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Massimo Lamperti
Andrew R. Bodenham
Mauro Pittiruti
Michael Blaivas
John G. Augoustides
Mahmoud Elbarbary
Thierry Pirotte
Dimitrios Karakitsos
Jack LeDonne
Stephanie Doniger
Giancarlo Scoppettuolo
David Feller-Kopman
Wolfram Schummer
Roberto Biffi
Eric Desruennes
Lawrence A. Melniker
Susan T. Verghese

International evidence-based recommendations on ultrasound-guided vascular access

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M. Lamperti (✉)
Department of Neuroanesthesia,
Neurological Institute Besta,
Via Celoria, 11, 20136 Milan, Italy
e-mail: doclampmd@gmail.com
Tel.: +39-2-23942420
Fax: +39-2-2666123

A. R. Bodenham
Anesthesiology, Leeds General Infirmary,
Leeds, UK

M. Pittiruti
Department of Surgery,
Catholic University, Rome, Italy

M. Blaivas
Department of Emergency Medicine,
Northside Hospital Forsyth,
Atlanta, GA, USA

J. G. Augoustides
Anesthesiology and Critical Care,
Perelman School of Medicine,
University of Pennsylvania,
Philadelphia, USA

M. Elbarbary
National and Gulf Center for Evidence
Based Health Practice, King Saud
University for Health Sciences,
Riyadh, Saudi Arabia

T. Pirotte
Department of Anesthesia and Intensive
Care Medicine, Cliniques Universitaires
Saint-Luc, Brussels, Belgium

D. Karakitsos
Intensive Care Unit,
General State Hospital of Athens,
Athens, Greece

J. LeDonne
Greater Baltimore Medical Center,
Baltimore, USA

S. Doniger
Pediatric Emergency Medicine,
Children's Hospital and Research Center,
Oakland, USA

G. Scoppettuolo
Infectious Diseases Unit,
Catholic University, Rome, Italy

D. Feller-Kopman
Bronchoscopy and Interventional
Pneumology, Johns Hopkins Hospital,
Baltimore, USA

W. Schummer
Department of Anesthesiology
and Intensive Care Medicine,
SHR Zentralklinikum Suhl,
Jena, Germany

R. Biffi
Division of Abdominopelvic Surgery,
European Institute of Oncology,
Milan, Italy

E. Desruennes
Department of Anesthesia,
Institute Gustave Roussy,
Villejuif, France

L. A. Melniker
Department of Emergency Medicine,
New York Methodist Hospital and Clinical
Epidemiology Unit, NY, USA

S. T. Verghese
Department of Anesthesiology,
Children's National Medical Center,
Washington (DC), USA

Abstract *Purpose:* To provide clinicians with an evidence-based overview of all topics related to ultrasound vascular access. *Methods:* An international evidence-based consensus provided definitions and recommendations.

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Medical literature on ultrasound vascular access was reviewed from January 1985 to October 2010. The GRADE and the GRADE-RAND methods were utilised to develop recommendations. *Results:* The recommendations following the conference suggest the advantage of 2D vascular screening prior to cannulation and that real-time ultrasound needle guidance with an in-plane/long-axis technique optimises the probability of needle placement. Ultrasound guidance can be used not only for central venous cannulation but also in peripheral and arterial cannulation. Ultrasound can be used in order to check for immediate and life-threatening complications as well as the catheter's tip position. Educational courses and training are required to achieve competence and minimal skills when cannulation is performed with ultrasound guidance. A recommendation to create an ultrasound curriculum on vascular access is proposed. This technique allows the reduction of infectious and mechanical complications. *Conclusions:* These definitions and recommendations based on a critical evidence review and expert consensus are proposed to assist clinicians in ultrasound-guided vascular access and as a reference for future clinical research.

Keywords Central venous access · Ultrasound guidance · Arterial cannulation · Vascular access · Critical care ultrasound · RAND · GRADE · Guideline · Evidence-based medicine

Introduction

Vascular cannulation is a fundamental clinical skill. Common vascular access procedures in adults and children include peripheral venous, central venous and arterial cannulation. Although these procedures can have major and minor complications, their success significantly depends on patient anatomy, comorbid conditions and operator skill [1, 2].

Ultrasound guidance for vascular access has been in clinical practice for more than 30 years and has been increasingly utilised for target vessel visualisation to minimise complications and increase success rates during vascular cannulation. Multiple studies have demonstrated significantly increased safety, effectiveness and efficiency of ultrasound-guided vascular access, as compared to cannulation by anatomical landmarks and/or acoustic Doppler [3–5]. However, the successful and safe integration of this tool into clinical practice requires additional training and experience.

Multiple published guidelines support the clinical utility of ultrasound guidance, but together they only partially address the best practice of ultrasound-guided vascular access [6–16]. Recommendations from our consensus vary significantly in their quality, methodology, clinical scope and targeted audience. A new systematic approach has been proposed to address ultrasound-guided practice [17, 18]. These ultrasound-guided vascular guidelines were structured systematically and were developed with sound and validated scientific methodology in an international multidisciplinary fashion in order to impact clinical practice decisively [19].

This paper is a condensed version of the formal recommendations on ultrasound guidance during vascular access. A detailed version is accessible online as supplemental material.

Methods

Experts in ultrasound-guided cannulation were identified on the basis of their previous peer-reviewed articles related to this topic during the past 10 years.

The literature search was performed in two ways. The first method entailed a systematic search by multiple panel experts checked by a professional librarian. The medical subject headings included 'ultrasound', 'central venous access', 'arterial cannulation', 'vascular access', peripherally inserted central catheter (PICC)', 'complications' and 'training'. The second method entailed a systematic search of English-language articles from 1985 to 2010 by an epidemiologist assisted by the librarian. The two bibliographies were then compared for thoroughness and consistency. The GRADE method was the utilised to score the literature and transform it into level of evidence. This grading scheme classifies recommendations as either strong recommendations or weak suggestions. The quality of evidence was further classified as high (grade A), moderate (grade B), or low (grade C) according the study design, consistency of results and directness of the evidence.

The expert panel met in Amsterdam (World Conference on Vascular Access, June 15, 2010) and Rome (WINFOCUS World Conference–GAVeCeLT Meeting, October 8, 2010). The experts formulated draft recommendations before each conference to serve as a foundation for subsequent discussion and evaluation. The voting process required expert judgment utilising GRADE factors. This process provided a structured and validated method for expert panel activities.

Results

A total of 229 articles were collated into a single bibliography. All of these articles were individually appraised on the basis of methodological criteria to determine the initial quality level. The final judgment about the evidence quality was completed after the articles had been assigned to their relevant recommendations.

General results

The panel of experts reviewed 9 proposed definitions and 50 recommendations. Of the 59 original proposals, only 47 achieved approval as final recommendations. These finalised statements each have an assigned evidence level and recommendation grade.

Recommendations

Consensus definitions (Table 1)

The panel of experts developed consensus definitions on ultrasound cannulation, ultrasound imaging and ultrasound needle visualization (Table 1).

Table 1 Recommended definitions

Domain code	Suggested definition	Level of evidence	Degree of consensus	Strength of recommendation
D1.S1. Ultrasound-guided cannulation	This term is defined as ultrasound scanning being performed to verify the presence and position of a suitable target vessel before skin puncture followed by real-time ultrasound imaging to guide the needle tip throughout the vessel puncture process	NA	Very good	Strong
D1.S2. Ultrasound-assisted cannulation	This term is defined as ultrasound scanning to verify the presence and position of a suitable target vessel before needle insertion without real-time ultrasound needle guidance	NA	Very good	Strong
D1.S3. Ultrasound verification of intravascular placement	This is defined as the use of ultrasound imaging to confirm the correct local placement of guidewires and catheters in the target vessel. It follows from this definition that ultrasound imaging may detect guidewire and/or catheter malposition	NA	Very good	Strong
D1.S4. Ultrasound-guided central venous cannulation	Central venous cannulation is achieved when the tip of the catheter is located either in the lower part of the superior vena cava or cavo-atrial junction. No recommendation can be made regarding the preferred site for ultrasound-guided central venous cannulation in a particular patient. The veins that are commonly cannulated include the internal jugular, axillary, brachiocephalic, subclavian and femoral veins. Peripheral upper extremity vessels such as the basilic, cephalic and brachial veins can also be utilised	NA	Very good	Strong
D1.S5. Ultrasound-guided arterial access	Ultrasound facilitates detection of arteries due to their pulsation and reduced compressibility. Ultrasound-guided arterial cannulation is defined as real-time needle guidance for puncture and cannulation. Ultrasound-assisted arterial cannulation is defined as arterial imaging to confirm location and patency followed by cannulation without real-time needle guidance	B	Very good	Strong
D1.S6. Complications of vascular access	Major complications of vascular cannulation include inadvertent arterial or venous puncture, bleeding, pneumothorax, airway compromise and nerve injury. These complications may be significantly reduced with ultrasound guidance during vascular cannulation	A	Very good	Strong
D3.S1. Ultrasound vascular imaging	Transverse vascular imaging is defined as ultrasound scanning of a blood vessel in its short axis. Longitudinal vascular imaging is defined as ultrasound scanning of a blood vessel in its long axis	NA	Very good	Strong
D3.S2. Needle orientation	The orientation of the cannulation needle is defined as in plane when the trajectory of the needle is fully included in the plane of the ultrasound beam. Needle orientation is defined as out of plane when the needle is only partially visualised during ultrasound imaging	NA	Very good	Strong
D3.S4. Ultrasound assessment of vessels	Target vessel assessment by ultrasound is defined as ultrasound scanning of all clinically relevant cannulation sites to determine the optimal site prior to cannulation. This clinical approach to the target vessel can also assess vessel size, depth, patency, respiratory collapse and proximity to vital structures	B		Strong

NA not applicable

It is clinically advantageous that ultrasound vascular imaging allows the demonstration of a patent and healthy vessel prior to cannulation [20, 21]. Real-time ultrasound needle guidance optimises the probability of needle placement in the vessel upon first pass while minimising the risk of complications [22, 23]. Although this approach reflects optimal practice, in true clinical practice it is not always possible to achieve this ideal.

The evidence suggests that novel ultrasound technologies, techniques and needles can improve the beneficial effects of ultrasound-guided vascular cannulation [24–27]. Furthermore, ultrasound imaging can confirm correct central venous catheter tip position [28, 29]. Although the majority of studies have focused on cannulation of the internal jugular vein [5, 8–12, 30–36], more recent studies have demonstrated the safety and efficacy of ultrasound-guided during femoral and subclavian cannulation [18, 37]. Multiple studies have consistently confirmed that the utilisation of ultrasound guidance during vascular guidance significantly reduces major complications [1–3, 6–14, 38, 39].

It is important to remember that transverse and longitudinal vessel imaging are defined according to the spatial relationship between the ultrasound probe and the vessel. In contrast, needle imaging by ultrasound is defined as in plane or out of plane on the basis of the positional relationship between the axis of the needle and the plane of the ultrasound beam. According to these definitions, an ultrasound-guided vascular approach has the following options: vessel cannulation in plane with the vessel imaged transversely or longitudinally; and, vessel cannulation out of plane with the vessel imaged transversely or longitudinally.

From a practical point of view, when the vessel is visualised in the transverse axis, the puncture is usually performed out of plane. Similarly, vessel puncture in plane is typically performed visualising the vessel in the long axis. Experienced operators may utilise a combination of these techniques by imaging the vessel obliquely with the cannulation needle remaining in plane to facilitate an optimal trajectory in especially challenging situations.

Although some operators have associated transverse imaging with an out-of-plane approach [40], this may not always be accurate because the internal jugular vein can be punctured in plane while being visualised in the transverse axis.

Ultrasound remains an important tool for choosing the optimal target vessel for optimal clinical outcome. A pre-cannulation ultrasound examination of the vessels in the area of interest will detect those whose puncture may be difficult or impossible. This may be due to variations in size, position and patency.

In the pre-ultrasound era, vessel cannulation choices were limited by landmark techniques. Ultrasound imaging offers cannulation opportunities that may not always be possible with anatomical landmarks alone. Clinical examples include the internal jugular vein (Fig. 1), the external jugular vein, the innominate vein [40], the subclavian vein [18, 41], the axillary/subclavian veins (Fig. 2) and the cephalic vein. Ultrasound imaging can also be used to optimise the choice of an upper extremity vein for positioning a peripherally inserted central venous catheter (PICC) (Fig. 3).

Available technology and technique for ultrasound vascular access (Table 2)

The expert consensus process has defined the preferred probes for ultrasound-guided cannulation and the preferred settings for challenging patients.

Higher probe frequencies are most suitable for superficial vessels because higher image resolution enables the visualisation of adjacent nerves and smaller arterial branches. Furthermore, these kinds of probes are ideal for guiding central venous cannulation in neonates and small children. Lower probe frequencies are required for imaging target vessels at a greater depth including obese patients [42].

Although there is clinical interest in three-dimensional (3D) ultrasound for vascular access, two-dimensional (2D) imaging is the current clinical standard [20, 43].

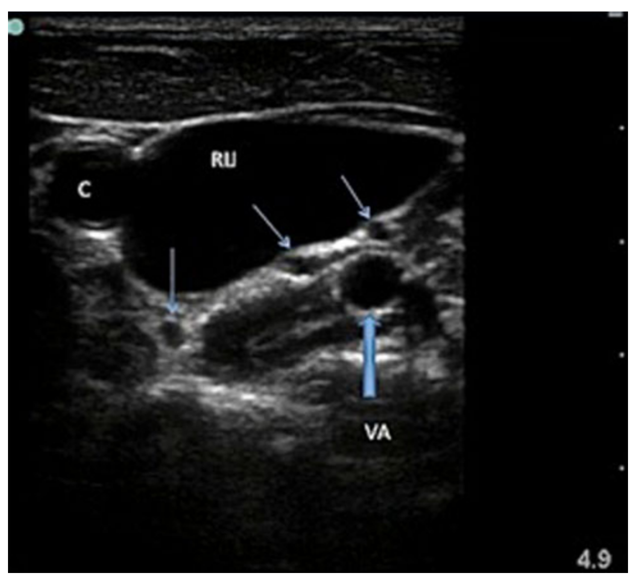

Fig. 1 Cross-sectional image through vessels as the base of the *right* neck as viewed from above the patient's head. The carotid artery (C) and large right internal jugular (RIJ) vein lie side by side. High-resolution ultrasound and accurate needle visualisation allow such collateral structures to be identified and avoided. The artery behind the vein vertebral artery (VA) is the thyro cervical trunk (a major branch of the subclavian artery), which is clearly vulnerable if the vein is transfixed out of plane by a needle in this area

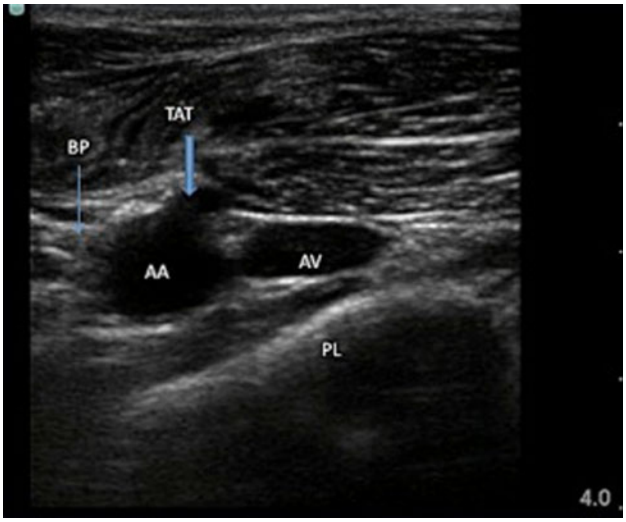

Fig. 2 Cross-sectional image of the infraclavicular axillary vessels as viewed from the *right* side of the patient. The depth of field is 4.0 cm. The axillary vein (AV) lies close to the axillary artery (AA) with the chest wall and pleura (PL) below. A significant branch of the axillary artery the thoraco-acromial trunk (TAT) is shown, which branches out with tortuous anterior branches crossing over the vein. The brachial plexus (BP) is typically in close proximity to the artery. High-resolution ultrasound and accurate needle visualisation allow such collateral structures to be identified and avoided

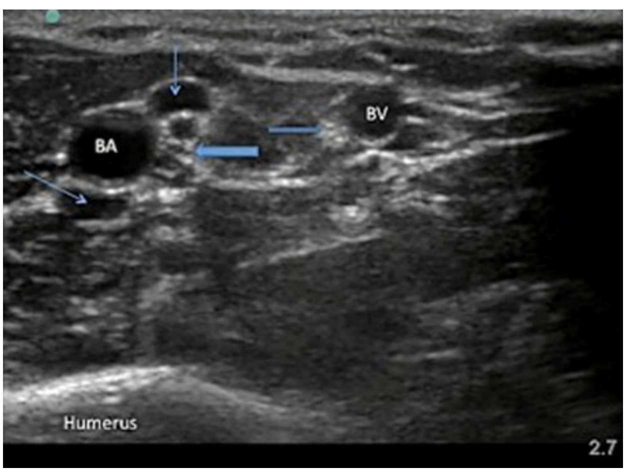

Fig. 3 Cross-sectional image of medial aspect of right upper arm, approximately midway between elbow flexure and axilla as viewed from the patient's feet. The depth of field is 2.7 cm. The brachial artery (BA) is accompanied by two partially compressed basilic veins (BV) (venae comitantes *small arrow*) and a nerve plexus (*large arrow*). The basilic vein is usually closely accompanied by the medial cutaneous nerves of the forearm (*medium arrow*). High-resolution ultrasound and accurate needle visualisation allow such collateral structures to be identified and avoided

Doppler imaging is regarded as an advanced ultrasound skill [42] without improving success [44].

Echogenic needles have been designed to provide better ultrasound visibility in the section proximal to the bevel. There is little evidence for their superiority over standard cannulation needles [20, 22–24].

Image saving is not a clinical standard in point-of-care ultrasound imaging such as during vascular cannulation. Nevertheless, images are often saved informally if they are of particular interest. This current practice may impact subsequent clinical management and information governance.

Continuous visualisation of the needle during its trajectory (in-plane technique) is particularly relevant when the major cannulation risk is to penetrate the posterior wall of the vein. In contrast, a transverse view of the vein associated with an out-of-plane puncture may be preferable in the setting of small target vessels or when vital structures are in close proximity to the target vessel. The in-plane puncture technique may require more training, because it implies having the skills to direct the needle exactly within the plane of the probe. Although the evidence base is not yet strong in this regard [20, 45–47], this expert panel believes that adequate training for ultrasound-guided central venous access should include knowledge and practice of both techniques.

Integration in clinical practice

Ultrasound vascular access in neonates and children (Table 3)

Clinical experience with ultrasound-guided vascular access in paediatrics started later than in adults [5, 31, 32, 46, 47]. Ultrasound-guided venous access results in a lower technical failure rate (overall and on first attempt), faster access and a reduction in mechanical complications [32, 48, 49]. However ultrasound visualisation, puncture and cannulation of central veins in neonates and children require more training and it has a longer learning curve than in adults.

Puncture of the internal jugular vein in neonates is still challenging and to date there are no large studies demonstrating the advantage of ultrasound guidance. For this reason, no evidenced-based recommendation can be made, but this panel of experts believes it is helpful to use ultrasound for routine puncture in both routine and difficult cases. By recommending "at least" ultrasound skin marking, we still recommend the ultrasound guidance as it improves the success rate, allowing pre-location of vessels; ultrasound guidance should be used as soon as minimal experience with ultrasound is achieved by the operator [49].

Ultrasound visualisation of the subclavian vein from the clavicle to the brachiocephalic vein is possible in many cases. A longitudinal view of these veins allows an in-plane needle approach where the needle tip and shaft are clearly seen [50]. Two different approaches have been described. The infra-clavicular approach [51] offers a

Table 2 Recommendations on available technology and ultrasound cannulation technique

Available technology and technique for ultrasound vascular access				
Domain code	Suggested definition	Level of evidence	Degree of consensus	Strength of recommendation
D2.S1	The frequencies of ultrasound transducers for vascular access range from 5 to 15 MHz. This broad range of frequencies may be incorporated into a single broad frequency probe	B	Very good	Strong
D2.S2	Probes may have a linear or curvilinear scanning surface (footprint). Small curvilinear probes may fit well within anatomically confined areas in children or adjacent to the clavicle. The footprint of the probe is important and typically ranges from 20 to 50 mm in length. Smaller footprint probes may be preferable for a paediatric patient	C	Very good	Strong
D2.S3	2D imaging is currently the standard technology for ultrasound-guided vascular access	B	Very good	Strong
D2.S4	Doppler functions during ultrasound vascular imaging require advanced competence from the operator	B	Very good	Strong
D2.S5	Needle guides can be used to improve the cannulation success for novice ultrasound users	B	Very good	Strong
D2.S6	The screen of the US machines should be placed in the line of sight of the needle insertion	B	Very good	Strong
D2.S7	US devices should have the ability to record and save images/loops for documentation and teaching. Ideally these should be stored on the hospital picture archiving and communication system (PACS) or similar along with other imaging. This is particularly important if abnormal pathology is seen, e.g. thrombus, or if complications have occurred	B	Very good	Strong
D3.S3	The utilisation of the in-plane technique, usually associated with a long-axis visualisation of the vessel, leads to higher precision and fewer complications. It should be used when possible, although it is more challenging	B	Very good	Strong

Table 3 Recommendations on ultrasound vascular access in neonates and children

Ultrasound vascular access in neonates and children				
Domain code	Suggested definition	Level of evidence	Degree of consensus	Strength of recommendation
D4.SD1.S1–2	Ultrasound guidance should be routinely used for short- and long-term central venous access in children and neonates	A	Very good	Strong
D4.SD1.S3	Ultrasound vessel imaging with ultrasound assistance as "a minimum" should be routinely performed before internal jugular vein puncture in neonates	A	Very good	Strong
D4.SD1.S4	In neonates, ultrasound screening should be used before subclavian vein puncture. Ultrasound-guided puncture should be considered for catheterization using the supra-clavicular route, but this technique requires experienced operators	C	Some	Weak
D4.SD1.S5	Ultrasound vessel screening should be routinely used before femoral vein puncture. Ultrasound-guided femoral puncture is recommended to decrease inadvertent arterial puncture	B	Very good	Strong
D4.SD1.S6	Ultrasound guidance can be considered when difficult peripheral venous access is required in areas such as the antecubital fossa and ankle. Blind deep antecubital fossa puncture should disappear	C	Very good	Strong
D4.SD1.S7	Ultrasound-guided arterial catheterization improves first-pass success and should be used routinely in children and neonates	A	Very good	Strong
D4.SD1.S8	After central venous catheter placement in paediatric patients including neonates, the ultrasound equipment should remain easily accessible at the patient's bedside to detect early life-threatening catheter-related complications such as pneumothorax, cardiac tamponade and hemothorax	B	Very good	Strong
D4.SD1.S9	There is no ideal site for cannulation in children; the best site should be determined after ultrasound examination	A	Very good	Strong

longer view of the vein and infra-clavicular exit site. With this approach, the operator has to deal with the acoustic shadowing from the clavicle. Strict alignment of the needle and probe is mandatory during the short distance of blind progression. The supra-clavicular approach [52], i.e. passing above the clavicle, offers perfect in-plane needle visualisation that is not interrupted by a bony structure. Owing to the probe orientation in the supra-clavicular fossa, only the distal end of the subclavian and the brachiocephalic veins is visualised. In small children and neonates, special care should be given to the brachial plexus by visualising it and avoiding a too lateral approach. This approach needs to balance issues of comfort and infection [53].

Ultrasound visualisation of femoral veins has been shown to be difficult in infants [54, 55]. Structures in the inguinal region are far less echogenic than in the neck region. The puncture of the femoral vein should be performed close to the inguinal ligament at the level of the common femoral artery. Low abdominal compression can be used to facilitate vein puncture. If no increase in diameter occurs, iliac vein thrombosis should be suspected [54].

In neonates and children, peripheral venous cannulae are usually inserted [49]. When superficial veins are not available and a difficult peripheral access occurs or is anticipated, ultrasound guidance should be considered for cannulation of deeper non-externally visible veins.

Ultrasound visualisation of superficial veins may be difficult because the probe may compress the veins. The use of a gel "stand off device" may be helpful in such situations. Deep veins can be effectively visualised and cannulated with ultrasound guidance [56].

Peripherally inserted central catheters should also be positioned with ultrasound guidance providing the arm veins are of appropriate size (at least 3 mm diameter).

Peripheral arteries in neonates and children are smaller and more difficult to detect than in adults. Therefore, it is recommended to use ultrasound-guided arterial catheterization routinely in these patients. The experience gained by using ultrasound routinely will be very beneficial in difficult or extreme cases [57].

Paediatric central venous cannulation is a delicate and potentially dangerous procedure, even if performed by ultrasound guidance. Therefore, it is strongly recommended to have the ultrasound equipment available soon after the procedure for early ultrasound detection of life-threatening complications [49].

Most of the benefit of ultrasound during central venous cannulation comes out not only from the act of ultrasound-guided puncture, but particularly from the pre-procedural ultrasound evaluation of all the possible venous options. This evaluation may allow a rationale choice of the most appropriate patent vessels to cannulate. In order to avoid the risk of venous thrombosis, this panel suggests that the external diameter of the catheter should not exceed 1/3 of the internal diameter of the vein. Similar measurements can avoid the insertion of a J-wire guide that is larger than the vessel [58]. Further research is required to compare both the mechanical and infectious complications for different access sites in neonates and children.

Ultrasound vascular access in adults (Table 4)

There is a broad consensus and an extensive body of evidence-based literature demonstrating that real-time ultrasound-guided venipuncture is associated with fewer immediate complications, faster access and reduced costs [3, 6–15, 20, 22, 24, 38, 59].

Although some investigators have suggested the use of ultrasound for assistance of vascular access [60], it is now evident that the full benefits of ultrasound are obtained only when coupling the pre-procedural ultrasound assessment with a real-time ultrasound-guided venipuncture.

Although most of the randomised clinical trials carried out in this area have focused on the internal jugular vein [9–12, 34, 36, 59, 60] and—to a lesser extent—on the subclavian vein [9, 41] and the femoral vein [6], it is likely that with growing clinical experience the benefits of ultrasound-guided venipuncture can be extended to all venous access sites.

The advantages of ultrasound guidance are evident for both short-term (non-tunnelled) and long-term (tunnelled, or totally implanted) central venous access [61], because in all cases the visualisation and puncture of a central vein are the main step of the manoeuvre.

Surgical cut-down and direct cannulation of a superficial vein for long-term access in adult patients should be discouraged, as studies have shown that it appears to be less efficient and clearly associated with an increased risk of infection [14, 15, 59]. Patients undergoing repeated long-term venous access procedures have a much higher frequency of thrombosed veins at the puncture site. Non-compressible veins, the presence of engorged collaterals or reverse venous flow on Doppler all suggest more central great vein blockage, which predictably leads to a failure to secure guidewire/catheter tip placement in the superior cava vein or right atrium. In short-term central venous catheters, ultrasound guidance allows the operator to obtain an insertion site in a satisfactory location for proper securement, adequate room for dressing and taking into account the patient's comfort. Thus, adoption of ultrasound guidance may have a significant favourable impact on the risk of catheter contamination and catheter-related infection [9, 15, 53] and on the risk of catheter-related venous thrombosis [62].

Although the evidence is less compelling when compared to direct central venous access, in the last decade there has been a growing clinical experience showing that ultrasound guidance is of importance when positioning PICCs.

Table 4 Recommendations on ultrasound vascular access in adults and cost-effectiveness

Domain code	Suggested definition	Level of evidence	Degree of consensus	Strength of recommendation
Ultrasound vascular access in adults				
D4.SD2.S1	Ultrasound guidance should be routinely used for short-term central venous access in adults	A	Very good	Strong
D4.SD2.S2	Ultrasound guidance should be routinely used for long-term central venous access in adults	A	Very good	Strong
D4.SD2.S3	PICCs should be routinely inserted at mid arm level by ultrasound guidance using micro introducer technique	A	Very good	Strong
D4.SD2.S4	Use of ultrasound guidance should be taken into consideration for any kind of peripheral intravenous line when difficult access is anticipated	B	Very good	Strong
D4.SD2.S5	Ultrasound-guided arterial catheterization improves first-pass success and should be used routinely in adults	A	Very good	Strong
D4.SD2.S6	Ultrasound can accurately detect pneumothorax and should be routinely performed after central venous catheter cannulation when the pleura could have been damaged	B	Very good	Strong
D4.SD2.S7	CEUS (contrast-enhanced ultrasound) is a valid method for detecting a central venous catheter tip in the right atrium	B	Very good	Strong
Cost-effectiveness of the use of ultrasound for vascular cannulation				
D5.S1–3	Ultrasound-guided vascular access has to be used because it results in clinical benefits and reduced overall costs of care makes it cost-effective	A	Very good	Strong

PICCs were considered a venous access device with limited indications, high risk of failure during positioning, low comfort for the patient and high risk of late complications. Most of these problems were related to the limited availability of superficial veins of the arm, to the unpredictable size and direction of arm veins, as well as the exit site in the antecubital area, which was associated with poor comfort and difficulty of securement and dressing.

With the introduction of ultrasound guidance and the modified Seldinger technique, it became rapidly evident that ultrasound-guided PICCs were very different from traditional PICCs [63]. Ultrasound guidance allowed PICC placement in the majority of patients, even when there were no obvious superficial veins in the antecubital area. Insertion in this area allows ease of securement and dressing, patient comfort, low mobility and low risk of contamination. Many studies suggest that ultrasound-guided PICCs are associated with an average risk of infection significantly lower than standard central venous catheters [63]. Most of this effect seems to be related to the location of the exit site at mid-arm, which is far from airway secretions. It may also be related to case selection where PICCs are chosen for less intensive treatment regimens.

Ultrasound-guided arterial puncture is less well documented in the literature, when compared to venous cannulation [64]. Nonetheless, meta-analysis [64] and expert consensus suggest that ultrasound cannulation of the radial, ulnar, brachial and femoral arteries can be achieved more easily and rapidly than standard landmark-based cannulation. This is particularly true when the pulsation of the artery is not evident, or when the artery is small. It is recommended that ultrasound should be used routinely in adults when trained operators are available.

If ultrasound guidance is not used routinely, then we suggest that repeated landmark-based attempts at multiple sites should be discouraged because of a high failure rate and risks to the patient. We suggest that operators stop such attempts early and visualise vessels with ultrasound to demonstrate a patent visible vessel, which can be cannulated in a controlled successful sequence with ultrasound guidance.

In order to check for immediate post-procedural lung complications, an ultrasound examination of the pleura has several advantages: it is bedside, easy to learn and it can be performed using the same probe used for cannulation [65].

Trans-thoracic echocardiography, particularly if carried out with contrast enhancement [66], has proven to be a valid method for the detection of the tip of the catheter in the right atrium. Limits of this procedure include the following: it cannot give precise information when the tip is in the superior vena cava; it typically requires a probe different from the probe used for ultrasound-guided cannulation; it requires specific training; it requires the injection of echo-contrast medium.

Cost-effectiveness of the use of ultrasound for vascular cannulation (Table 4)

Cost-effectiveness analysis techniques can be used when comparing varying test modalities. For a strategy to be more cost-effective the costs of care need to be decreased and/or the outcome improved. When both cost and outcomes are improved, then the strategy of choice is termed "dominant." There is a growing body of evidence that demonstrates the clinical and economic value of ultrasound-assisted vascular access. In general, an overall improvement in success rates, reduction in the time taken for procedures and a reduction in complications suggest better outcomes and lower costs. The added value of ultrasound assistance might be especially important for patients undergoing repeated access procedures. Given these findings, expanding of resources and application could provide significant cost savings.

Decision and sensitivity analyses can be used to quantitatively measure and report the magnitude of the cost-effectiveness and potential cost savings [3, 6]. There is still debate on the cost-effectiveness of routine use of ultrasound for vascular access [67]. Meta-analysis [3, 6] and guidelines [14] demonstrated that the use of ultrasound guidance is clearly cost-effective not only in terms of the reduction of major complications but most of all regarding the reduction in access time. This cost was never considered in most economical evaluations but it is important when an emergency central vascular access is necessary or when the scheduled surgery is delayed because of a failed or multiple attempts procedure.

Education and training in ultrasound for vascular access placement (Table 5)

Imaging of the target vein by ultrasound prior to cannulation is clinically useful to confirm the presence of a target vein of adequate size for cannulation. This cannot be assumed because nearly 10 % of patients have abnormal venous anatomy, including the absence of the vein of interest [68]. Furthermore, it is advantageous to confirm a reasonable target vessel (vein or artery) before setting up the sterile field because this clinical approach will facilitate optimal site selection and minimise delays. This advantage is even more significant in the setting of small vessels such as in paediatric care. Ultrasound-guided cannulation, more than ultrasound assistance, has been demonstrated to be safer and more effective [69]. A major advantage of this method is that the learner receives visual feedback during vascular cannulation. The needle trajectory can be visualised and adjusted in real time to ensure a direct approach to the vessel of interest with no risk of puncture of nearby vital structures.

Accreditation of the ultrasound vascular access skills (Table 5)

Ultrasound for vascular access has disseminated widely throughout clinical practice, but not always with the

Table 5 Recommendations on education, training and accreditation in ultrasound vascular access

Domain code	Suggested definition	Level of evidence	Degree of consensus	Strength of recommendation
Education and training in ultrasound for vascular access placement				
D6.S1A–S2A	Ultrasound-assistance should be included in the design and conduct of education and training for venous and arterial cannulation	B	Weak	Some
D6.S1B–S2B	Ultrasound guidance should be included in the design and conduct of education and training for venous and arterial cannulation	A	Perfect	Strong
D6.S3	Clinical simulation techniques should be included in the design and conduct of education and training for all forms of vascular cannulation	B	Good	Strong
D6.S3–4	Ultrasound guidance should be used for any vascular access procedure in adults as in children and neonates when the trainee has obtained appropriate competence	B	Good	Strong
Accreditation of the ultrasound vascular access skills				
D7.S1	Accreditation, credentialing or documentation of proficiency of a clinical learner in ultrasound vascular procedures should include formal education and training (clinical simulation) in an ultrasound-based curriculum	NA	Good	Strong
D7.S2–3	Accreditation, credentialing or documentation of proficiency of a clinical learner in ultrasound vascular procedures should include independent evaluation of these procedures performed in real practice by the candidate	NA	Good	Strong
D7.S4	There should be development of a consensus standard for the accreditation of training and education programs in ultrasound-guided cannulation	NA	Good	Strong

NA not applicable

support of formal training [69]. Although there is a general community consensus that formal education and training is necessary, barriers to this goal are apparent such as hardware deficiencies, insufficient instructor availability and a perceived lack of time required to achieve certified competency [70]. Formal education with theoretical lessons on ultrasound physics, ultrasound anatomy (knobology) and hands-on-training on inanimate models could achieve standardisation across medical centres [70].

Clinical simulation provides an optimal training milieu for the teaching and practice of ultrasound guidance by learners from multiple clinical environments. Simulation models can also provide essential psychomotor feedback required for optimal learning of ultrasound-guided cannulation [69]. Recent studies demonstrate the importance of independent evaluation of learner performance before and after the teaching intervention [71] to allow objective confirmation of whether the learner has mastered the content of the clinical course. There is a lack of consensus and evidence for standards of training and certification in ultrasound vascular cannulation. Recently, the WoCoVA (World Conference on Vascular Access) Foundation created a task force of experts to define evidence-based minimal requirements for teaching ultrasound-guided cannulation as well as the minimal skills required for achieving competence.

Sterility during ultrasound vascular procedures (Table 6)

Aseptic technique is a cornerstone in catheter-related bloodstream infection (CRBSI) prevention. The adoption of maximal barrier precautions during catheter insertion is recommended by current Centers for Diseases Control and Prevention (CDC) guidelines to ensure asepsis [53]. Maximal barrier precautions are very effective in significantly reducing the risk of CRBSI [72].

When a catheter insertion is performed with ultrasound guidance, maximal barrier precautions must logically and necessarily include a sterile cover for the probe and cable and the use of sterile gel.

The sterile cover for the probe and cable should enable the operator to cover these tools without risk of contamination and cover the whole of the cable. Sterile gel should be used inside and outside the sleeve.

Prevention of infectious and mechanical complications with ultrasound-guided cannulation (Table 6)

Ultrasound guidance, by reducing the number of required needle passes through the skin and procedure times, is likely to minimise bacterial contamination of the central access insertion site. Furthermore, the risk of a haematoma and venous thrombosis is also reduced which is

Table 6 Recommendations regarding sterility using ultrasound guidance and prevention of infectious and mechanical complications using ultrasound-guided cannulation

Domain code	Suggested definition	Level of evidence	Degree of consensus	Strength of recommendation
Sterility during ultrasound vascular procedures				
D8.S1	Sterile techniques should always be used during the placement of a vascular access device, including hand washing; sterile full body drapes; wearing of sterile gowns, gloves, caps and masks covering both the mouth and nose. Probe and cable sterility have to be maintained using sterile gel and appropriate probe and cable shields	A	Very good	Strong
Prevention of infectious and mechanical complications with ultrasound-guided cannulation				
D8.S2	Ultrasound guidance should be used in order to decrease the rate of CRBSI in adults and children	C	Very good	Strong
D8.S3–4	A multi-faceted strategy, including the use of ultrasound guidance with specific preventive and educational measures and the promotion of good practices applied by both medical and nursing staff, is suggested in order to reduce the incidence of CRBSI	B	Good	Strong
D8.S5	Ultrasound guidance should be used to avoid cannulation of thrombotic sites	A	Very good	Strong
D8.S6	Ultrasound guidance, by reducing puncture attempts, technical failure rates and mechanical complications, has to be preferred because of a reduced incidence of catheter-related thrombosis	A	Very good	Strong

likely to further reduce the risk of access site infection. A multi-faceted strategy has been demonstrated to reduce the risk of CRBSI [53]. The use of ultrasound guidance for catheter insertion should be included in such a multi-faceted approach, with the specific goal of infection prevention. Health-care personnel should be aware that the use of ultrasound enhances the safety of the manoeuvre by reducing the risk of infection, in addition to avoidance of mechanical complications. The CDC guidelines recommend that multi-faceted strategies are "bundled". The concept of "bundle" was introduced by the Institute for Healthcare Improvement [73] and developed in large studies [74].

The positive effect of ultrasound guidance on the risk of infection was clearly shown in a randomised study designed to evaluate whether ultrasound-guided catheterization of the internal jugular vein was superior to the standard landmark method [9].

The CDC guidelines for the prevention of intravascular catheter-related infections recommend the use of ultrasound guidance to place central venous catheters [53].

Compression ultrasound allows the detection of thrombosed veins and it is a very accurate and time-sparing method to detect thrombosis, whether partial or total [75]. The conventional risk factors for thrombosis are summarised in the Virchow's triad: vascular injury, stasis and hypercoagulability. On this basis, factors involved in the pathogenesis of catheter-related thrombosis include vessel wall injury as a result of the needle insertion; venous stasis or occlusion as a result of the catheter placement; the central position of the tip; the material of the catheter; the nature of substances being infused. The use of ultrasound guidance can reduce the vessel wall injury and alter the choice of a vein to ensure an appropriate size for cannulation [76].

Summary

Significant evidence has supported the use of ultrasound guidance for central venous cannulation. This document has several differences from previously published manuscripts regarding ultrasound guidance during vascular access [14–16]. It addressed conflicting terminology of ultrasound vascular access through a validated methodology for the consensus process. It is based upon an evidence-based structured process in all recommendations regarding clinical outcomes not only for central venous cannulation but also for vascular access in neonates and for arterial cannulation. It addressed important issues regarding the optimal technique to use and how to apply it in everyday practice in order to reduce and detect life-threatening complications by using ultrasound. There are some topics that still need to be defined such as education, training and accreditation and further research is needed to clarify the role of ultrasound in infectious risk reduction. In conclusion, given the evidence from literature and based on voting results, ultrasound guidance has to be suggested as the method of choice for any kind of vascular cannulation given its higher safety and efficacy.

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