Kudo M, Nolsoe C, Piscaglia F, et al. Guidelines and good clinical practice recommendations for Contrast Enhanced Ultrasound (CEUS) in the liver - update 2012: A WFUMB-EFSUMB initiative in cooperation with representatives of AFSUMB, AIUM, ASUM, FLAUS and ICUS. Ultrasound Med Biol. 2013; 39: 187- 210.

8. Piscaglia F, Nolsoe C, Dietrich C, Cosgrove D, Gilja O, Bachmann Nielsen M, Albrecht T, et al. The EFSUMB Guidelines and Recommendations on the Clinical Practice of Contrast Enhanced Ultrasound (CEUS): update 2011 on non-hepatic applications. Ultraschall Med. 2012; 33: 33-59.

9. Dietrich CF, Nolsoe CP, Barr RG, Berzigotti A, Burns PN, Cantisani V, Chammas MC, et al. Guidelines and Good Clinical Practice Recommendations for Contrast-Enhanced Ultrasound (CEUS) in the Liver-Update 2020 WFUMB in Cooperation with EFSUMB, AFSUMB, AIUM, and FLAUS. Ultrasound Med Biol. 2020; 46: 2579-2604.

10. Dietrich CF, Nolsoe CP, Barr RG, Berzigotti A, Burns PN, Cantisani V, Chammas MC, et al. Guidelines and Good Clinical Practice Recommendations for Contrast Enhanced Ultrasound (CEUS) in the Liver - Update 2020 - WFUMB in Cooperation with EFSUMB, AFSUMB, AIUM, and FLAUS. Ultraschall Med. 2020; 41: 562-585.

11. Cosgrove D, Piscaglia F, Bamber J, Bojunga J, Correas J, Gilja O, Klauser A, et al. EFSUMB guidelines and recommendations on the clinical use of ultrasound elastography. Part 2: Clinical applications. Ultraschall Med. 2013; 34: 238-253.

12. Ferraioli G, Wong VW, Castera L, Berzigotti A, Sporea I, Dietrich CF, Choi BI, et al. Liver Ultrasound Elastography: An Update to the World Federation for Ultrasound in Medicine and Biology Guidelines and Recommendations. Ultrasound Med Biol. 2018; 44: 2419-2440.

13. Dietrich CF, Bamber J, Berzigotti A, Bota S, Cantisani V, Castera L, Cosgrove D, et al. EFSUMB Guidelines and Recommendations on the Clinical Use of Liver Ultrasound Elastography, Update 2017 (Long Version). Ultraschall Med. 2017; 38: e16-e47.

14. Dietrich CF, Bamber J, Berzigotti A, Bota S, Cantisani V, Castera L, Cosgrove D, et al. EFSUMB Guidelines and Recommendations on the Clinical Use of Liver Ultrasound Elastography, Update 2017 (Short Version). Ultraschall Med. 2017; 38: 377-394.

15. Dietrich C. EFSUMB guidelines 2015 on interventional ultrasound. Med Ultrason. 2015; 17: 521-527.

16. Dietrich C. Comments and illustrations regarding the guidelines and good clinical practice recommendations for contrast-enhanced ultrasound (CEUS)--update 2008. Ultraschall Med. 2008; 29: S188-202.

17. Dietrich C, Chiorean L, Potthoff A, Ignee A, Cui X, Sparchez Z. Percutaneous sclerotherapy of liver and renal cysts, comments on the EFSUMB guidelines. Z Gastroenterol. 2016; 54: 155-166.

18. Dietrich C, Cui X, Schreiber-Dietrich D, Ignee A. EFSUMB guidelines 2011: comments and illustrations. Ultraschall Med. 2012; 33: S11-21.

19. Dietrich CF, Shi L, Koch J, Lowe A, Dong Y, Cui XW, et al. Early detection of pancreatic tumors by advanced EUS imaging. Minerva Gastroenterol Dietol. 2020.

20. Dietrich CF, Shi L, Wei Q, Dong Y, Cui XW, Lowe A, et al. What does liver elastography measure? Technical aspects and methodology. Minerva Gastroenterol Dietol. 2020.

21. Dietrich CF, Burmeister S, Hollerbach S, Arcidiacono PG, Braden B, Fusaroli P, et al. Do we need elastography for EUS? Endosc Ultrasound. 2020; 9: 284-290.

22. Dietrich CF, Ferraioli G, Sirli R, Popescu A, Sporea I, Pienar C, et al. General advice in ultrasound based elastography of pediatric patients. Med Ultrason. 2019; 21: 315-326.

23. Metz S, Horrow J, Balcar I. A controlled comparison of techniques for locating the internal jugular vein using ultrasonography. Anesth Analg. 1984; 63: 673-679.

24. (NICE). NIfCE. Guidance on the Use of Ultrasound Locating Devices for Placing Central Venous Catheters. London UK: NICE 2002; Technology appraisal guidance no 49.

25. Sznajder J, Zveibil F, Bitterman H, Weiner P, Bursztein S. Central vein catheterization. Failure and complication rates by three percutaneous approaches. Arch Intern Med. 1986; 146: 259-261.

26. Mansfield P, Hohn D, Fornage B, Gregurich M, Ota D. Complications and failures of subclavian-vein catheterization. N Engl J Med. 1994; 331: 1735-1738.

27. Goldfarb G, Lebrec D. Percutaneous cannulation of the internal jugular vein in patients with coagulopathies: an experience based on 1,000 attempts. Anesthesiology. 1982; 56: 321- 323.

28. Merrer J, De Jonghe B, Golliot F, Lefrant J, Raffy B, Barre E, et al. Complications of femoral and subclavian venous catheterization in critically ill patients: a randomized controlled trial. JAMA. 2001; 286: 700-707.

29. FE J. Internal jugular vein catheterization. N Y State J Med. 1978; 78: 2168-2171.

30. Randolph A, Cook D, Gonzales C, Pribble C. Ultrasound guidance for placement of central venous catheters: a meta-analysis of the literature. Crit Care Med. 1996; 24: 2053-2058.

31. Rabindranath K, Kumar E, Shail R, Vaux E. Use of real-time ultrasound guidance for the placement of hemodialysis catheters: a systematic review and meta-analysis of randomized controlled trials. Am J Kidney Dis. 2011; 58: 964-970.

32. Rabindranath K, Kumar E, Shail R, Vaux E. Ultrasound use for the placement of haemodialysis catheters. Cochrane Database Syst Rev. 2011: CD005279.

33. Wu S, Ling Q, Cao L, Wang J, Xu M, Zeng W. Real-time two-dimensional ultrasound guidance for central venous cannulation: a meta-analysis. Anesthesiology. 2013; 118: 361-375.

34. Mehta N, Valesky W, Guy A, Sinert R. Systematic review: is real-time ultrasonic-guided central line placement by ED physicians more successful than the traditional landmark approach? Emerg Med J. 2013; 30: 355-359.

35. Leung J, Duffy M, Finckh A. Real-time ultrasonographically-guided internal jugular vein catheterization in the emergency department increases success rates and reduces complications: a randomized, prospective study. Ann Emerg Med. 2006; 48: 540-547.

36. Turker G, Kaya F, Gurbet A, Aksu H, Erdogan C, Atlas A. Internal jugular vein cannulation: an ultrasound-guided technique versus a landmark-guided technique. Clinics (Sao Paulo). 2009; 64: 989-992.

37. Kaye A, Fox C, Hymel B, Gayle J, Hawney H, Bawcom B, Cotter T. The importance of training for ultrasound guidance in central vein catheterization. Middle East J Anaesthesiol. 2011; 21: 61-66.

38. Karakitsos D, Labropoulos N, De Groot E, Patrianakos A, Kouraklis G, Poularas J, et al. Real-time ultrasound-guided catheterisation of the internal jugular vein: a prospective comparison with the landmark technique in critical care patients. Crit Care. 2006; 10: R162.

39. Fragou M, Gravvanis A, Dimitriou V, Papalois A, Kouraklis G, Karabinis A, et al. Real-time ultrasound-guided subclavian vein cannulation versus the landmark method in critical care patients: a prospective randomized study. Crit Care Med. 2011; 39: 1607-1612.

40. Hayashi H, Amano M. Does ultrasound imaging before puncture facilitate internal jugular vein cannulation? Prospective randomized comparison with landmark-guided puncture in ventilated patients. J Cardiothorac Vasc Anesth. 2002; 16: 572-575.

41. Cavanna L, Civardi G, Vallisa D, Di Nunzio C, Cappucciati L, Berte R, et al. Ultrasound-guided central venous catheterization in cancer patients improves the success rate of cannulation and reduces mechanical complications: a prospective observational study of 1,978 consecutive catheterizations. World J Surg Oncol. 2010; 8: 91.

42. Napolitano M, Malato A, Raffaele F, Palazzolo M, Lo Iacono G, Pinna R, et al. Ultrasonography-guided central venous catheterisation in haematological patients with severe thrombocytopenia. Blood Transfus. 2013; 11: 506-509.

43. Serafimidis K, Sakorafas G, Konstantoudakis G, Petropoulou K, Giannopoulos G, Danias N, et al. Ultrasound-guided catheterization of the internal jugular vein in oncologic patients; comparison with the classical anatomic landmark technique: a prospective study. Int J Surg. 2009; 7: 526-528.

44. Benter T, Teichgraber U, Kluhs L, Papadopoulos S, Kohne C, Felix R, et al. Anatomical variations in the internal jugular veins of cancer patients affecting central venous access. Anatomical variation of the internal jugular vein. Ultraschall Med. 2001; 22: 23-26.

45. Barrera R, Mina B, Huang Y, Groeger J. Acute complications of central line placement in profoundly thrombocytopenic cancer patients. Cancer. 1996; 78: 2025-2030.

46. Shokoohi HBK, McCarthy M, Khedir Al-tiae T, Sattarian M, Ding R, Liu YT, et al. Ultrasound-guided peripheral intravenous access program is associated with a marked reduction in central venous catheter use in noncritically ill emergency department patients. Ann Emerg Med. 2013; 61: 198-203.

47. Brass P, Hellmich M, Kolodziej L, Schick G, Smith A. Ultrasound guidance versus anatomical landmarks for subclavian or femoral vein catheterization. Cochrane Database Syst Rev. 2015; 1: CD011447.

48. Abboud P, Kendall J. Ultrasound guidance for vascular access. Emerg Med Clin North Am. 2004; 22: 749-773.

49. Shojania K, Duncan B, McDonald K, Wachter R, Markowitz A. Making health care safer: a critical analysis of patient safety practices. Evid Rep Technol Assess (Summ). 2001: 1-668.

50. Shekelle P, Wachter R, Pronovost P, Schoelles K, McDonald K, Dy S, et al. Making health care safer II: an updated critical analysis of the evidence for patient safety practices. Evid Rep Technol Assess (Full Rep) 2013: 1-945.

51. Lamperti M, Bodenham A, Pittiruti M, Blaivas M, Augoustides J, Elbarbary M, et al. International evidence-based recommendations on ultrasound-guided vascular access. Intensive Care Med. 2012; 38: 1105-1117.

52. Troianos C, Hartman G, Glas K, Skubas N, Eberhardt R, Walker J, et al. Guidelines for performing ultrasound guided vascular cannulation: recommendations of the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. J Am Soc Echocardiogr. 2011; 24: 1291-1318.

53. Jauch K, Schregel W, Stanga Z, Bischoff S, Brass P, Hartl W, et al. Access technique and its problems in parenteral nutrition - Guidelines on Parenteral Nutrition, Chapter 9. Ger Med Sci. 2009; 7: Doc19.

54. Pittiruti M, Hamilton H, Biffi R, MacFie J, Pertkiewicz M, Espen. ESPEN Guidelines on Parenteral Nutrition: central venous catheters (access, care, diagnosis and therapy of complications). Clin Nutr. 2009; 28: 365-377.

55. Bishop L, Dougherty L, Bodenham A, Mansi J, Crowe P, Kibbler C, et al. Guidelines on the insertion and management of central venous access devices in adults. Int J Lab Hematol. 2007; 29: 261-278.

56. AIUM practice guideline for the use of ultrasound to guide vascular access procedures. J Ultrasound Med. 2013; 32: 191-215.

57. American College of Emergency P. American College of Emergency Physicians. Use of ultrasound imaging by emergency physicians. Ann Emerg Med. 2001; 38: 469-470.

58. Lutz H. Patient Information and Informed Consent. In: Interventional Ultrasound Conference Berlin. 2010.

59. Nuernberg DJ, A. Informed Consent. In: Dietrich CFN, D.;, ed. Interventional Ultrasound. A Practical Guide and Atlas: Georg Thieme Verlag, 2014; 34-36.

60. Alderson P, Burrows F, Stemp L, Holtby H. Use of ultrasound to evaluate internal jugular vein anatomy and to facilitate central venous cannulation in paediatric patients. Br J Anaesth. 1993; 70: 145-148.

61. Denys B, Uretsky B. Anatomical variations of internal jugular vein location: impact on central venous access. Crit Care Med. 1991; 19: 1516-1519.

62. Maecken T, Marcon C, Bomas S, Zenz M, Grau T. Relationship of the internal jugular vein to the common carotid artery: implications for ultrasound-guided vascular access. Eur J Anaesthesiol. 2011; 28: 351-355.

63. Turba U, Uflacker R, Hannegan C, Selby J. Anatomic relationship of the internal jugular vein and the common carotid artery applied to percutaneous transjugular procedures. Cardiovasc Intervent Radiol. 2005; 28: 303-306.

64. Troianos C, Kuwik R, Pasqual J, Lim A, Odasso D. Internal jugular vein and carotid artery anatomic relation as determined by ultrasonography. Anesthesiology. 1996; 85: 43-48.

65. Perin D, Erdmann A, Higashi G, Sasso G. Evidence-based measures to prevent central line-associated bloodstream infections: a systematic review. Rev Lat Am Enfermagem. 2016; 24: e2787.

66. Septimus E, Moody J. Prevention of Device-Related Healthcare-Associated Infections. F1000Res. 2016; 5.

67. Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz 2017; 60: 171-206.

68. Menegueti M, Ardison K, Bellissimo-Rodrigues F, Gaspar G, Martins-Filho O, Puga M, et al. The Impact of Implementation of Bundle to Reduce Catheter-Related Bloodstream Infection Rates. J Clin Med Res. 2015; 7: 857-861.

69. Snarski E, Mank A, Iacobelli S, Hoek J, Styczynski J, Babic A, et al. Current practices used for the prevention of central venous catheter-associated infection in hematopoietic stem cell transplantation recipients: a survey from the Infectious Diseases Working Party and Nurses' Group of EBMT. Transpl Infect Dis. 2015; 17: 558-565.

70. Klompas M, Branson R, Eichenwald E, Greene L, Howell M, Lee G, et al. Strategies to prevent ventilator-associated pneumonia in acute care hospitals: 2014 update. Infect Control Hosp Epidemiol. 2014; 35: 915-936.

71. Rello J, Lode H, Cornaglia G, Masterton R, Contributors VAPCB. A European care bundle for prevention of ventilator-associated pneumonia. Intensive Care Med. 2010; 36: 773-780.

72. Randall C, Schmeiser E, Fiers E, Little A, Dogbey G, Richardson G. Ultrasound investigation of leg position to enhance femoral vein exposure for cannulation. J Emerg Med. 2014; 47: 176-181.

73. Docktor B, So C, Saliken J, Gray R. Ultrasound monitoring in cannulation of the internal jugular vein: anatomic and technical considerations. Can Assoc Radiol J. 1996; 47: 195-201.

74. Sekhar A, Sun M, Siewert B. A tissue phantom model for training residents in ultrasound-guided liver biopsy. Acad Radiol. 2014; 21: 902-908.

75. Barsuk J, McGaghie W, Cohen E, Balachandran J, Wayne D. Use of simulation-based mastery learning to improve the quality of central venous catheter placement in a medical intensive care unit. J Hosp Med. 2009; 4: 397-403.

76. Barsuk J, McGaghie W, Cohen E, O'Leary K, Wayne D. Simulation-based mastery learning reduces complications during central venous catheter insertion in a medical intensive care unit. Crit Care Med. 2009; 37: 2697-2701.

77. Evans L, Morse J, Hamann C, Osborne M, Lin Z, D'Onofrio G. The development of an independent rater system to assess residents' competence in invasive procedures. Acad Med. 2009; 84: 1135-1143.

78. Latif RK, Bautista A, Memon S, Smith E, Wang C, Wadhwa A, et al. Teaching aseptic technique for central venous access under ultrasound guidance: a randomized trial comparing didactic training alone to didactic plus simulation-based training. Anesth Analg. 2012; 114: 626-633.

79. Ma I, Brindle M, Ronksley P, Lorenzetti D, Sauve R, Ghali W. Use of simulation-based education to improve outcomes of central venous catheterization: a systematic review and meta-analysis. Acad Med. 2011; 86: 1137-1147.

80. Madenci A, Solis C, de Moya M. Central venous access by trainees: a systematic review and meta-analysis of the use of simulation to improve success rate on patients. Simul Healthc . .2014; 9: 7-14.

81. Lamperti M, Biasucci D, Disma N, Pittiruti M, Breschan C, Vailati D, et al. European Society of Anaesthesiology guidelines on peri-operative use of ultrasound-guided for vascular access (PERSEUS vascular access). Eur J Anaesthesiol. 2020; 37: 344-376.

82. Matalon T, Silver B. US guidance of interventional procedures. Radiology. 1990; 174: 43- 47.

83. Denys B, Uretsky B, Reddy P. Ultrasound-assisted cannulation of the internal jugular vein. A prospective comparison to the external landmark-guided technique. Circulation. 1993; 87: 1557-1562.

84. Nolsoe C, Lorentzen T, Skjoldbye B, Bachmann Nielsen M. The basics of interventional ultrasound. Ultraschall Med. 2007; 28: 248-263.

85. Erickson C, Liao M, Haukoos J, Douglass E, DiGeronimo M, Christensen E, et al. Ultrasound-guided small vessel cannulation: long-axis approach is equivalent to short-axis in novice sonographers experienced with landmark-based cannulation. West J Emerg Med. 2014; 15: 824-830.

86. Vogel J, Haukoos J, Erickson C, Liao M, Theoret J, Sanz G, et al. Is long-axis view superior to short-axis view in ultrasound-guided central venous catheterization? Crit Care Med. 2015; 43: 832-839.

87. Stone M, Moon C, Sutijono D, Blaivas M. Needle tip visualization during ultrasound- guided vascular access: short-axis vs long-axis approach. Am J Emerg Med. 2010; 28: 343-347.

88. Clemmesen L, Knudsen L, Sloth E, Bendtsen T. Dynamic needle tip positioning - ultrasound guidance for peripheral vascular access. A randomized, controlled and blinded study in phantoms performed by ultrasound novices. Ultraschall Med. 2012; 33: E321-E325.

89. Mahler S, Wang H, Lester C, Skinner J, Arnold T, Conrad S. Short- vs long-axis approach to ultrasound-guided peripheral intravenous access: a prospective randomized study. Am J Emerg Med. 2011; 29: 1194-1197.

90. Sommerkamp S, Romaniuk V, Witting M, Ford D, Allison M, Euerle B. A comparison of longitudinal and transverse approaches to ultrasound-guided axillary vein cannulation. Am J Emerg Med. 2013; 31: 478-481.

91. Tammam T, El-Shafey E, Tammam H. Ultrasound-guided internal jugular vein access: comparison between short axis and long axis techniques. Saudi J Kidney Dis Transpl. 2013; 24: 707-713.

92. Lorentzen T, Nolsoe C, Ewertsen C, Nielsen M, Leen E, Havre R, et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part I. General Aspects (Short Version). . Ultraschall Med. 2015; 36: 464-472.

93. Blaivas M, Brannam L, Fernandez E. Short-axis versus long-axis approaches for teaching ultrasound-guided vascular access on a new inanimate model. Acad Emerg Med. 2003; 10: 1307-1311.

94. Blaivas M, Adhikari S. An unseen danger: frequency of posterior vessel wall penetration by needles during attempts to place internal jugular vein central catheters using ultrasound guidance. Crit Care Med. 2009; 37: 2345-2349.

95. Phelan M, Hagerty D. The oblique view: an alternative approach for ultrasound-guided central line placement. J Emerg Med. 2009; 37: 403-408.

96. Bannon M, Heller S, Rivera M. Anatomic considerations for central venous cannulation. Risk Manag Healthc Policy. 2011; 4: 27-39.

97. Milling Jr T, Rose J, Briggs W, Birkhahn R, Gaeta T, Bove J, et al. Randomized, controlled clinical trial of point-of-care limited ultrasonography assistance of central venous cannulation: the Third Sonography Outcomes Assessment Program (SOAP-3) Trial. Crit Care Med. 2005; 33: 1764-1769.

98. Ray B, Mohan V, Kashyap L, Shende D, Darlong V, Pandey R. Internal jugular vein cannulation: A comparison of three techniques. J Anaesthesiol Clin Pharmacol. 2013; 29: 367-371.

99. O'Grady N, Alexander M, Burns L, Dellinger E, Garland J, Heard S, et al. Guidelines for the prevention of intravascular catheter-related infections. Am J Infect Control . 2011; 39: S1-34.

100. Soni N, Reyes L, Keyt H, Arango A, Gelfond J, Peters J, et al. Use of ultrasound guidance for central venous catheterization: a national survey of intensivists and hospitalists. J Crit Care. 2016; 36: 277-283.

101. Skolnick M. The role of sonography in the placement and management of jugular and subclavian central venous catheters. AJR Am J Roentgenol. 1994; 163: 291-295.

102. Silberzweig J, Mitty H. Central venous access: low internal jugular vein approach using imaging guidance. AJR Am J Roentgenol. 1998; 170: 1617-1620.

103. Fry W, Clagett G, O'Rourke P. Ultrasound-guided central venous access. Arch Surg. 1999; 134: 738-740.

104. Gualtieri E, Deppe S, Sipperly M, Thompson D. Subclavian venous catheterization: greater success rate for less experienced operators using ultrasound guidance. Crit Care Med. 1995; 23: 692-697.

105. Taylor B, Yellowlees I. Central venous cannulation using the infraclavicular axillary vein. Anesthesiology. 1990; 72: 55-58.

106. Metz R, Lucking S, Chaten F, Williams T, Mickell J. Percutaneous catheterization of the axillary vein in infants and children. Pediatrics. 1990; 85: 531-533.

107. Andel H, Rab M, Felfernig M, Andel D, Koller R, Kamolz LP, et al. The axillary vein central venous catheter in severely burned patients. Burns. 1999; 25: 753-756.

108. Galloway S, Bodenham A. Ultrasound imaging of the axillary vein--anatomical basis for central venous access. Br J Anaesth. 2003; 90: 589-595.

109. Nickalls R. A new percutaneous infraclavicular approach to the axillary vein. Anaesthesia. 1987; 42: 151-154.

110. Arvaniti K, Lathyris D, Blot S, Apostolidou-Kiouti F, Koulenti D, Haidich A. Cumulative Evidence of Randomized Controlled and Observational Studies on Catheter-Related Infection Risk of Central Venous Catheter Insertion Site in ICU Patients: A Pairwise and Network Meta- Analysis. Crit Care Med. 2017; 45: e437-e448.

111. Sharma A, Bodenham A, Mallick A. Ultrasound-guided infraclavicular axillary vein cannulation for central venous access. Br J Anaesth. 2004; 93: 188-192.

112. Bodenham A, Lamperti M. Ultrasound guided infraclavicular axillary vein cannulation, coming of age. Br J Anaesth. 2016; 116: 325-327.

113. Tripathi M. Subclavian vein cannulation: an approach with definite landmarks. Ann Thorac Surg. 1996; 61: 238-240.

114. Bo-Linn G, Anderson D, Anderson K, McGoon M. Percutaneous central venous catheterization performed by medical house officers: a prospective study. Cathet Cardiovasc Diagn. 1982; 8: 23-29.

115. Jastremski M, Matthias H, Randell P. Femoral venous catheterization during cardiopulmonary resuscitation: a critical appraisal. J Emerg Med. 1984; 1: 387-391.

116. Castro D, Lee A, Lee M, Beenish S. Femoral Vein Central Venous Access. Treasure Island (FL) StatPearls Publishing 2020.

117. Ortega R, Song M, Hansen C, Barash P. Videos in clinical medicine. Ultrasound-guided internal jugular vein cannulation. N Engl J Med. 2010; 362: e57.

118. Nasr-Esfahani M, Kolahdouzan M, Mousavi SA. Inserting central venous catheter in emergency conditions in coagulopathic patients in comparison to noncoagulopathic patients. J Res Med Sci. 2016; 21: 120.

119. van de Weerdt E, Biemond B, Baake B, Vermin B, Binnekade J, van Lienden K, et al. Central venous catheter placement in coagulopathic patients: risk factors and incidence of bleeding complications. Transfusion 2017; 57: 2512-2525.

120. Peris A, Zagli G, Bonizzoli M, Cianchi G, Ciapetti M, Spina R, et al. Implantation of 3951 long-term central venous catheters: performances, risk analysis, and patient comfort after ultrasound-guidance introduction. Anesth Analg. 2010; 111: 1194-1201.

121. Quraishy N, Bachowski G, Benjamin R. A Compendium of Transfusion Practice Guidelines. 1st ed. American National Red Cross. 2010.

122. (CBO) DIfHI. Blood transfusion guideline. Utrecht (Netherlands) 2011.

123. Committee JUBTaTTSPA. Handbook of Transfusion Medicine. UK Blood Services. 2013.

124. Bundesärztekammer. Cross-Sectional Guidelines for Therapy with Blood Components and Plasma Derivates - 4th revised edition Transfusion Medicine and Hemotherapy. 2009; 36: 354-492.

125. McGrath T, Farabaugh E, Pickett M, Wagner D, Griswold-Theodorson S. Obesity hinders ultrasound visualization of the subclavian vein: implications for central venous access. J Vasc Access. 2012; 13: 246-250.

126. McGee D, Gould M. Preventing complications of central venous catheterization. N Engl J Med. 2003; 348: 1123-1133.

127. Tanhehco Y, Zantek N, Alsammak M, Chhibber V, Li Y, Becker J, et al. Vascular access practices for therapeutic apheresis: Results of a survey. J Clin Apher. 2019; 34: 571-578.

128. Moon C, Blehar D, Shear M, Uyehara P, Gaspari R, Arnold J, et al. Incidence of posterior vessel wall puncture during ultrasound-guided vessel cannulation in a simulated model. Acad Emerg Med. 2010; 17: 1138-1141.

129. Cook D, Randolph A, Kernerman P, Cupido C, King D, Soukup C, et al. Central venous catheter replacement strategies: a systematic review of the literature. Crit Care Med. 1997; 25: 1417-1424.

130. Pearson M. Guideline for Prevention of Intravascular-Device–Related Infections. Infection Control & Hospital Epidemiology. 2015; 17: 438-473.

131. Maki D, Stolz S, Wheeler S, Mermel L. Prevention of central venous catheter-related bloodstream infection by use of an antiseptic-

impregnated catheter. A randomized, controlled trial. Ann Intern Med. 1997; 127: 257-266.

132. Raad I, Darouiche R, Dupuis J, Abi-Said D, Gabrielli A, Hachem R, et al. Central venous catheters coated with minocycline and rifampin for the prevention of catheter-related colonization and bloodstream infections. A randomized, double-blind trial. The Texas Medical Center Catheter Study Group. Ann Intern Med. 1997; 127: 267-274.

133. Timsit J, Farkas J, Boyer J, Martin J, Misset B, Renaud B, et al. Central vein catheter- related thrombosis in intensive care patients: incidence, risks factors, and relationship with catheter-related sepsis. Chest 1998; 114: 207-213.

134. Beaudoin F, Merchant R, Lincoln J, Gardiner F, Liebmann O, Cohn J. Bedside ultrasonography detects significant femoral vessel overlap: implications for central venous cannulation. CJEM. 2011; 13: 245-250.

135. Lordick F, Hentrich M, Decker T, Hennig M, Pohlmann H, Hartenstein R, et al. Ultrasound screening for internal jugular vein thrombosis aids the detection of central venous catheter-related infections in patients with haemato-oncological diseases: a prospective observational study. Br J Haematol. 2003; 120: 1073-1078.

136. Yilmaz K, Akinci M, Dogan L, Yologlu Z, Atalay C, Kulacoglu H. Central venous catheter- associated thrombosis in the perioperative period: a frequent complication in cancer patients that can be detected early with doppler examination. Tumori. 2010; 96: 690-694.

137. Ahmad F, Turner S, Torrie P, Gibson M. Iatrogenic femoral artery pseudoaneurysms--a review of current methods of diagnosis and treatment. Clin Radiol. 2008; 63: 1310-1316.

138. Hanson J, Atri M, Power N. Ultrasound-guided thrombin injection of iatrogenic groin pseudoaneurysm: Doppler features and technical tips. Br J Radiol. 2008; 81: 154-163.

139. Webber G, Jang J, Gustavson S, Olin J. Contemporary management of postcatheterization pseudoaneurysms. Circulation. 2007; 115: 2666-2674.

140. Paulson E, Kliewer M, Hertzberg B, O'Malley C, Washington R, Carroll B. Color Doppler sonography of groin complications following femoral artery catheterization. AJR Am J Roentgenol. 1995; 165: 439-444.

141. Coughlin B, Paushter D. Peripheral pseudoaneurysms: evaluation with duplex US. Radiology 1988; 168: 339-342.

142. Jenssen C, Brkljacic B, Hocke M, Ignee A, Piscaglia F, Radzina M, Sidhu PS, et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part VI - Ultrasound-Guided Vascular Interventions. Ultraschall Med. 2016; 37: 473-476.

143. Vezzani A, Manca T, Vercelli A, Braghieri A, Magnacavallo A. Ultrasonography as a guide during vascular access procedures and in the diagnosis of complications. J Ultrasound. 2013; 16: 161-170.

144. Maury E, Guglielminotti J, Alzieu M, Guidet B, Offenstadt G. Ultrasonic examination: an alternative to chest radiography after central venous catheter insertion? Am J Respir Crit Care Med. 2001; 164: 403-405.

145. Vezzani A, Brusasco C, Palermo S, Launo C, Mergoni M, Corradi F. Ultrasound localization of central vein catheter and detection of postprocedural pneumothorax: an alternative to chest radiography. Crit Care Med. 2010; 38: 533-538.

146. Lanza C, Russo M, Fabrizzi G. Central venous cannulation: are routine chest radiographs necessary after B-mode and colour Doppler sonography check? Pediatr Radiol. 2006; 36: 1252- 1256.

147. Matsushima K, Frankel H. Bedside ultrasound can safely eliminate the need for chest radiographs after central venous catheter placement: CVC sono in the surgical ICU (SICU). J Surg Res. 2010; 163: 155-161.

148. Weekes A, Johnson D, Keller S, Efune B, Carey C, Rozario N, et al. Central vascular catheter placement evaluation using saline flush and bedside echocardiography. Acad Emerg Med. 2014; 21: 65-72.

149. Bedel J, Vallee F, Mari A, Riu B, Planquette B, Geeraerts T, et al. Guidewire localization by transthoracic echocardiography during central venous catheter insertion: a periprocedural method to evaluate catheter placement. Intensive Care Med. 2013; 39: 1932-1937.

150. Park Y, Lee J, Byon H, Kim H, Kim J. Transthoracic echocardiographic guidance for obtaining an optimal insertion length of internal jugular venous catheters in infants. Paediatr Anaesth 2014; 24: 927-932.

151. Lichtenstein D, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. Lung sliding. Chest 1995; 108: 1345-1348.

152. Lichtenstein D, Meziere G, Lascols N, Biderman P, Courret J, Gepner A, et al. Ultrasound diagnosis of occult pneumothorax. Crit Care Med. 2005; 33: 1231-1238.

153. Refai M, Salati M, Tiberi M, Sabbatini A, Gentili P. Clinical pathway for thoracic surgery in an Italian centre. J Thorac Dis. 2016; 8: S23-28.

154. Xing X, Gao Y, Wang H, Qu S, Huang C, Zhang H, et al. Correlation of fluid balance and postoperative pulmonary complications in patients after esophagectomy for cancer. J Thorac Dis. 2015; 7: 1986-1993.

155. Mayr N, Michel J, Bleiziffer S, Tassani P, Martin K. Sedation or general anesthesia for transcatheter aortic valve implantation (TAVI). J Thorac Dis. 2015; 7: 1518-1526.