Ultrasound-assisted vascular access in children

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Vascular access in children can be challenging. There is a considerable body of evidence supporting the use of ultrasound to aid central venous access in adults, but less so in children. Benefits for experienced operators may be small, but there is evidence of benefit for those acquiring skills and for less frequent operators. Special considerations to bear in mind in paediatrics are the smaller size of the patient, the greater mobility of some of the vascular structures, the smaller and more superficially positioned vessels, greater variability in the anatomy, potentially less cooperative patients, and the smaller size of the equipment. The success and complication rates will depend on factors which include site of cannulation, ultrasound technique, the size and condition of the child, operator experience, and the presence of vascular anomalies, coagulation abnormalities, or previous cannulations.

Key points
Ultrasound is widely available, decreases the complications of paediatric vascular access (if used appropriately), and is a useful training tool.

Scrupulous attention to ultrasound technique and knowledge of normal (and common variations) anatomy is essential to avoid complications.

Ultrasound is particularly useful for assisting access to the internal jugular and femoral veins in all age groups and the subclavian vein in infants.

A small footprint hockey-stick probe of frequency 7–10 MHz is adequate for most children, but higher frequency probes are useful for smaller veins and difficult cases.

Developments in ultrasound technology including three- and four-dimensional probes are likely to improve vessel resolution and successful cannulation in children.

Advantages of ultrasound techniques over landmark insertion methods

(i) Clearly demonstrates vein presence, diameter, patency, direction, and relation to surrounding structures.
(ii) Puncture site and angle of approach of needle to target can be optimized to minimize the risk of complications.
(iii) Using real-time ultrasound can guide needle tip into vessel or can observe vessel compression so a transfixion technique can be used (Fig. 1).
(iv) Guidewire placement within the correct vessel can be confirmed (Fig. 2).
(v) Some immediate complications can be diagnosed or excluded (haematoma/carotid puncture/pneumothorax/haemothorax/pericardial effusion) with appropriate training.

Disadvantages of ultrasound techniques over landmark insertion methods

(i) More complex technique and need for good hand-eye coordination. Poor technique may lead to failure to visualize the needle tip. If the shaft of the needle is mistaken for the tip or if tissue deformation only is seen, then a false impression of the needle position may be given.
(ii) Limitations of ultrasound physics can cause errors, for example, reverberation artefact (Fig. 2) may give a false impression that the needle tip is deeper than it actually is.
(iii) In small infants, the physical size of the probe may be limiting.
(iv) Cost and maintenance of ultrasound equipment.

Ultrasound machines and probes

Over the last few years, there has been considerable advancement in the quality of ultrasound imaging available at the bedside. Initial ambivalence on the part of the paediatric anaesthetic community may in part be related to early experience with inappropriate technology. Although several machines are currently on the market, none offers a clear advantage. The optimal machine should incorporate a lightweight linear array probe with a small footprint, clear screen, high-quality two-dimensional imaging and availability of colour and spectral Doppler. Probes operating at 7–10 MHz are suitable for internal jugular puncture in most children and infants. Higher frequency imaging (13 MHz) will give higher definition and is of value for cannulation of smaller vessels such as antecubital fossa veins, long saphenous veins, and femoral vessels in infants. Lower tissue penetration with high-frequency probes leads to poorer visualization of deeper structures. However, this is of less practical importance in
children. A robust design, ease of use, ability to run on battery, and fast start up are further considerations.

**Principles of ultrasound vascular imaging**

**Positioning**

The machine, operator, and patient should be orientated in a straight line (Fig. 3).

The patient should be positioned to give easy access to the area of interest while avoiding compression or distortion of the anatomy. Aseptic precautions are mandatory.

**Initial examination**

Establish correct orientation; the probe is orientated so that the left side of the screen (as seen by the operator) corresponds to the left side of the patient.

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**Fig 1** (A and B) Ultrasound images of the left femoral vessels in newborn child. In (A), the artery (FA) and vein (FV) are clearly seen with the needle on the anterior wall of the vein. In (B), the needle has been advanced further causing the vein to be compressed. When cannulating small veins, it is common for the vein to be compressed in this way. Overly tentative advancement of the needle will often lead to failure in cannulation. Assuming no vulnerable structure lies deep to the vessel, it is often advisable to aim to transfix the vessel (with a careful, visualized, short thrusting movement) then withdraw the needle without imaging (while aspirating) until free flow of blood is seen.

**Fig 2** (A and B) In image (A), the IJV is imaged in long axis. The typical appearance of the vessel in long axis is a thick dark line extended across the screen. The guidewire is seen to lie freely within the lumen as a bright echogenic line. Deep to the line, a series of fainter parallel lines are seen, this is reverberation artifact (RA). In this view, it is easy to differentiate this artifact from the true image of the wire; however, when imaging a needle ‘out of plane’, this artifact can create a false impression of the depth of the needle. Image (B) is an alternative long-axis view of the jugular and brachiocephalic veins (right, RBC; left, LBC). The image is achieved by following the vein caudally in short axis until the probe is against the clavicle. The probe is then angled down acutely to point towards the heart. In this way, the patency of the vessels and the correct position of the wire can be confirmed as far as the superior vena cava (SVC) or right atrium.
Vessels are echolucent (black) and compressible. Anterior and posterior vessel walls are bright, whereas lateral walls are less distinct. Doppler mode can demonstrate vascular flow. Veins are more compressible and less pulsatile than arteries. Venous flow is towards the heart. Examine structures around and deep to target vessel to avoid arteries, nerves, and pleura.

Cannulate

Hold needle in dominant hand and probe in non-dominant hand. Commonly, vessel is visualized in transverse (short axis) plane. Vessel will appear as round or elliptical. The needle is introduced above the probe (out of plane) and appears as a small, bright dot (Fig. 1).

Alternatively, vessel viewed in longitudinal (long axis) plane. Vessel appears as black bar across the screen (Fig. 2). The needle is introduced from the side of the probe (in plane) and appears as a bright, white line across the screen.

Using either approach aim to visualize the needle tip, rather than the shaft continuously during advancement.

Peripheral access

Ultrasound may be a useful adjunct when cannulating veins in the antecubital fossa and above the elbow. Light touch is required to avoid compression of the vessel and transfixion is common during cannulation. Ultrasound assistance may help avoid the brachial artery and median nerve. This site may also be useful for peripherally inserted central catheters in neonates, infants, and children. The long saphenous vein can also be visualized with ultrasound.

External jugular vein

The external jugular vein (EJV) is consistently found in the superficial fascia of the neck crossing the sternocleidomastoid muscle obliquely (the vein may be duplicated). In case of difficulty, it is easily visualized on ultrasound examination more laterally and superficially than the internal jugular. It may be increased in size by head-down positioning, Valsalva manoeuvre, and distal occlusion (above the clavicle). It can be used in an emergency if there is no delay (otherwise intraosseous access may be more appropriate), although it is not technically easy to perform EJV cannulation in the awake child. Efforts to pass lines into the deeper veins are inconsistent (50–90%) as wires often fail to traverse the vein as it penetrates the deep fascia above the clavicle.

Internal jugular vein

The internal jugular vein (IJV) is a large and accessible vein from which a line can usually be easily passed into the superior vena cava (especially on the right). Compared with adults, cannulation of the right IJV (RIJV) may be more difficult due to short neck, shallow mobile compressible vein, variable anatomy, and overall reduced space to place the ultrasound probe. The overall and first pass success rates are therefore decreased, even with ultrasound; however, complication rates are not increased. Difficulty may also occur if there have been previous cannulations.

Anatomy

The vein is most commonly in the anterolateral position in relation to the carotid artery (CA) (Fig. 4). Variations in anatomy occur in up to 18% of children under 6 yr of age [absent (<1%)/small/ medial/extremely lateral]. The relationship to the CA changes with distance from the subclavian junction, with greater venous overlapping lower in the neck. Location, size, relationship to the CA, and thrombus can all be observed on ultrasound examination, as can complications such as pneumothorax and pericardial effusion (with suitable training). Very low in the neck, the subclavian or vertebral arteries may also be seen posterior to the vein.
Vein size, head position, and associated manoeuvres

Optimal positioning for cannulation is debatable. Most practitioners will extend the neck and rotate the head away from the site of cannulation. This will improve access to the neck in infants, but will also increase overlap of the vein and artery. Therefore, a neutral position is advocated. The use of ultrasound would detect excessive overlap and allow adjustment of position and site of cannulation. Head-down position, Valsalva, and liver compression will increase the vein diameter in children, but is of limited value in infants. Small diameter veins may cause difficulty with J-wires (the diameter of which is often greater than that of the vessel). Alternatively, straight wires may fail to pass sharp turns in the direction of the vein and may increase the risk of perforation. It is wise to have alternative wires of both kinds available.

Length and size of line

Correct positioning of central catheters is essential to avoid potentially life-threatening complications. Most are not checked until a postoperative chest X-ray (CXR) is obtained. Formulae for insertion length based on patients' height or weight have been reported, but do not take into account variation in puncture site and head position. An alternative is the use of surface landmarks to determine length. In practice, lines are more secure if placed up to their full length. Five-centimetre lines are suitable for most newborns, whereas 8 cm lines should be used in patients >10 kg. On CXR, the carina is a useful landmark, generally being above the pericardial reflection. The diameter of line should be selected according to the intended application. Lines should be no larger than required with no more lumens than necessary. Larger diameter lines carry an increased risk of complication (thrombosis or stenosis of the vessel); however, recommendations made by manufacturers may be unnecessarily conservative. Even in small neonates, 4 Fr double lumen or 5 Fr triple lumen lines are frequently placed during cardiac surgery when multiple infusions and large volume transfusion are anticipated. Alternatively, a 3 Fr or 20 G single lumen catheter will be acceptable for many applications.

Femoral vein

The femoral vein (FV) has traditionally been favoured in small children (to avoid intrathoracic complications). Care must be taken to avoid inadvertent puncture of the femoral artery (FA). Drawbacks are increased risk of infection, kinking, less accurate filling pressures, and increased incidence of thrombosis compared with the RIJV (range reported 4–35%). General anaesthesia is usually required, although insertion with local or regional anaesthesia is possible.

Anatomy

The FV lies superficially in the femoral triangle immediately medial and deep to the FA. The most common anatomical arrangement is shown in Figure 5. The common mnemonic NAVE (Nerve Artery Vein Empty space Lacunar ligament) from lateral to medial can be used to remember the anatomy; however, the external landmarks do not always predict the internal anatomy.

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![Ultrasound images of the RIJV taken in a 2-month-old infant (a) and adult (b) in the same scale (maximum depth of 3.2 cm). In absolute size, the adult vessels are much larger and deeper than in the infant. In practice, when cannulating an infant's vessel, the image would be magnified to place the vein at half to two-thirds of the depth of the screen (or the maximum resolution of the machine/probe), thus allowing greater resolution of the superficial structures. The anatomy is variable in both adults and children. In this adult, the CA is completely overlapped by the vein and lies deeper than is common. Mean diameter of the vein has been reported as 0.47 cm in infants and 1.94 cm in adults (without associated manoeuvres).]
percentage of overlap increases more distal to the inguinal ligament. The position of the sapheno-femoral junction is also variable and a potential cause of confusion. The vein is generally cannulated close to the inguinal ligament, but should not be punctured above the ligament as external compression may not be possible. Location, size, relationship to the FA, and thrombus can all be observed on ultrasound examination.

Vein size, position, and associated manoeuvres
Ultrasound studies demonstrate that reverse Trendelenburg positioning, Valsalva manoeuvre, or compression (1–2 cm above the inguinal ligament) can increase the size of the vein. There is no summative increase with multiple manoeuvres and compression may be the simplest and most effective of these techniques. Most practitioners put a bolster or sandbag under the ipsilateral hip and advocate a small amount of external rotation.

Length and size of line
Advice on size is similar to RIJV. As the inferior vena cava is longer than the superior vena cava, length is less critical. In obese children, short multilumen lines can cause problems of subcutaneous extravasation from proximal side holes.

Subclavian vein
The subclavian vein (SCV) is a common site for central venous access (especially longer term), due to reduced infection rates, reduced mechanical problems, and patient comfort. The vein is less mobile and less likely to collapse than the IJV. There is, however, a significant risk of complication with landmark techniques (3–34%) related to age, side of insertion (R>L, as there are more technical problems), and indication. The success rates in landmark studies in infants are consistently only around 80%, with the worst results in those <6 months. Ultrasound techniques offer the promise of improved results, although there is limited evidence even in adults.

Anatomy, techniques, and position
The SCV is formed as a continuation of the axillary vein as it passes the lateral border of the first rib and runs medially in the space between the clavicle and the first rib to the medial border of scalenus anterior where it joins the IJV to form the brachiocephalic vein. It can be visualized and cannulated above or below the clavicle with either long- or short-axis views, depending on the preferred technique. An interesting technique that has been very successful in a small study in infants and children involves obtaining a supraclavicular long-axis view of the SCV, combined with an infraclavicular in plane puncture. The needle is seen passing through the anterior wall of the SCV which can be catheterized under direct vision in the direction of its confluence with the IJV. The ipsilateral IJV can also be scanned to exclude or adjust wire malposition. This study of 25 patients had 100% success and no complications.

SCV diameter is maximal with Trendelenburg positioning, no shoulder roll, and neutral head position. Some head rotation and a small roll may be required to create space in infants.

Arterial lines
A small pilot study appeared to demonstrate a significant increased success rate when ultrasound was used for radial cannulation in infants. Ultrasound does allow for cannulation of vessels in atypical sites such as the mid-forearm, where pulses are less readily palpable. It is the authors’ practice to use ultrasound when cannulating FAs in infants and newborns. Ultrasound may also allow cannulation in situations where palpation is more difficult, such as low cardiac output conditions.
Training in the use of ultrasound

There are currently no national standards for training anaesthetists in ultrasound-guided vascular access in adults or children. The British Medical Ultrasound Society and The Royal College of Radiologists have attempted to define levels of competency in ultrasound use for non-radiologists (www.rcr.ac.uk/docs/radiology/pdf/ultrasound.pdf), where vascular access is within the critical care block. They suggest a minimum of 25 supervised line insertions on top of theory for basic accreditation in adults. There is no guidance in children.

A survey of paediatric anaesthetists in 2007 suggested that 74% of consultants had received some training in ultrasound use. Of these, 78% of the training was delivered in the workplace and 22% had attended external courses (usually 1 day). It is very unlikely that many would have fulfilled the above requirements.

References


Conflict of interest

None declared.

Training should ideally include:

Theoretical knowledge
Ultrasound physics and manipulation of image.
Relevant topographical anatomy, sonoanatomy, and common anatomical variants.

Practical supervision
Classroom and clinical situations.
‘Phantoms’, models, or computer simulators.

Named supervisor
Difficult with rotating trainees.

Logbook
With regular review and audit.

Formalized assessment accreditation and revalidation
Not yet available in anaesthesia.

Future developments

Machines are already getting smaller, faster, and have greater resolution than just a few years ago. This trend is likely to continue. The miniaturization of probes is especially welcomed in paediatric practice. Software that automatically steers the ultrasound beam more perpendicular to the needle, to enhance visibility, has already been developed. Manufacturers continue to try and improve needle-tip echogenicity. The development of three- and four-dimensional probes that allow tracking of needles without the need to move probes is increasingly reported in the literature and low footprint (hockey stick) three-dimensional probes are commercially available with potential application in paediatrics. It is also hoped that the gaps in training and accreditation can be addressed to ensure the best use of the available technology.

Please see multiple choice questions 8–12.