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REVIEW ARTICLES

Misplaced central venous catheters: applied anatomy and practical management

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Editor's key points

- This is a review with important practical applications and educational value.
- The authors present the issues related to misplaced central venous catheters.
- Normal and abnormal anatomy has been presented in the context of misplaced catheters.
- Useful practical aspects of managing misplaced catheters have been discussed in detail.

Summary. Large numbers of central venous catheters (CVCs) are placed each year and misplacement occurs frequently. This review outlines the normal and abnormal anatomy of the central veins in relation to the placement of CVCs. An understanding of normal and variant anatomy enables identification of congenital and acquired abnormalities. Embryological variations such as a persistent left-sided superior vena cava are often diagnosed incidentally only after placement of a CVC, which is seen to take an abnormal course on X-ray. Acquired abnormalities such as stenosis or thrombosis of the central veins can be problematic and can present as a failure to pass a guidewire or catheter or complications after such attempts. Catheters can also be misplaced outside veins in a patient with otherwise normal anatomy with potentially disastrous consequences. We discuss the possible management options for these patients including the various imaging techniques used to verify correct or incorrect catheter placement and the limitations of each. If the course of a misplaced catheter can be correctly identified as not lying within a vulnerable structure then it can be safely removed. If the misplaced catheter is lying within or traversing large and incompressible arteries or veins, it should not be removed before consideration of what is likely to happen when it is removed. Advice and further imaging should be sought, typically in conjunction with interventional radiology or vascular surgery. With regard to misplaced CVCs, in the short term, a useful aide memoir is: 'if in doubt, don't take it out'.

Keywords: central vein anatomy; central venous catheter; inferior vena cava; misplaced catheter; superior vena cava

The central veins are the target for placement of the internal section of central venous catheters (CVCs) and their tips. Large numbers are performed yearly, estimated at 200 000 in the UK in 1994, the majority via the upper body.[1] This number is likely to be increasing yearly for short- and long-term access. Ultrasound, ECG guidance, real-time X-ray imaging, and other aids dramatically increase the successful placement of needles, guidewires, and catheters, but significant numbers of catheter misplacements can still occur, particularly if operators are not fully proficient in such techniques. In addition, there are a large number of congenital and acquired abnormalities of the venous system, which will be encountered on an intermittent basis by anyone regularly performing such procedures.

We present an illustrated narrative review of this complicated area of practice and discuss practical management issues. It is generally easy to recognize and manage such abnormalities if you have seen or read about it before, but not if faced with them for the first time in a stressful clinical situation. Much of the literature is in the form of isolated case

reports or small series, which are cumbersome and time-consuming to access, and do not always provide pragmatic guidance or solutions to the problem. This information to our knowledge has not been drawn together previously in the anaesthetic or critical care literature.

Indications for a CVC

CVCs are inserted for a large number of different indications. These include administering drugs (vasopressors/inotropes, antibiotics, chemotherapy), monitoring central venous pressure (CVP), measurement of central venous oxygen saturation (Scv_{O_2}), renal replacement therapy, total parenteral nutrition, poor peripheral venous access, cardiac catheterization, and transvenous cardiac pacing. Many different types of catheters exist, for example, tunnelled or non-tunnelled, mono-lumen or multi-lumen, dialysis catheters, and peripherally inserted central catheters (PICCS). CVCs are inserted in a number of hospital locations (intensive care units, theatres, wards, radiology department) and by a number of

different healthcare professionals with varying techniques for insertion and for ensuring correct catheter placement. Whatever the indication or type of the central catheter inserted, the usual aim is to place the catheter tip in as optimal central vein location as is possible, avoiding misplacement and other complications of insertion.

Ideal catheter tip placement

The ideal catheter tip position has been the subject of much debate.[2][3] However, it is widely accepted that the tip of the catheter should be in as large a central vein as possible [typically the superior vena cava (SVC) or inferior vena cava (IVC)], ideally outside of the pericardial sac, and parallel with the long axis of the vein, such that the tip does not abut the vein or heart wall at an acute angle or end on.

There are potential complications associated with all tip positions. The most proximal venous valves lie 2.5 cm from the termination of the internal jugular (IJ) and subclavian veins (SCVs), and in the femoral vessels (Fig. 1). Incorrect catheter placement proximal to these valves will lead to

inaccurate CVP monitoring or potential irritation of the valve area by the catheter or infused fluids. In order to prevent the rare but lethal complication of cardiac tamponade, the tip should ideally lie proximal to the boundaries of the pericardial sac; however, too proximal placement of the tip increases the risk of thrombosis.[4][5]

The importance of achieving the ideal catheter tip position depends to some extent on the indication for the CVC. A misplaced catheter lying in a longitudinal plane of a large central vein may be suitable for some applications, for example, infusion of non-hypertonic fluids and monitoring CVP. However, other infusions such as parenteral nutrition, cancer chemotherapy, sclerosant drugs, and vasopressors require greater dilution and mixing of drugs for successful longer-term use. Similarly, extracorporeal circuits for dialysis, haemofiltration, apheresis, or cardiopulmonary bypass need very high blood flows past the catheters, plus separation of inflow and outflow catheters to avoid blood recirculation. Measuring central venous oxygen saturations (as a surrogate for mixed venous oxygen saturations) requires the catheter tip to lie either in or close to the right atrium (RA) to minimize
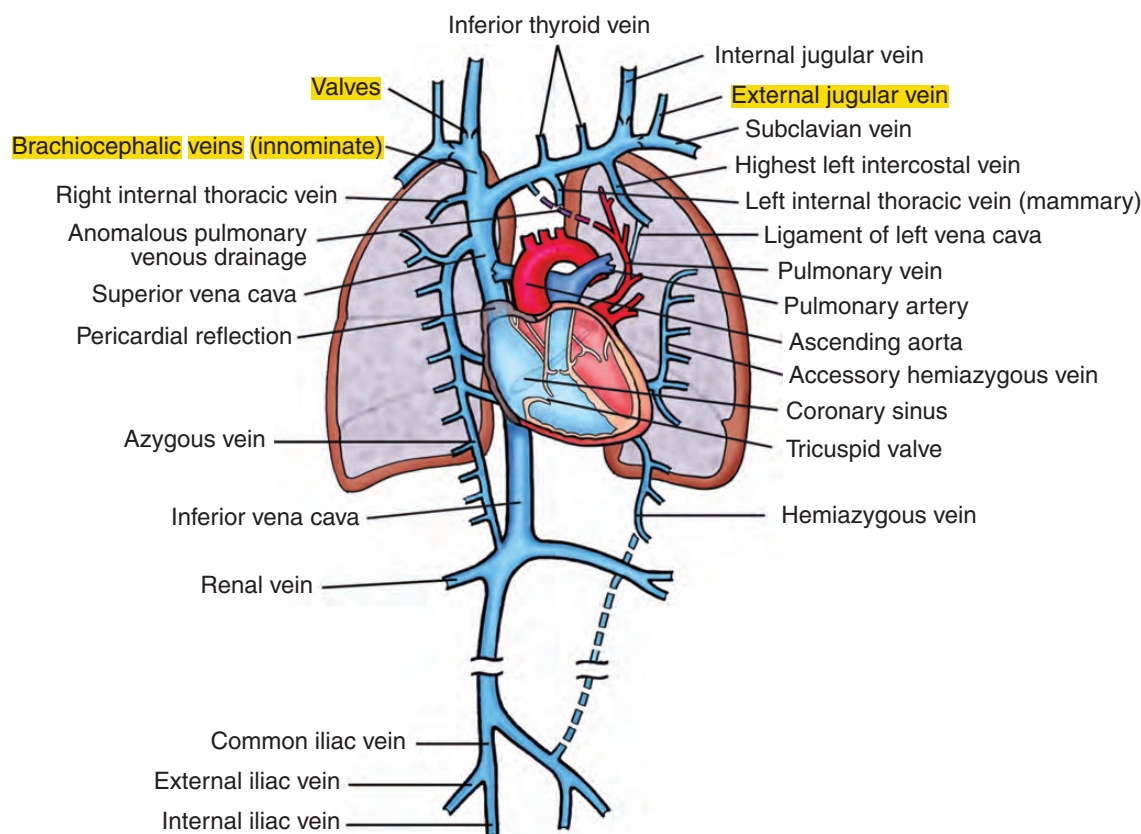
Fig 1 A simplified schematic illustration of the major central veins. There can be considerable variability. Some of the more common congenital venous abnormalities are shown, such as an anomalous pulmonary venous drainage (see text). A persistent left vena cava would occur if the ligament of the left vena cava remained patent after failure of the degeneration of the embryological anterior cardinal vein. This can be seen to connect to the coronary sinus.

measurement error. In all these situations the catheter tip needs to be either in, or very close to, the RA. Poor catheter positioning is a common reason for premature failure of CVCs due to vein or catheter thrombosis or other reasons.

Anatomy of the central veins

Relatively detailed anatomical knowledge of the central veins is a prerequisite for safe placement of CVCs, and to enable identification of abnormalities when they occur.

A description of the normal anatomy of the central veins follows. The anatomy of the IJ, subclavian, axillary, femoral, and other routes of access to the central veins are well described elsewhere, and this article will mainly focus on the central veins within the thorax and, to a lesser extent, the abdomen.[6][7] Such anatomy is complicated and variable. We provide a schematic overview in the form of a roadmap in Figure 1. This shows the major vessels and branches, and some more common variants. Such simplified images may be helpful when performing procedures or reviewing images. We also show volume rendered reformatted computed tomography (CT) anatomy images later in the text showing normal and variant anatomy.

Vein wall anatomy

Venous walls are relatively thin and fragile in comparison with arterial walls, rendering them at greater risk from iatrogenic injury. Structurally, they are composed of three layers: an inner endothelial layer (tunica intima), a middle muscular layer (tunica media), and an outer connective tissue layer (tunica adventitia). These layers are not distinct in all veins, but relative to arteries, there is a larger proportion of the outer connective tissue layer and a smaller proportion of the middle muscular layer. This allows the venous system to be distensible and compliant and act as a blood reservoir, but is the reason for their relative fragility. The longitudinal organization of the layers means that tears in the vein walls tend to extend along the long axis, causing larger defects with the potential for serious bleeding.

Brachiocephalic veins

The brachiocephalic (innominate) veins are two large trunks, placed one on either side of the root of the neck and formed by the union of the IJ and SCVs of the corresponding side; they are devoid of valves.[7]

The right brachiocephalic vein is ~2.5 cm long, and begins behind the sternal end of the clavicle and passes almost vertically downwards, joining with the left brachiocephalic vein, just below the cartilage of the first rib, close to the right border of the sternum. Here it forms the SVC. It lies anteriorly and to the right of the brachiocephalic artery. The right brachiocephalic vein, at its commencement, receives the right vertebral vein and, lower down, the right internal thoracic (mammary) and right inferior thyroid veins. Sometimes the vein from the first intercostal space also joins here. Owing to its relatively straight course into the SVC, in terms of

catheter placement, it could be functionally considered as a proximal limb of the SVC.

The left brachiocephalic vein, some 6 cm long, begins posterior to the sternal end of the left clavicle and runs obliquely downwards and to the right, behind the upper half of the manubrium sterni to the sternal end of the first right costal cartilage. Here, it unites with the right brachiocephalic vein to form the SVC. Behind it are the three large arteries, the right brachiocephalic, left common carotid, and the left subclavian artery, arising from the aortic arch, together with the vagus and phrenic nerves. The left brachiocephalic vein may occupy a higher level, crossing the jugular notch and lying directly in front of the trachea. Its tributaries are the left vertebral, left internal thoracic (mammary), and left inferior thyroid, and the left highest intercostal veins, and occasionally, some thymic and pericardiac veins. Its angle of approach to the right brachiocephalic vein is very variable and this is an important determinant of the ease of central catheter positioning from the left IJ and SCV routes. The more acute the angle is, the longer the distal section of catheter needed to be able to traverse the corner, and to lie in the longitudinal axis of the SVC or upper RA. This is important to avoid acute angulation against the wall of the SVC or RA, with the attendant risks of thrombosis, catheter failure, or perforation. Typically, catheter tips need to lie at the caval/atrial junction or upper RA after left-sided CVC placements.[8]

The right brachiocephalic vein receives lymph from the right lymphatic duct, and the left brachiocephalic vein receives lymph from the thoracic duct. Such anatomy is very variable.[9]

Superior vena cava

The SVC drains venous blood from the upper half of the body (Fig. 1). It measures ~7 cm in length and is formed by the junction of the two brachiocephalic veins behind the lower border of the first right costal cartilage near the sternum. It descends vertically behind the first and second intercostal spaces, ending in the upper part of the RA, opposite the upper border of the third right costal cartilage. In its course, it describes a slight curve, the convexity of which is posterior and to the right side.

The SVC lies anterolateral to the trachea and posterolateral to the ascending aorta. The right phrenic nerve lies between the SVC and the mediastinal pleura. The terminal half of the SVC is in the middle mediastinum, where it lies beside the ascending aorta. The lower half of the vessel is within the pericardial sac. Just before it pierces the pericardium, it receives the azygos vein and several small veins from the pericardium and other structures from within the mediastinal cavity. The upper level of the pericardial sac, as it traverses the SVC, lies below the level of the carina. Hence, the use of the carina as an X-ray landmark to identify the placement of a CVC tip outside of the pericardium, therefore minimizing the small but serious risk of cardiac tamponade if the tip perforates the vessel wall.[10][11]
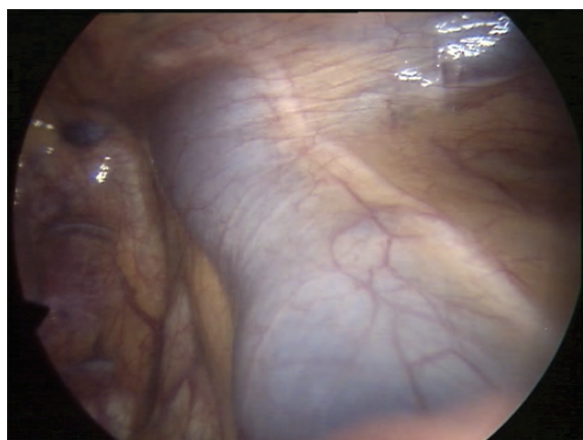
Fig 2 Right-sided thoracoscopic image of the superior vena cava. Note the close anatomical proximity of the vein wall to the pleura, with the vein bulging laterally into the pleural space. A tear of the vein at this site risks massive bleeding into the low pressure pleural space.

The SVC lies in close anatomical proximity to the mediastinal pleura (Fig. 2) in the upper thorax. Perforation of the vein wall here, with a guidewire, dilator, or catheter, may cause uncontrolled bleeding into the low pressure pleural space. A catheter while left *in situ* may control such bleeding which then becomes evident on removal. With age or disease, the SVC may become increasingly tortuous, which can cause difficulty when attempting to advance a guidewire or catheter. The SVC has no valves.

Azygous veins

The azygous and hemiazygous venous systems drain the back, thoracic, and abdominal walls (Fig. 1). They exhibit much variation. The azygous vein usually arises from the posterior aspect of the IVC at the level of the first or second lumbar vertebra, and connects the IVC to the SVC. It enters the thorax through the aortic hiatus in the diaphragm and ascends in the posterior mediastinum, passing close to the right sides of the bodies of the inferior eight thoracic vertebrae. It arches over the superior aspect of the root of the lung to enter the posterior aspect of the SVC just before it pierces the pericardium. It bulges into the pleural space or may even lie free within the pleural space. The azygous venous system offers an alternative means of venous drainage from the lower body (thoracic, abdominal, and back regions), when there is obstruction of the IVC, and can offer a route of access for the catheter to enter the SVC. The smaller hemiazygous system provides venous drainage for the left chest and upper abdomen and anastomoses with the azygous system.

Inferior vena cava

The IVC drains blood from the lower half of the body (Fig. 1). It is formed from the junction of the common iliac veins. It is

about 2.5 cm wide and ascends along the anterior of the vertebral column to the right of the aorta. It then perforates the diaphragm and continues cranially and medially for about 2.5 cm. Here, it pierces the fibrous pericardium and opens into the lower part of the RA. There are no functional valves in the IVC.

Catheter misplacement

Misplacement of a CVC refers to a catheter, whose tip does not lie in the 'ideal' position. There is a range or severity varying from i.v. misplacement of the catheter tip, which is very common, to the rarer more dangerous situation where catheters lie outside of the venous system. Misplaced catheters have been reported in almost every possible anatomical position, including the arterial system, mediastinum, pleura, pericardium, trachea, oesophagus, subarachnoid space, and other aberrant sites. Certain patterns are well recognized as clinically important from audits, medicolegal analyses, and clinical experience.[12] [13] Catheter misplacement can occur at the time of insertion or after a period of time due to migration of the tip.

Certain congenital and acquired abnormalities of the venous anatomy predispose to catheter misplacement. We discuss the diagnosis and management of some of the more common sites for catheter misplacement in patients with normal anatomy, acquired anatomical abnormalities, and congenital anatomical abnormalities. More detailed descriptions can be found elsewhere.[14]

Catheter misplacement in patients with normal venous anatomy

The site and frequency of misplacement depends on several factors; the site of insertion, the technique used, and body positioning. The veins that are used for access have their own peculiarities in anatomical structure, which predispose to unique aberrant positions for the catheters inserted.[15] [16] Catheters may have traversed a great vein or artery, but the tip lies outside: in pleura, pericardium, mediastinal, or peritoneal space. Bleeding or other problems may only become evident on withdrawal of the catheter. This could be verified on CT imaging or by injecting contrast on withdrawal.

I.V. misplacement

Incorrect or suboptimal catheter position is relatively common during placement of catheters without X-ray screening, particularly from the subclavian or left-sided routes due to the necessity to traverse corners. Providing such misplacements are recognized, usually no problems ensue. In most circumstances, a malpositioned or kinked catheter should be repositioned, replaced, or removed as soon as practicable. In patients with difficult venous access and a 'precious' catheter, an individual risk–benefit analysis should be made about retaining and using the catheter.

Minor vein wall tears are common and generally will go unrecognized during guidewire/dilator/catheter insertion,

and are usually without consequence as the low-pressure system is tamponaded by the surrounding structures. Major bleeding can occur when a tear connects to a low-pressure body cavity (such as the pleural, peritoneal, or pericardial spaces). Dilators can cause significant damage if force is applied and the guidewire is kinked.[17] Massive haemothorax can occur due to uncontrolled bleeding and is exacerbated by infused fluids through a misplaced catheter within the pleural cavity. In such cases, the catheter should be left in situ (to help plug the hole in the vein) and further urgent advice sought from surgery or interventional radiology.

Intra-arterial misplacement

Arterial puncture with an access needle is one of the most common complications related to central venous access via the right IJ vein and at other sites.[18] Incidences range from 1% to 11%.[19] After recognition, the needle is removed and pressure applied, and in most cases, no problems ensue. If unrecognized then a guidewire or catheter may be inserted. The occurrence of accidental arterial cannulation should usually be obvious from the colour and the pulsatile nature of the blood back flow; however, case reports suggest this is not always recognized.[20] Pressure transducer monitoring is an accurate means of detecting line misplacement but is usually only connected to a catheter after placement and is therefore more often used as a method to confirm improper catheter placement rather than to prevent it (Fig. 3a and b).

Fluoroscopic guidance of catheter placement is commonly considered to be a reliable method, but this may fail to demonstrate incorrect arterial insertion of a catheter in the ascending aorta adjacent to the SVC or in the presence of a vascular anomaly (e.g. right-sided aortic arch), unless contrast is injected to show the direction of blood flow.[21]

Arteries may be damaged at the puncture site or more centrally with various consequences. A localized haematoma or false aneurysm may cause damage to local structures such as nerves or cause airway compression requiring immediate surgical decompression.[22] Arterial dissection, thrombosis, embolus, and unintentional cannulation may cause distal ischaemic damage.[13] Massive bleeding may occur into body cavities.

Removal of large-bore catheters (>9 Fr) from an artery requires careful consideration. If the artery is accessible (e.g. carotid), then removal of the catheter and compression is one option, but this may risk brain ischaemia from haematoma, dislodged emboli, or lack of blood flow. Surgical removal of the catheter with a procedure similar to a carotid endarterectomy is another option, or endovascular treatment particularly for arteries difficult to access (e.g. behind the clavicle).[23] Arterial defects can also be closed percutaneously with a closure device and/or temporarily by balloon tamponade if the catheter has been left in situ.[24 25] Catheters left in major arteries over time should be covered by systemic heparinization to help prevent embolic phenomena.

Extravascular placement

Any nearby structure is potentially at risk from needle puncture, guidewire, dilator, and catheter placement. Perforation of the great veins (or arteries) can occur during catheter insertion (direct damage from the needle, guidewire, or dilator), or at a later time (tip migration through the vessel wall). The major early risk of haemorrhage is uncontrolled bleeding into low-pressure spaces such as the pericardium, pleura, and peritoneum. Later bleeding may only become evident on catheter removal.

Pericardium

The rare but often fatal complication of cardiac tamponade occurs in the context of a CVC, when there is a perforation of the RA or lower SVC (lying within the pericardial reflection). This can occur after a period of time due to erosion by the
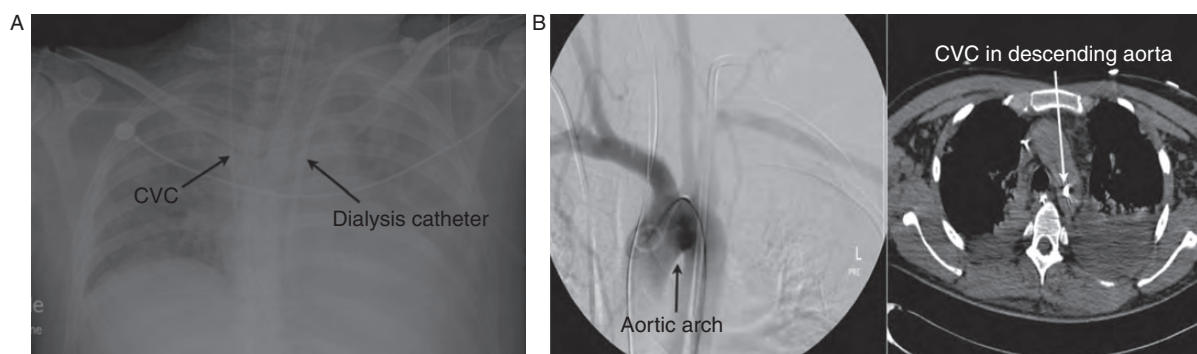
Fig 3 (A) A large-bore dialysis catheter inserted via attempted left IJ puncture is seen to take an abnormal course projected over the left mediastinum. Pulsatile blood was evident and the catheter was recognized to be intra-arterial. It was left in situ and management discussed with vascular surgery and interventional radiology. (B) Further imaging with and contrast injection via a pigtail catheter in the aorta and CT shows the catheter entering the arterial tree via the left subclavian artery passing into the descending aorta. The hole in the artery was successfully repaired with a stent graft placed over the defect.

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catheter tip. Reported cases suggest that it is typically pressurized fluid infusion, rather than low pressure venous bleeding that is the problem.[12] [26] Often this is a post-mortem diagnosis, but if tamponade is confirmed on echocardiography after clinical suspicion, then treatment is indicated. Aspiration of the infused fluid should be attempted through the catheter (which should be left *in situ*), followed by urgent pericardiocentesis and stenting or surgical repair if required.

Pleural space

The right border of the SVC, azygous, hemiazygous, and internal thoracic veins are immediately adjacent to the pleura (Fig. 2). Damage to these or adjacent arteries (notably subclavian arteries) can cause significant bleeding into the low-pressure pleural space (Figs 3 and 4). Alternatively if the catheter tip lies in the pleural cavity, then even without major bleeding, haemothorax or pleural effusions may result from the infusion of blood or fluids through the catheter. Similar problems can occur with femoral catheters and the low-pressure peritoneal space.

Mediastinum

A CVC may perforate through a vessel wall entering the mediastinum. There is a particular risk if excessive force has been used to advance the guidewire/dilator or catheter. Supplementary Figure S1 shows an example of a CVC passing into the mediastinum as confirmed with contrast injection.

CVCs that lie correctly within the venous system may move or become dislodged so that the proximal port of a multi-lumen catheter lies outside of the vein. Infusion of pressurized fluid through such an opening will lead to extravasation with a risk of swelling, compression of mediastinal or neck structures, or tissue necrosis.[27]

Catheter migration

A catheter tip originally in the desired position can migrate over time. Catheter tip movement after insertion is dependent on multiple factors, including phase of respiration, catheter type, insertion site, body habitus, development of clot, and body position. The catheter tip will change position on moving from lying to standing. Most insertions are performed in a supine or head-down position. Subsequent radiographs may show descent of the abdominal contents and diaphragm and change in the catheter position relative to the mediastinal contents.[28] This is more pronounced in overweight patients and with longer tunnelled catheters.[16] Mobile skin and dependent breast tissue in obese patients causes similar problems.[29] PICCs can move several centimetres on arm movement.

## Acquired anatomical abnormalities predisposing to CVC misplacement

Acquired abnormalities of the central veins are more common than congenital abnormalities. The predominant acquired abnormality is a partial or complete obstruction or stenosis of a central vein, leading to difficulties or a failure to pass a guidewire or catheter. If this is not recognized then there is a real danger of guidewires, dilators, or catheters being pushed out through the vein wall.

Acquired obstruction of the central veins can be classified into two types: those due to factors external to the vein and those due to factors internal, caused by the vein itself or its contents. The clinical signs and symptoms of great vein obstruction vary with the site and speed of obstruction. Acute obstruction leads to venous hypertension proximal to the obstruction with pain and swelling. Typically over time, venous collaterals develop to allow adequate venous drainage and symptoms resolve. Such collaterals can be seen externally,
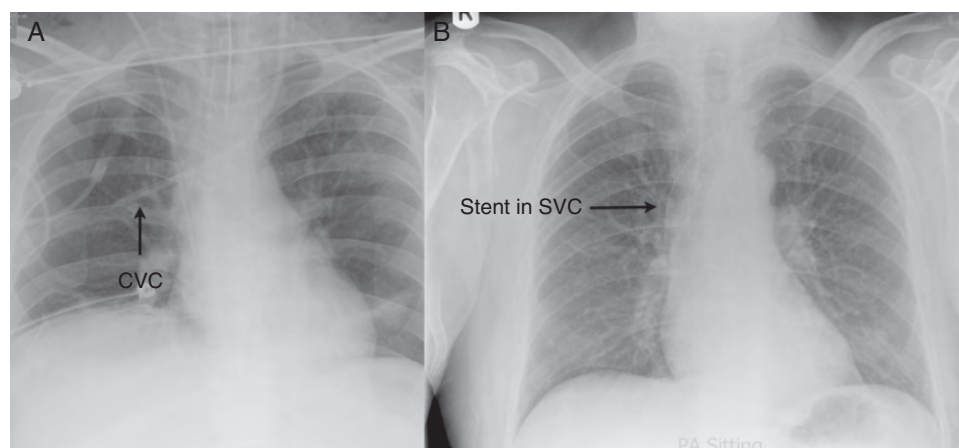
Fig 4 (A) A left-sided dialysis catheter has perforated through the right wall of the SVC and the tip has entered the right hilum and pleural space, with tear to the pleura and pulmonary vessels. The patient collapsed and blood and fluids infused through the catheter entered the right pleural space to produce a haemothorax. The catheter was left *in situ* and referral to radiology for successful stenting procedure (B).
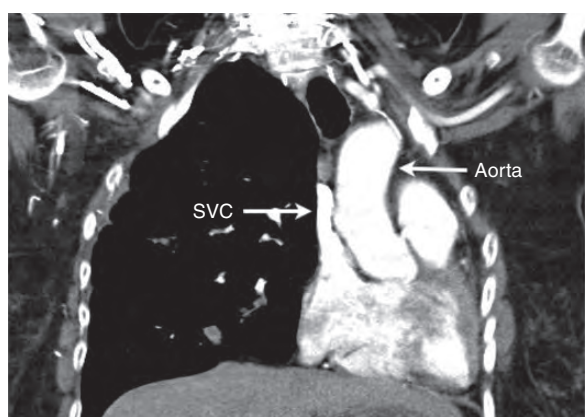
Fig 5 A CT image of a patient with a left pneumonectomy showing gross mediastinal shift. The SVC and any catheter within it will lie to the left of the midline.

for example, on the chest wall or abdomen, or internally, with ultrasound or other imaging. Total acute SVC obstruction is rare but may present with facial, neck and upper extremity swelling, dyspnoea at rest, and cough.

Central vein obstruction from any cause can present as failure to thread a guidewire or catheter. It is important to note that normal ultrasound appearance at the puncture site (e.g. IJ vein) does not rule out significant central vein obstruction. However, evidence of overfilled high-pressure veins (main target vein and collaterals) should arouse suspicion in the absence of another cause (fluid overload, CCF, etc.). The diagnosis can be confirmed by angiography or Doppler ultrasound studies (loss of respiratory variation in vein size and abnormal direction of blood flow).

External factors

External factors typically cause central vein obstruction by compression. These are usually mass lesions, of which more than 85% are malignant, for example, lung cancer, breast cancer, lymphoma, or germ cell tumours. Benign causes include substernal thyroid goitre, thymoma, cystic hygroma, tuberculous masses, histoplasmosis, or syphilis. The risks and benefits of passing a catheter through such a compressed vein should be carefully assessed, as it may precipitate complete venous obstruction. Furthermore, these patients frequently cannot lie flat for procedures, due to dyspnoea.

Mediastinal shift from pneumonectomy, lung collapse, or effusions will shift all structures from the midline including the SVC. If such abnormalities are not appreciated, this can cause confusion when reviewing the X-ray images (Fig. 5).

Thrombosis

Thrombosis and stenosis are the most common causes of internal great vein obstruction. One-third of all upper limb vein thromboses are related to i.v. catheters.[30] The insertion and presence of a CVC results in damage to the vessel wall which

predisposes to thrombosis formation. Factors increasing the risk of thrombosis include recent surgery, malignancy, thrombophilia, chemotherapy, immobilization, haemodialysis, pregnancy, and diabetes. There is evidence of a relationship between high placement of the catheter tip (upper SVC or above) and thrombosis.[31] [32] There is also an association with CVCs placed via the left SCV, probably due to the likely proximal placement of the tip when using this route due to the longer intra-thoracic course of the left brachiocephalic vein. The angle between the left brachiocephalic vein and the SVC may result in left-sided lines abutting the endothelium of the lateral SVC, with mechanical and cytotoxic damage predisposing to thrombosis.[5] Catheter-related thrombosis is associated with a 2.6 times increase in catheter-related sepsis in ITU patients.[4] Whether the thrombus predisposes to sepsis or vice versa is unclear.[33]

Most central vein thromboses associated with CVCs remain subclinical, or complications such as a pulmonary embolism (PE) are the first presenting symptom.[34] In those that are not, symptoms and signs of central venous obstruction (oedema and pain) are the most common.[35] The reported incidence of PE as a complication of catheter-related thrombosis is very variable (between 15% and 25%) and again may be subclinical. It is not considered mandatory to screen for PE in non-symptomatic patients with confirmed catheter-related central vein thrombosis (and often patients are anticoagulated anyway), but a high index of suspicion for PE is required if there is clinical deterioration.

Optimal management of CVC related thrombosis is not clear.[36] Immediate removal of the catheter may be the best option, but consideration must be given to the complications of reinsertion if the patient has an ongoing requirement for central venous access. Questions remain about the optimal method of anticoagulation and the relative merits of local or systemic thrombolysis vs anticoagulation. Mechanical clot removal can also be used in symptomatic cases with specialist input from vascular radiology or surgery.
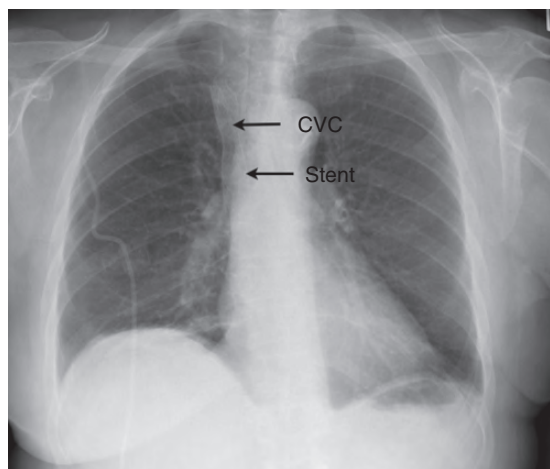
Stenosis

The incidence of central venous stenosis, post-long-term CVC placement has been reported as up to 50% in haemodialysis patients.[37] [38] Predisposing factors for central vein stenosis include placement of multiple catheters, longer duration in situ, subclavian venous location, poor catheter tip positions, and placement from the left side of the neck.[39]

As in the case of a central vein thrombosis, partial central venous stenosis may be clinically silent, particularly when slow in onset and if venous collaterals have time to develop.

Stenotic lesions can be treated with percutaneous angioplasty, stent placement, or both. The functionality of the vascular access is restored, at least temporarily, although multiple interventions are often required. Surgical bypass of the obstruction should be considered in resistant cases. Central venous cannulae can be passed through dilated or stented vessels with reasonable longer-term patency, when there are no viable alternatives (Figs 6 and 7).
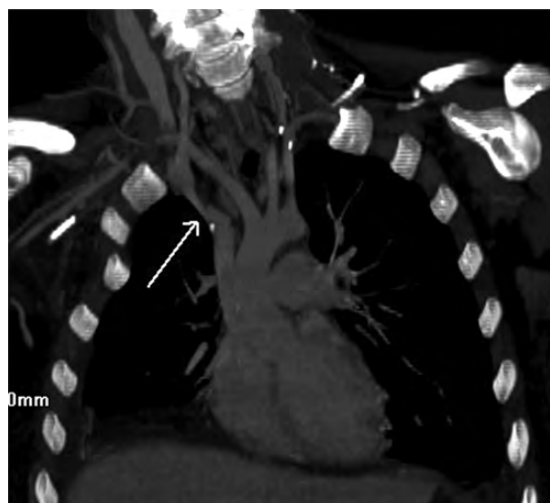
Fig 6 A CT image showing a narrowed (stenotic) section of the right brachiocephalic vein, after previous long-term central venous catheters, which could impede future attempts at CVC placement from the right side.

Fig 7 In this patient, a CVC has been sited successfully through a stent, previously inserted to correct SVC stenosis, which was secondary to long-term venous access for home TPN.

Congenital anatomical abnormalities predisposing to CVC misplacement

An understanding of the more common congenital anatomical variations is important for those regularly placing CVCs. A brief description of the embryological development of the central veins is given in order to understand the origin of congenital anatomical variations.

Embryology of the central veins

At 6 weeks gestation, the cardinal veins constitute the main venous drainage system of the embryo. The anterior cardinal veins drain the cranial structures, while the posterior cardinal veins drain those caudal. They both empty into a common cardinal vein, which enters into the sinus venosus.

An oblique anastomosis forms between the anterior cardinal veins during the 8th week of gestation. It shunts blood from the left to the right. When the caudal part of the left anterior cardinal vein degenerates, the anastomosis forms the left brachiocephalic vein. The remnant of the left anterior cardinal vein forms the ligament of the left vena cava (Fig. 1). The right anterior cardinal vein and right common cardinal vein form the SVC.

The right horn of the sinus venosus becomes incorporated into the RA, while the left horn becomes the coronary sinus. The posterior cardinal veins largely involute, the root of the azygous being the only adult derivative. The IVC forms during a series of changes in the primitive veins of the trunk that occur as blood returning from the caudal part of the embryo shifts from the left to the right side of the body.[40]

Congenital variations

There are numerous congenital venous abnormalities, most of which are asymptomatic so may only become apparent after CVC placement with subsequent imaging, indicating an abnormal path for the catheter. We will briefly review the more common abnormalities, as fuller descriptions can be found elsewhere.[41]

Persistent left-sided or double SVC

The most common variant of the SVC is the persistent left SVC (PLSVC), which occurs with a prevalence of 0.3–0.5% in healthy individuals and 1.3–4.5% in those with additional cardiac defects.[42] This may occur with a normal right-sided SVC (as in 82% of cases) or without (as a single left-sided SVC). Left-sided SVCs are derived from the left anterior cardinal vein and the left common cardinal vein, thus they usually drain into the coronary sinus and then into the RA. They can, however, drain into the left atrium (8%), giving a risk of systemic air or particulate emboli from catheter usage. Figure 1 shows the course of the ligament of the left vena cava, which would correspond with the location of a PLSVC if present. A PLSVC alone causes no physiological derangement; however, it may be associated with other congenital cardiac abnormalities, including septal defects, Tetralogy of Fallot, and situs inversus.[43] A PLSVC is often missed due to its coexistence with a normal right-sided SVC as CVCs are more often inserted on the right side with the tip passing into the right SVC as normal.

There are numerous reports of an incidental diagnosis of a PLSVC based on further investigation after a CVC is noted to take an abnormal left para-mediastinal intra-thoracic course on X-ray.[43–45] Placement of a CVC safely in a PLSVC is possible, but care should be taken, as placing guide wires,
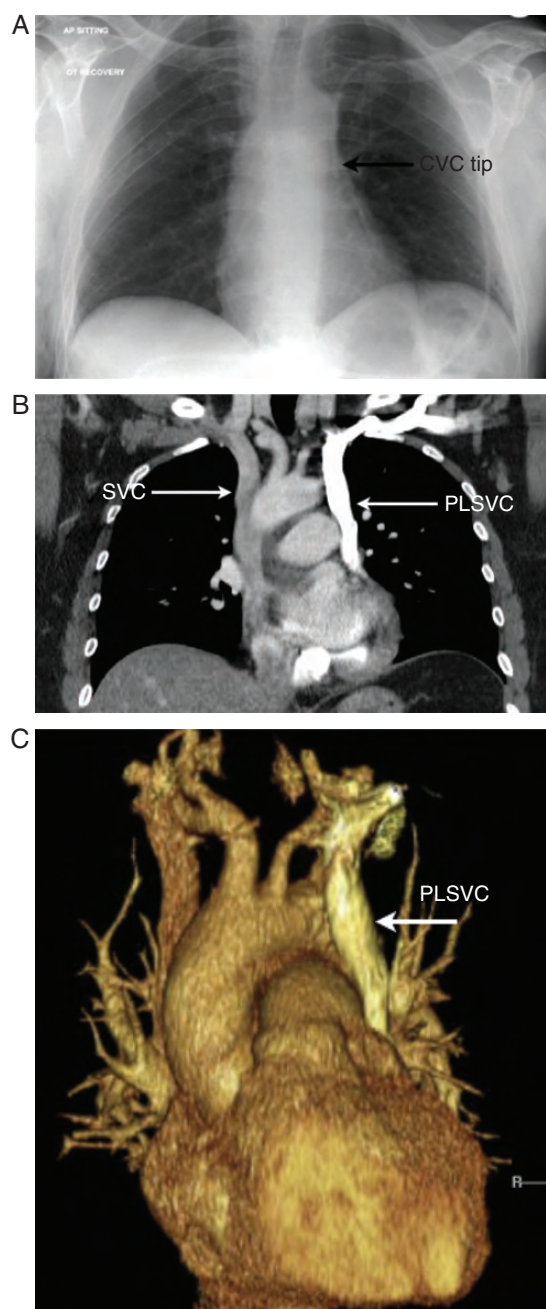
Fig 8 (A) A routine CXR after apparently uncomplicated CVC insertion via the left SCV. Low-pressure venous blood flowed freely from the catheter. The catheter is seen to take an abnormal left para-mediastinal intra-thoracic course. A subsequent venogram (not shown) showed the catheter to be situated in a persistent left vena cava draining via the coronary sinus into the RA. The catheter was left *in situ* and used without problems. (B) A CT image of a PLSVC in a different patient with no CVC *in situ*. This shows dual right and left SVCs as an incidental finding. The left SVC is enhanced due to contrast injection from the left side. The enhancement can be seen behind the heart representing drainage into the RA from an enlarged coronary sinus. (C) A volume rendered CT reconstruction of PLSVC of the same patient as in Figure 8B. The remainder of the anatomy is normal with the right-sided SVC seen descending posterior to the ascending aorta.

dilators, or catheters near the coronary sinus must be avoided to prevent arrhythmias occurring[46] (Fig. 8A–C).

Dextrocardia

If in the embryo, the heart tube bends to the left rather than to the right, the heart is displaced to the right, and the heart and its vessels are reversed as in a mirror image. Its incidence has recently been reported at ~1 in 12 000 pregnancies.[47] In association with situs inversus (transposition of the viscera), the incidence of associated cardiac abnormalities is much lower than with situs solitus or ambiguous (normal or indeterminate) viscera. In situs inversus, the SVC and IVC will lie to the left of the midline. Mesocardia is a condition where the longitudinal axis of the heart lies in the midsagittal plane, but the great vessels lie in the normal configuration.[48]

Variations of the IVC

The embryogenesis of the IVC is a complex process involving the formation of several anastomoses between three paired embryonic veins. The result is numerous variations in the basic venous plan of the abdomen and pelvis.[49] The incidence of dual IVC is reported to be 0.3% where the left IVC typically ends at the left renal vein, which then crosses anterior to the aorta to join the right IVC (Supplementary Fig. S2). In the so-called azygous continuation of the IVC, the pre-renal IVC passes posterior to the diaphragmatic crura to enter the thorax as the azygous vein. The incidence of this is 0.1%.[50] Congenital abnormalities of the IVC are rarely noticed, as CVCs placed from the lower extremity are not routinely imaged.

Azygous vein abnormalities

The azygous vein frequently arises from the posterior IVC at or below the level of the renal veins. It exhibits much variation, not only in its origin but also in the course, tributaries, anastomoses, and termination. As the azygous system offers an alternative means of venous drainage from the thoracic, abdominal, and back regions to the IVC, there may be dilation of the azygous vein if the IVC or SVC are blocked, or there is high CVP (e.g. in the presence of portal hypertension). If the azygous vein is abnormally large, it is more likely that a guidewire or catheter may pass into it. The backwards angulation where it joins the SVC means that misplaced catheters lying in the azygous vein may not be apparent on plain X-ray.

Partial anomalous pulmonary venous drainage

Partial anomalous pulmonary venous return is a congenital abnormality where one or more of the pulmonary veins are connected to either the RA or one of the systemic veins such as the SVC, IVC, brachiocephalic vein, coronary sinus, or azygous vein. If functionally small, it is often asymptomatic. Figure 1 shows a schematic illustration of a pulmonary vein connecting to the left brachiocephalic vein. This causes a left to right shunt. It occurs in 0.04% of the population and is often associated with other congenital heart
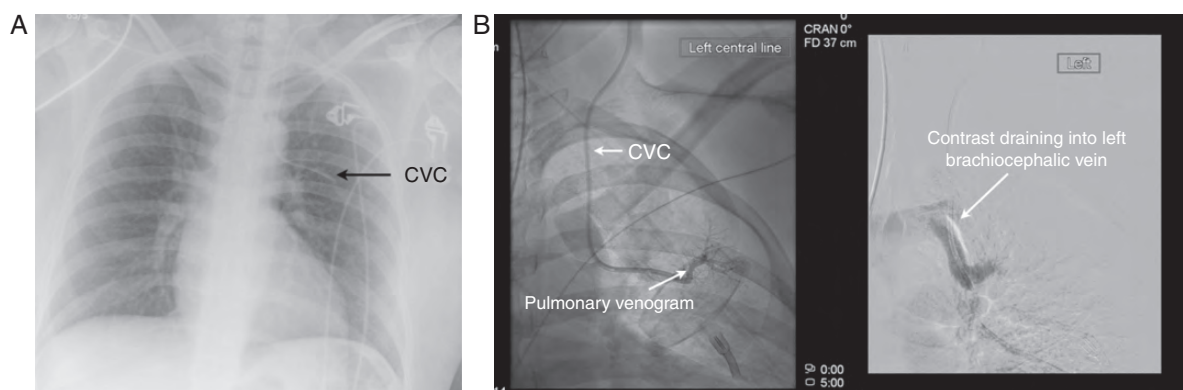
Fig 9 (A) A CVC inserted via the left IJ is noted to have taken an abnormal course on CXR tracking to the left side. Non-pulsatile low-pressure bright red blood was aspirated. It was not clear where the catheter tip lay, so it was left *in situ* and a contrast study was requested. (B) Contrast injected through the catheter reveals a pulmonary venogram with contrast draining to the left brachiocephalic vein. Therefore, the catheter tip lies in an anomalous pulmonary vein. The catheter was then safely withdrawn a small distance and repositioned in a central vein. Airway filter and related tubing are also seen on this image.

defects.[51] Total anomalous pulmonary venous return is a rare congenital heart defect where all the pulmonary veins drain into the RA.

Placement of a CVC tip in an anomalous pulmonary vein may be recognized by an abnormal intra-thoracic course on X-ray prompting further imaging (Fig. 9A and B). If the tip becomes wedged in the anomalous pulmonary vein, the resulting transmission of the pulmonary arterial pressure waveform will cause an abnormal central venous waveform with flow of oxygenated bright red blood.[52]

Imaging related to CVC positioning

Plain radiographs

Plain radiographs can be used to confirm catheter position within the chest and to detect pneumothorax, haemothorax, or effusions after CVC placement. There are limitations to such imaging, for assessment of true catheter position in part due to their 2D projection. The close anatomical proximity of major arteries, veins, and pleura in the neck and chest causes difficulties and it is not possible to reliably state whether the distal section of the catheter is in an artery, vein, pleura, or mediastinum in the chest from a plain PA chest radiograph [chest X-ray (CXR)]. Hence the often-guarded statement in radiology reports, for example 'the catheter appears projected over the SVC'.

Supplementary Figure S3A and B illustrates the limitations of the plain CXR; a CVC appears to lie in the correct position but actually is lying within the internal thoracic (mammary) vein. Figure 10 shows a cross-sectional CT image of the thorax, where the close anatomical proximity of the structures anterior and posterior to the SVC (hence in line with an AP view on CXR) can be appreciated.
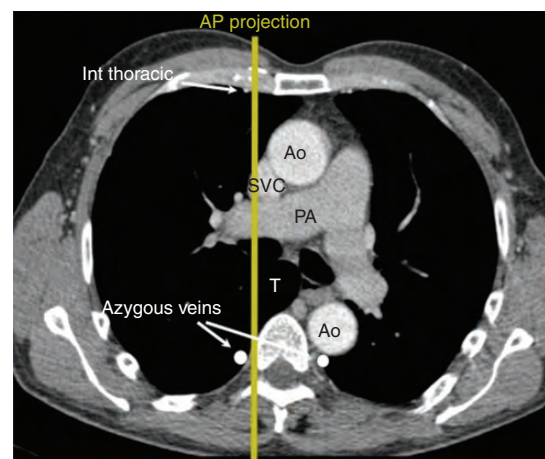
Fig 10 CT cross-sectional image of a thorax. Note how structures overly each other on an AP projection. Hence a catheter tip situated in any structure anterior or posterior to the SVC may not be identified as such on a plain CXR. Ao, aorta; PA, pulmonary artery; T, trachea; Int thoracic, internal thoracic (mammary) vein. The azygous and hemiazygous veins are approximately represented by a white dot for illustration.

Ultrasound

Ultrasound can be used to assess the jugular, femoral, axillary, and arm veins to aid insertion of a CVC, but is of limited value in confirming tip position in the SVC. Transoesophageal ultrasound can be used if available to directly image the SVC, but this has practical limitations due to availability and operator training. Transthoracic echo can identify catheters in the RA, particularly with the injection of bubble contrast but is not used in routine practice.

Image intensifier

Real-time X-ray imaging uses an image intensifier. It can be used during CVC placement to guide wires and catheters centrally.[53] Without the injection of contrast, it has similar limitations to a plain CXR.

Injection of contrast allows many further observations to be made, including the following:

- Enhanced visualization of fine catheters.
- If injected from the site of access via a cannula or needle, a 'road map' of patent veins passing centrally is provided (Supplementary Fig. S4A).
- Blockage of central veins will be seen by the lack of flow of contrast and the presence of collateral veins (Supplementary Fig. S4B).
- Injection of contrast through a catheter into central veins is seen as a jet of contrast, which then mixes with blood and flows forward in the SVC and into the RA and ventricle. This demonstrates correct CVC placement.
- Extravascular pooling of contrast confirms that the luminal section of the catheter is outside the vessel (Supplementary Fig. S1).
- Pooling or backtracking of contrast around the catheter in the vessels is suggestive of thrombus or a fibrin sleeve.
- Intra-arterial injection of contrast would be demonstrated as an arteriogram with flow away from the heart.
- Catheters in pleura, pericardium, or peritoneum will show spread and then pooling of contrast in dependent areas.

Image intensifiers are available in most operating theatres but only tend to be used for placement of longer-term venous access devices or pain procedures. There is no reason why anaesthetists, with some simple training and experience, should not use them if difficulties ensue with other devices.

So-called linograms are essentially venograms with imaging after injection of contrast into the CVC. These studies are used to assess line patency through the SVC, line position, and to detect complications such as leakage and the development of fibrin sheaths.

CT and magnetic resonance imaging

CT and magnetic resonance imaging are cross-sectional imaging modalities that can provide information about catheters, central veins, arteries, thrombus, dissection, and adjacent structures. They offer definitive imaging but are expensive and impractical for routine use. They are very useful to guide management of complications (see Fig. 3).

Preventing misplacement of catheters

There is much guidance as to the techniques used for safe placement of CVCs. Interventions intended to prevent misplaced CVCs include the routine use of: ultrasound guidance, manometry (needle and catheter), pressure waveform analysis, blood gas analysis, image intensifier, and ECG guidance. Simple observations such as the patient complaining of neck or ear pain can alert operators to misplacement (into an IJ vein).

The use of ultrasound enables identification of the target vein, detection of anatomical variations, or thrombosis at the site of insertion but has obvious limitations in preventing catheter tip misplacement distal to the site of insertion. If there is any doubt as to the position of the needle tip, then attaching a pressure transducer to the needle should help to determine if placement is within the venous or arterial system before inserting the guidewire. Similarly, blood gas analysis before insertion of the guidewire is possible, although not very practical due to the time delay in obtaining a result.

The use of an image intensifier is discussed above.

ECG guidance is useful to verify central placement of catheters within the chest at the caval atrial junction, but characteristic P wave changes may be seen whenever a guidewire or conducting catheter is close to the right or left atrium irrespective of whether it is in a vein, artery, mediastinum, or other structure.[54 55] Similarly, there are new devices, which have an electromagnetic coil on the guidewire or catheter and an external sensor on the chest wall, which allows verification of placement over the area of the SVC, but does not prove the device is within the SVC.[56]

Knowledge of the limitations of all these devices is essential to safe practice.

Management of misplaced CVCs

The management of misplaced catheters will depend on the location of the catheter, indication for central access, and clinical condition of the patient. If there is a suspicion that a catheter is misplaced then there must be further consideration before removal, due to the risk of complications, in particular uncontrolled haemorrhage. 'If in doubt, don't take it out!'

First, consider the following questions:

(i) Can blood be aspirated through all lumens?
(ii) Is the blood venous (i.e. low pressure, non-pulsatile, dark, deoxygenated blood)?
(iii) Is the transducer waveform consistent with a CVP waveform? First, set the scale and numerics correctly for a CVP pressure range. Then if the pressure is high and off the scale, convert to arterial scale to check for arterial pressure waveform, rather than just assuming it is blocked.
(iv) Is the catheter on CXR consistent with placement within a central vein (i.e. overlies the trajectory of the SVC) and not kinked?

If the answer to these four questions is yes then the catheter is likely to be in a central vein and can be used. If the answer is no, to any of the questions, or doubt exists, then further consideration as to the catheter's tip whereabouts is

Table 1 Guide to identifying misplaced catheters

Catheter tip placement	Aspirated blood	Transducer waveform	CXR
Venous misplacement: *normal anatomy*			
Subclavian/axillary/internal jugular	Low pressure, non-pulsatile, dark, low Pa_{O_2}	Low-pressure central venous waveform	Catheter seen to overlie corresponding vein on CXR
Azygous/internal thoracic (mammary)			Catheter misplacement may not be obvious on CXR (Supplementary Figs S1 and S3A)
Venous misplacement: *abnormal anatomy*			
PLSVC	Low pressure, non-pulsatile, dark, low Pa_{O_2}	Low-pressure central venous waveform	Catheter in a PLSVC will follow an abnormal left-sided course (Fig. 9A)
Anomalous pulmonary venous connection	Low pressure, oxygenated bright red blood	Transmission of pulmonary arterial pressure waveform only if wedged	Multiple variations of anomalous venous connections may lead to differing CXR appearances
Arterial misplacement	Pulsatile, bright red blood, high Pa_{O_2}	Arterial pressure waveform. Trace may be lost if wedged in smaller branch, or hypotensive patient	Placement within the ascending aorta may be mistakenly interpreted as a normal SVC placement on CXR. Other great veins and arteries in close proximity
Extravascular misplacement	Blood may be aspirated in the presence of bleeding, infused blood, or a pleural/pericardial/peritoneal collection	Waveform not consistent with vascular placement	Do not be reassured by an apparently normal CXR. Intra-pleural placement may be obvious (Fig. 4) or hidden. Further imaging will be required. Bleeding into body cavities may occur on removal of devices

required. Typically, the position should be verified with further imaging, such as injection of contrast (linogram/venogram) or cross-sectional CT imaging.

Table 1 is a guide to identifying misplaced catheters. No test or observation is 100% reliable in isolation. It may appear obvious from aspirating the catheter if the blood is arterial or venous, but this will have to be correlated with the clinical circumstances. If the catheter has been misplaced into the pleural/pericardial/peritoneal space and bleeding has occurred or citrated blood transfused then this blood may not clot and low-pressure blood may be aspirated freely back from the line. This blood may be oxygenated if associated with a pneumothorax and may have a similar or different haemoglobin concentration to a sample from the systemic circulation.

Catheters lying centrally but apparently not in an artery or vein need careful consideration before these are pulled out as great vessels may have been traversed with obvious implications for bleeding if removed. In the short term, it is generally safer to leave the device *in situ* and consult a vascular surgeon or interventional radiologist rather than a hasty removal with pressure applied to the access site.

Conclusion

All staff inserting, looking after, or removing CVCs should have a working knowledge of the applied anatomy of the central veins. An appreciation of the more common patterns of catheter misplacement and optimal management of related complications can significantly reduce the risks of adverse outcomes. A simple take-home message for misplaced catheters in the first instance is 'if in doubt, don't take it out', seek further advice and imaging, typically by referral to vascular surgery or interventional radiology.

Supplementary material

Supplementary material is available at *British Journal of Anaesthesia* online.

Declaration of interest

A.R.B. is a member of the Editorial Boards of *British Journal of Anaesthesia* and *Journal of the Intensive Care Society*.

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