BJA

REVIEW ARTICLE

Long-term central venous access

S. Galloway and A. Bodenham*

Leeds General Infirmary, Leeds, UK

*Corresponding author. Department of Anaesthesia, Leeds General Infirmary, Great George Street, Leeds LS1 3EX, UK. E-mail: andy.bodenham@leedsth.nhs.uk

There is increasing use of long-term central venous access devices, both in and out of hospital. Historically, techniques such as multiple central venous access procedures, arteriovenous fistula usage and multiple scalp vein puncture were common.

Anaesthetists will encounter long-term venous access devices already *in situ* in day-to-day practice. In addition, there is an increasing practice whereby anaesthetists are directly involved in the insertion and removal of such devices. Despite the apparent similarity between short- and long-term access devices, there are important differences in design, usage and patterns of complication that are relatively specific to longer-term venous access. This review will assume a working knowledge of short-term catheterization and highlight these differences.

We will confine the review to venous access devices and not comment on surgically created arteriovenous fistulae and other implanted devices, e.g. for access to the portal vein, CSF, epidural space, pleural or peritoneal cavity. This review relates mainly to adult practice, but much of it applies to patients of all ages, including the smaller child.

Definition

We are unaware of any precise definition of what constitutes long as opposed to short-term venous access. Capaccioli suggests that any time period less than 3 months is short-term.[17] Others would suggest that long-term is anything over 6 weeks.[68] We would agree with this latter definition and suggest that an arbitrary time for any central venous catheter with a planned duration of use greater than 6 weeks is probably a reasonable definition. An alternative definition would relate to the presence of a cuff or other implanted anchorage device. Most devices work on the principle of being inserted relatively peripherally, and then passed into the central circulation so that their tip lies in the inferior/superior vena cava or right atrium.

Indications

The indications for long-term venous access are widening and are summarized in Table 1. The aim is to use a biocompatible catheter in a large vein, which allows adequate dilution of infused products; reduced pain on injection; delay in the development of thrombosis; and free aspiration of blood.

Types of catheter

Hickman-type catheters

These are the most common devices in current use. Originally described by Hickman and colleagues in 1979,[46] it has been extensively copied and adapted since then. They are available in a wide range of sizes for adult and paediatric use. They may have single, double or triple lumens. They are usually manufactured from materials such as soft silicon rubber or PVC. Details regarding the different materials will be covered later in this article, but they are structurally and functionally the same. The cost is approximately £60–80 per catheter, including the percutaneous insertion equipment. Hickman catheters are characterized by a variable-sized Dacron cuff which provides an anchorage in a subcutaneous tract as fibrous tissue tends to grow into the interstices of the cuff. The cuff may act as a microbial barrier, although controlled trials have failed to show a difference in colonization rates between cuffed and non-cuffed catheters.[26 54] Similar cuffs are present on Broviac, Groshong and other tunnelled catheters.

Table 1 Indications for long-term venous access

Cancer chemotherapy
Long-term antibiotic therapy (e.g. infected prosthetic joints, bacterial endocarditis, cystic fibrosis)
Parenteral nutrition (e.g. short bowel syndrome)
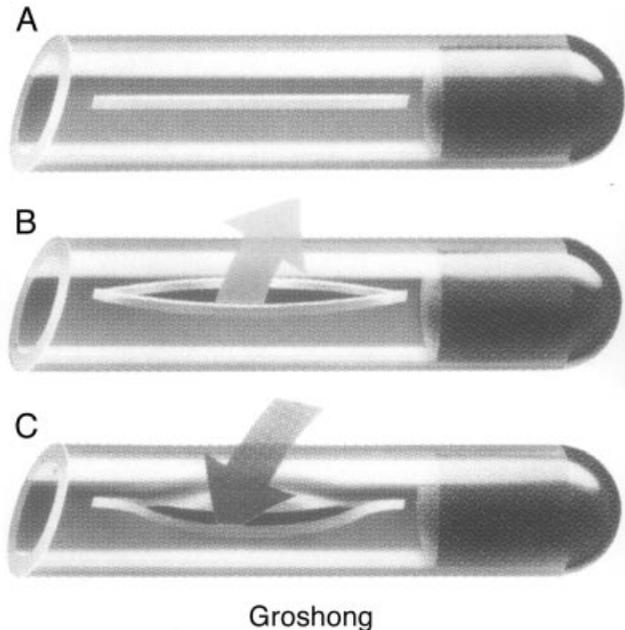Haemodialysis
Repeated blood transfusions
Repeated venesection

Fig 1 Magnified image of single-lumen Groshong catheter tip. (A) Valve closed. (B) Valve opened, fluid injected through catheter. (C) Valve open, blood aspirated from vein into catheter. Illustration courtesy of C. R. Bard.

Fig 2 Port system with 8.4 Fr silicone catheter ready to be inserted by sliding over previously placed sutures into subcutaneous pocket on anterior chest wall (Portacath®; Deltec, St Paul, MN, USA). This patient had sickle-cell disease requiring recurrent blood transfusions. Note old scars from previous port procedures. The procedure was performed by the authors under local anaesthesia to avoid any need for exchange transfusion.

Broviac catheters

This was the original design from which the Hickman catheter was a modification.[16] The major difference between the two is the internal (lumen) diameter. This was 1.6 mm for the original Hickman catheter (as opposed to 1.0 mm for a Broviac catheter)[13] in order to facilitate repeated blood sampling. The main features are covered in the discussion of Hickman catheters.

Groshong catheters

These are made of PVC and are available in different, fixed lengths. The tip of Hickman and Broviac catheters are open ended; catheters are cut to the desired length. In contrast, Groshong catheters have a formed blunt end with a slit-like orifice just proximal to the distal end (Fig. 1). This acts as a valve with the following functions: it stops back-bleeding; it prevents air entry and embolism from negative intrathoracic pressure; and it obviates the need for a heparin lock as saline
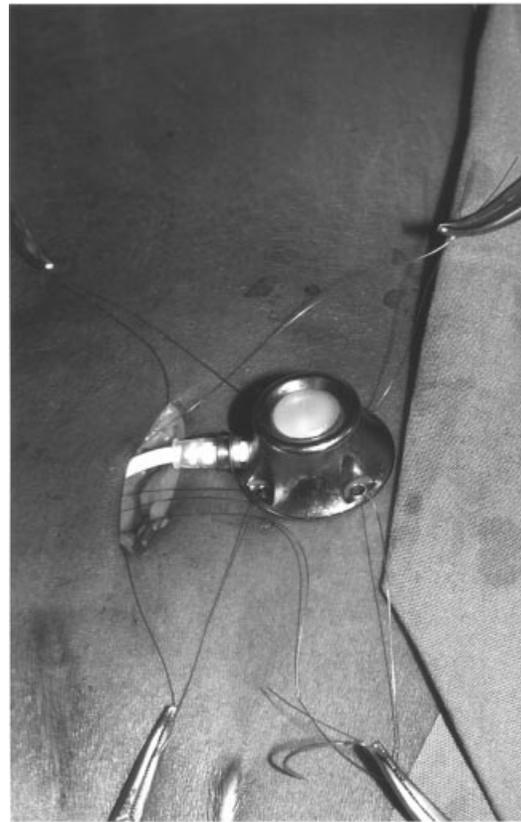
can be used instead. External clamping of the catheter is not required, which will reduce long-term catheter damage. A pressure difference must be generated by either suction or positive pressure to open the distal valvular slit. The valve function is able to withstand intravascular pressures between −7 and +80 mm Hg. This valve requires pressurized infusion systems, which may prove an inconvenience when using blood products. Another disadvantage of these devices is their increased cost, but this may be balanced by the decreased cost of saline flushes compared with heparin. This valve technology is now also available in the hub of catheters, on implantable ports, peripherally inserted catheters and short-term catheters.[47]

Ports

Ports are totally implantable devices (Fig. 2). The intravascular segment is made of similar material to Hickman and Groshong catheters. The thick injection membrane of the system is housed in a titanium or plastic case, which is surgically implanted under the skin's

subcutaneous tissue, usually on the patient's chest wall or upper arm. It is then accessed with a special non-coring Huber type needle. This provides a more acceptable cosmetic option, and allows the patient to swim or bathe, which are restricted practices with externally exiting catheters. Port kits are expensive (around £600), time-consuming to insert, and the accessing needles have a fine bore which restricts flows for blood transfusion or venesection. The access needle sticks out of the skin, making it inconvenient for longer-term continuous infusion. In the UK, they are most commonly used for short intermittent injections or infusions of drugs for conditions such as cystic fibrosis. In Europe, their use is more widespread. They may be useful for induction of anaesthesia in children undergoing repeated short procedures, e.g. lumbar puncture or bone marrow biopsy.

PICC catheters (peripherally inserted central catheters)

These are fine-bore soft catheters which are passed from cubital veins up the axillary vein, into a central vein. They are used as an alternative to Hickman-type catheters and have proved very successful in some centres, often inserted by nursing staff on the ward. Despite the relative ease with which they can be inserted, they have limitations. First, the catheter tip is difficult to manipulate and suboptimal positioning may have to be accepted unless X-ray screening is used. Failure to achieve a central tip position has been shown to occur in between 25% and 40% of attempts.[28 67 87] This can have adverse effects. For example, the rate of thrombosis related to the catheter rises from 21% if the catheter tip is in the superior vena cava to 60% if placed in the axillary, subclavian or innominate vessels.[52] Secondly, studies using ultrasound and fluoroscopy have shown an average displacement of 2–3 cm (and in some cases up to 9 cm) of the tip of the catheter by arm movement.[50 73] This may trigger arrhythmias[12 98] or increase the risk of thrombus formation due to endoluminal damage[84] or cardiac perforation. Thirdly, the narrow gauge of the catheter limits infusion flow rates and makes aspiration difficult. Fourthly, a high percentage of catheters are removed because of premature failure (21%), often as a result of phlebitis (8.2%) or occlusion (8.2%).[67] This failure rate is higher than that for tunnelled catheters.[47]

Dialysis catheters

There are a number of long-term dual-lumen dialysis catheters with or without anchoring cuffs. These are typically inserted via the right internal jugular vein. The subclavian vein is generally avoided to prevent subclavian vein thrombosis or narrowing, which interferes with subsequent arteriovenous fistula formation in that arm. In addition, there are developments in dual-lumen port-type devices for accessing central veins for intermittent

haemodialysis. These require passage of large-bore dialysis needles and have not entered mainstream practice in the UK, but have been tested and found to have adequate flow rates.[59]

How long can catheters and ports function?

The lifetime of catheters is dependent on insertion techniques and sterility, catheter care, infection, thrombosis, and mechanical wear with repeated use. We regularly see Hickman-type catheters last more than 18 months. Assuming optimal asepsis at insertion, there is gradual attrition due to catheter-related sepsis and thrombosis, as will be explained below. The external portion of the catheter will break after many months of clamping, and cuffs and ports can erode through the skin. There are repair kits available for catheters in the event of external breakage. Port membranes deteriorate as a result of repetitive punctures (manufacturers state 1000–2000 punctures depending on needle gauge used). Such devices have the best survival rates of all long-term access devices.

Materials

The ideal catheter material is chemically inert, non-thrombogenic, flexible, radio-opaque and transparent. Stiff catheters have the potential to damage vessel walls and accelerate thrombosis. Soft catheters, which have a tendency to remain more centrally placed in the bloodstream, are less likely to cause such problems. Older materials, such as polyethylene and polypropylene, are relatively stiff materials. Newer materials such as polyurethane have advantages in terms of mechanical strength and resistance to chemical degradation but are still quite stiff. The softest material currently available is silicone elastomer (Silastic, silicone rubber), which is widely regarded as the least traumatic and thrombogenic material available. Soft catheters can be difficult to insert unless they are stiffened with an insert such as a stylet or guidewire, and may rupture if the device is distended[100] or compressed (e.g. pinch-off, which is described later). Radio-opaque catheters made of all these materials are now available.

Chemical composition has an impact on thrombogenicity. Older materials such as polyethylene are more thrombogenic than newer polymers like polyurethane. Attempts to reduce thrombogenicity with anticoagulant coatings have been largely unsuccessful. However, coating catheters with Hydromer (polyvinylpyrrolidone – a hydrophilic substance), forms a barrier between the catheter material and the blood, to inhibit coagulation.

The material of choice for long-term venous access is silicone elastomer,[48] despite the possible difficulty of insertion. The alternative material of choice would be Hydromer-coated polyurethane. Different materials have a different risk of catheter-related sepsis. Teflon, silicone elastomer and polyurethane have much lower risk than more

traditional polyvinyl-type catheters,[93] and of these, silicone has been shown to have the lowest rate of infection when inserted peripherally.[61] Theoretical work suggests that materials differ in their susceptibility to microbial adherence and colonization, but there is little evidence of this *in vivo* and no evidence of an effect on long-term catheter-related sepsis.[96]

Attempts to reduce the risk of catheter-related sepsis have included addition of antiseptic or antibiotic compounds. Chlorhexidine or silver sulphadiazine coatings have been studied repeatedly and often shown to reduce the risk of catheter colonization by between 1.5 and eight times.[65 78 97] However, only one study has shown a clinically relevant decrease in catheter-related sepsis, from 4.6 to 1.4%,[65] although most authors suggest that the effect on catheter-related bacteraemia and mortality is negligible.[45 78] There have been reports of anaphylaxis to the chlorhexidine coating.[95]

Studies of minocycline and rifampicin coatings have shown lower rates of infection than for antiseptic impregnated catheters.[23 85] The rate of colonization decreased from 22.8–26 to 7.9–8%. More importantly, the rate of catheter-related sepsis fell from 3.4–5 to 0–0.3%. It must be stated that none of these catheters was in place for longer than 14 days, and there is no evidence of any long-term effects. The disadvantage of these catheters, in addition to the two- or three-fold increase in price, is the potential risk of increased antibiotic resistance. This has not been systematically studied,[78] and there is a lack of evidence. Further surveillance will be required in the event that use of such catheters becomes more widespread. Developments in technology have allowed impregnation of catheter materials themselves rather than surface coating, which tends to leach away.[78] The cost of treating catheter-related sepsis is such that the saving made by the introduction of antibiotic-coated catheters would be of the order of $100 million in the USA, with 7000–12 000 deaths prevented.[78] However, to date no long-term devices have been marketed with such coatings or impregnation.

Silver-impregnated exit site cuffs have been shown to reduce colonization in short-term non-tunnelled catheters[64] but not in longer-term catheterization (>20 days).[41]

Insertion techniques

The majority of procedures in adults are done percutaneously utilising the Seldinger technique. Percutaneous procedures when performed with care have been shown to

Fig 3 (A) Adult female with difficult venous access. The patient had underlying haematological malignancy. Note bilateral old, healed scars from Hickman lines (small arrows). Healing recent left-sided puncture site from left subclavian access (arrow). New dual-lumen Hickman line inserted via left internal jugular vein. Prominent right chest wall venous collaterals secondary to right-sided great vein obstruction. (B) Right axillary–subclavian venogram on the patient shown in panel A. Contrast injected peripherally flows from the axillary vein into the start of the blocked subclavian vein and then passes through numerous collaterals into the stump of the blocked right internal jugular vein. Collaterals then drain into the azygos/superior vena cava confluence. This explains failed attempts to pass guidewires centrally after easy right subclavian and internal jugular vein puncture. (C) Chest X-ray from the patient shown in panel A. The dual-lumen Hickman line is seen to pass via the left internal jugular vein and left innominate vein so that its tip lies at the junction of the superior vena cava and right atrium.

be superior to surgical cut-downs in terms of theatre time, cosmetic result, local infective complications and placement complications.[1 2 62] A study comparing surgical cut-downs with percutaneous techniques found a failure rate of 4.5% and multiple attempts in 13% in the surgical group,
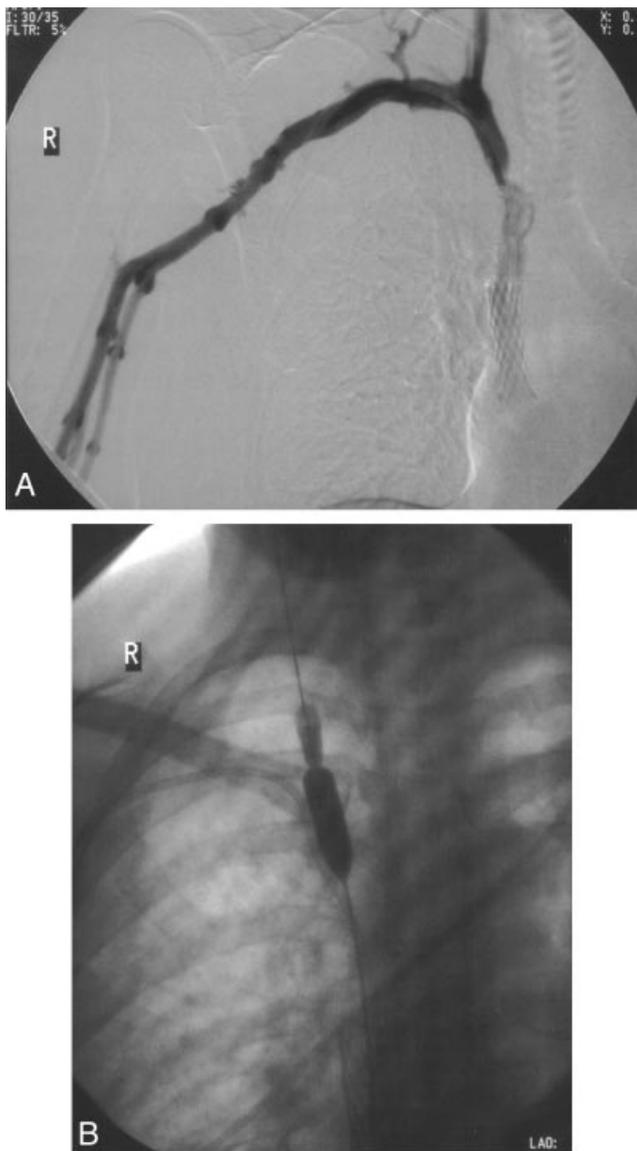

Fig 4 (A) Digital subtraction venogram of right subclavian and innominate vein. Contrast has been injected up from the right wrist. A Hickman catheter passes from the right subclavian area into a stent lying between the low superior vena cava and right atrium. There is narrowing of the right internal jugular vein above its junction with the subclavian vein. This patient had been on home total parenteral nutrition for 19 yr with multiple central venous access procedures. She required further venous access due to low-grade infection of the Hickman catheter. (B) X-ray from the patient shown in A. The narrowing in the right internal jugular vein is being widened by balloon angioplasty. Note X-ray contrast filling the balloon with characteristic waisting in which the vessel narrowing constricts the balloon during the dilation process. After these procedures, her original Hickman catheter was removed and a new catheter inserted a few days later.

compared with none in the percutaneous group. Furthermore, 3.7% of surgically placed catheters were misplaced compared with none in the percutaneous group. There were subsequently 4.0 infections per 1000 catheter days in the surgical group compared with 1.9 in the percutaneous group. The only disadvantage of the percutaneous technique is the rate of pneumothorax, which this study determined at 3.3% (compared with 0.8% for the surgical group).[62] Some authors also believe that surgical access will compromise the vein for future use in a way that percutaneous puncture does not.[25] There remains a place for surgical cut-downs, particularly in the smaller child.

Patients requiring long-term venous access may well be challenging because of several previously successful or failed venous access procedures, underlying medical problems, and anticoagulation. Specialized imaging and radiological intervention may be required (Figs 3 and 4). The usefulness of ultrasound-guided vein access in this setting has been highlighted.[44] Recent NICE (www.nice.org.uk) guidelines on this topic support the routine use of this technology for the internal jugular route, but there is insufficient evidence to make recommendations on other sites of access. However, there is no reason why ultrasound should not give similar advantages in infraclavicular axillary[38] or femoral access. Nevertheless, there has been considerable criticism of the NICE guidelines.[72 94]

The cost of ultrasound in this context is modest compared with that of many other medical technologies and compares well against the cost of complications. Minor and major complications are very expensive in clinical, legal and other terms, e.g. delayed surgery or discharge. The hidden costs of patient discomfort, vein damage, thrombosis and catheter-related sepsis have never been measured, but must surely relate to multiple punctures even if venous cannulation is eventually successful.

Most studies have been on uncomplicated patients, often under general anaesthesia.

Patients requiring long-term venous access are likely to have increased frequency of vein blockage or thrombosis and anticoagulation, making ultrasound guidance advantageous in this group. Observational studies with ultrasound have shown significant numbers of underlying vascular abnormalities in such patients, with obvious relevance to subsequent venous access. An alternative site is often required.[34 44]

A typical insertion sequence

Choose an appropriate site (the jugular, subclavian or femoral vein) using ultrasound as indicated. Full aseptic conditions in a sterile environment are compulsory. General anaesthesia and local anaesthesia with or without intravenous sedation are all appropriate. A flexible J-tip guidewire is passed centrally with X-ray verification. The catheter or port assembly is then tunnelled or surgically placed, usually on the anterior chest wall. The catheter is cut to an appropriate

length. This can be done by screening the guidewire into position and measuring the length inserted, or visualization of the catheter on the external chest wall with or without X-ray screening.

A splitting sheath is passed over an introducing dilator into a central vein. The dilators and sheath are stiff and generally longer than required.[76] There is a risk of vessel perforation; however, there is no need to insert the dilator or sheath to its full length. The length of needle that is required to puncture the vein gives a guide to the amount of dilator (and splitting sheath) that should be inserted. The dilator and sheath entering the vein is accompanied by a sudden give.

The catheter is then passed through the splitting sheath, which is withdrawn and peeled apart. Such sheaths often kink if passed around an angle in the vein and need to be withdrawn to allow the catheter to pass. The correct position of the intravascular catheter tip is adjusted under X-ray control. The internal segment of cuffed devices can be adjusted by pulling the cuff inwards or outwards along the tract.

Misplaced catheters or guidewires may enter or coil in the internal jugular vein, the innominate vein, the azygos vein or the internal mammary vein. Positioning can be facilitated by asking the patient to breathe in deeply, which straightens the great vessels as the heart and diaphragm descend on inspiration. Soft catheters can be stiffened by the use of a long (70 cm) guidewire of the type used by interventional radiologists, passed through the catheter, if the standard wire in the kits is too short (50 cm). In more difficult cases, the vascular anatomy and catheter position can be determined by injecting X-ray contrast through the catheter.

There is ongoing debate as to the optimum position for catheter tips, but most centres would leave the tip either in the lower superior vena cava or upper right atrium.[32] There have been reports of cardiac tamponade resulting from atrial or ventricular perforation if the tip of the catheter lies within the pericardial sac. The pericardium may ascend along the medial wall of the superior vena cava up to a distance of 5 cm, giving a risk of cardiac perforation even if the catheter tip lies outside the atrium.[91] The risk of this type of perforation is low and higher positioning leads to an increased risk of vein puncture, hydrothorax or mediastinal fluid,[22] and thrombus formation.[84]

Catheter tips can change position on moving from lying to standing. Most insertions are done in a supine or head-down position. Subsequent X-rays show descent of the abdominal contents and diaphragm and a change in the catheter position relative to the mediastinal contents.[74] This may lead to catheter malposition. It is revealing to screen the catheter tip position whilst the patient inspires deeply. Similarly, there is evidence that pendulous breast tissue may exert traction on the extra-thoracic portion of a tunnelled catheter, which will cause outward movement with the potential for extravasation.[70]

Catheters commonly fall out or migrate outwards unless adequately fixed in; we are even aware of one catheter accidentally pulled out by a patient's dog. This fixation should include suturing of the external portion, using temporary wings, if they are included in the kit. At least 3 weeks is required for cuff fixation in healthy patients.

There is debate as to the value of a post-insertion chest X-ray after such an insertion sequence.[39] This is very different from the standard for anaesthesia or intensive care, where post-procedural radiographs are usually mandatory. If the position of the catheter has been verified fluoroscopically, then the tip position is not in doubt and an additional X-ray will add little information.[60] It must be remembered that there will be exceptions to this rule. For example, cases where excessive tip movement is expected because of pendulous breast tissue should be routinely X-rayed in the sitting position to ascertain final tip position. In our experience, the occurrence of a pneumothorax (which is rare in skilled hands) is often not detected on an early chest X-ray. Day-case patients go home to return with clinical signs later.

The intravascular portion of a port system is sited in the same fashion as other catheters, but the body of the port requires a percutaneous pocket to be created surgically. There are suture holes in the base of the port which are anchored to fascial layers with non-absorbable sutures. To avoid a large incision, these sutures should be placed first and the port slid down into the pocket. This technique,

Table 2 Advantages and disadvantages of different routes for central venous access[58]

	Advantages	Disadvantages
Arm veins (cephalic, basilic)	Simple to access, veins visible and palpable	Failure to achieve central position
	No vital organs close	High incidence of thrombosis
	Patient comfort	Low maximum infusion rates
Internal jugular	Simple to insert	Patient discomfort
	Direct route to central veins	Higher rate of late complications, especially infection
	High flow rate, low risk of thrombosis	Tunnelling more difficult to chest wall
	Lower risk of pneumothorax	
Subclavian/axillary	Less patient discomfort	Curved insertion route
	Lower risk of long-term complications	Difficult to access
		Acute complications – pneumothorax, haemothorax, nerve damage
Femoral	High flow, good for dialysis	Higher rate of infection/thrombosis
	Easy insertion	More discomfort
		Difficult in obese patients

similar to that used by cardiac surgeons for the insertion of artificial valves, is known as the parachute technique (Fig. 2).

For safe, efficient practice, a sterile area such as the radiology suite or an operating theatre is required for insertions. Ready access to ultrasound and X-ray screening is required. We currently perform such procedures for oncology and other specialties both on an *ad hoc* basis in the emergency theatres, and also on a dedicated list. We can insert six Hickman catheters in a 3.5 h session as well as one or two removals. Almost all are performed under local anaesthesia and i.v. sedation, many as day cases. A service can be provided on an outpatient basis,[1] with only a short period of observation. The organization of a service depends on the number of patients that are seen. A fully dedicated session would be likely to be impracticable for the throughput of a smaller district general hospital unless combined with other procedures.

Sites of access

There are a number of different sites available for access with advantages and disadvantages of each (Table 2). There is very little accurate evidence for such choices. Many choose the subclavian site on the basis of perceived cleanliness and ease of tunnelling from the anterior chest wall, as well as a cosmetic consideration.[17] The right subclavian vein has a shorter, more direct route to the superior vena cava than the left. Studies regarding infection risk have tended to concentrate on catheters which exit directly through the skin from the venotomy site rather than the tunnelled type of catheter. It is not clear whether such tunnelling to a cleaner exit site renders different vein puncture sites similar in terms of infection risks. In the event of a superior vena cava thrombosis or obstruction, access to this vessel should usually be avoided. The femoral route with tunnelling to the abdominal wall is a suitable alternative.

There are a large number of other sites that are used on a more occasional basis, e.g. the portal vein, direct IVC puncture[9] [53] (including a trans-hepatic approach),[51] arteriovenous fistulae, internal mammary vein, scalp veins,[86] cephalic vein,[18] pudendal vein,[36] gonadal vein,[20] inferior epigastric vein,[57] and intercostal[75] and azygos veins.[79]

Removal techniques

Safe techniques for removal of long-term catheters are as important as for insertion. Poor techniques risk poor cosmetic results, infection, catheter damage, and embolization to the heart or pulmonary artery. Recently inserted or infected catheters can be removed with traction alone, but established catheters require a cut-down technique under local anaesthesia over the cuff site. Cuff location can be difficult, but palpation with gentle traction on the catheter or use of a fine probe up the exit tract can often reveal its

position. After skin incision, blunt dissection will reveal a fibrous sheath, which must be incised before the inner portion of the catheter can be secured. This is the most important part of the procedure. The intravascular part must be retrieved before the catheter is cut. Subsequently, pressure can be applied over the vein puncture site to stop bleeding. Removal of the cuff allows the outer portion of the catheter to be removed. Closure of the wound completes the procedure.[37]

Ports are removed by making an incision into the dense fibrous sac which forms round the port in the longer term. There are typically four small anchoring sutures attaching the port through holes to deeper tissues. These will need to be cut for removal. The same conditions regarding the risk of catheter damage and embolization apply as to other catheters.

Training and accreditation

We are aware that an increasing number of anaesthetists perform such insertion procedures, and there are issues regarding training and accreditation in insertion techniques. Who should teach insertion and removal of these devices? It is easy when there is a local expert who can pass on expertise, but for the purposes of instituting a brand-new catheter insertion service, who will provide the education?

Many different specialties have experience in such techniques. Procedures are done by radiologists, anaesthetists, surgeons, renal physicians, cardiologists, oncologists and oncology nurses. There is no evidence to suggest one specialty is better than another in respect of complications. What is more important is to have appropriately trained, skilled operators who do adequate numbers of these procedures to develop and retain their skills. Ideally, one requires skills in local anaesthesia, i.v. sedation, central venous access, use of ultrasound for venous access, X-ray screening, and the management of complications such as bleeding, pneumothorax and arrhythmias.

Complications related to long-term access

Pinch-off

This term refers to entrapment of subclavian catheters between the clavicle and first rib (Fig. 5A). Over time, repeated compression causes catheter fracture, resulting in extravasation of fluids, or catheter breakage and embolization of the intravascular portion of the catheter. This phenomenon may occur in as many as 1% of all long-term central venous catheterizations via the subclavian vein.[5] [81] Clinically, pinch-off may present as postural-related difficulty in injection (injection is easier with the patient supine with arm and shoulder raised), or the patient may complain of infraclavicular discomfort and swelling due to extravasation of infused fluids. The condition needs to be recognized, and there are characteristic X-ray appearances showing

scalloping of the catheter on plain chest X-ray (Fig. 5B). The condition can be avoided by choosing a more lateral puncture site of the vein during subclavian catheterization[3 5] or using alternative sites of vein access. If a subclavian access site is felt to be very tight when dilators are passed,

consideration should be given to siting the catheter elsewhere.

Catheter-related vein thrombosis

This is a recurrent problem with longer-term venous access devices. It has been found in as many as 40% of patients at autopsy,[4] and ultrasound studies have shown an incidence of 33–67% after more than 1 week.[11 88] But clinical rates are low, especially in long-term access. It is thought that thrombus starts at the site of the venepuncture and then migrates along the catheter to eventually occlude the tip. Such thrombus can be seen on ultrasound floating around the catheter within the vessel lumen, or as a ghost after catheter removal. The sequelae of thrombus are obstruction to infusion of fluids and withdrawal of blood. There may be more sinister results. Catheter-related subclavian or axillary vein thrombosis is associated with an incidence of pulmonary embolus of up to 12%.[89] There is a strong link between thrombus and infection and good evidence that reduction of thrombus rates will reduce episodes of infection (see below).

Blockage of major veins may occur as a result of thrombosis or ongoing scarring of the vein. This may lead to local problems, e.g. swelling of the arm from axillary thrombosis. Central blockage of the superior vena cava (SVC) or inferior vena cava may lead to more serious problems. There are cases in the literature of acute airway obstruction secondary to SVC obstruction, as a result of subclavian Hickman catheter insertion.[77] In the presence of long-term venous thrombosis and obstruction, venous collaterals open up to bypass such blockages. These may or may not be visible superficially (Fig. 3A); if they are then attending, staff should be aware of the likelihood of underlying major vessel obstruction (Fig. 3B), with obvious implications for venous access. Innocuous-looking scars from previous access may herald such problems. It is debatable whether it is a good idea to pass catheters through such a narrowing. Even if this is technically possible, the presence of yet another catheter may produce complete blockage. Such stenoses may be dilated by balloon angioplasty or stenting (Fig. 4A and B).

The issue of whether to remove the catheter in the presence of vessel thrombosis, if it still functions, has yet to be resolved. Although removal of the catheter seems
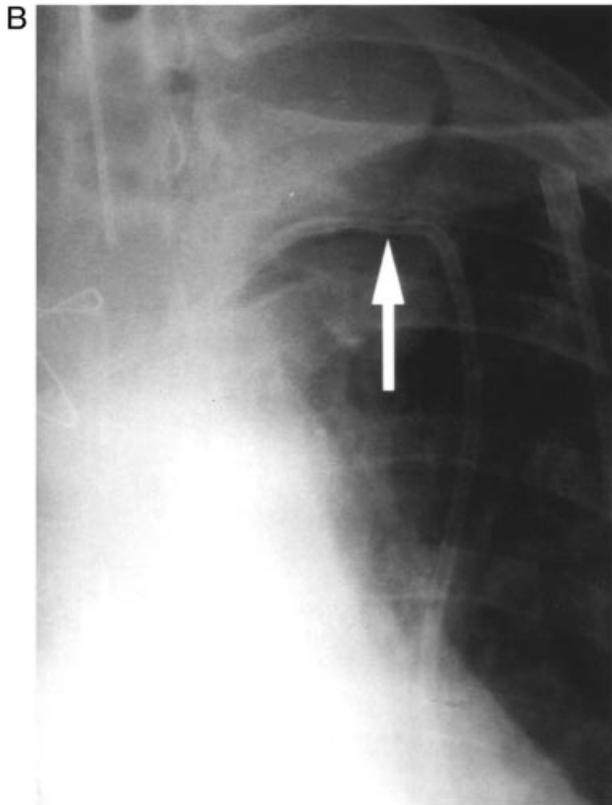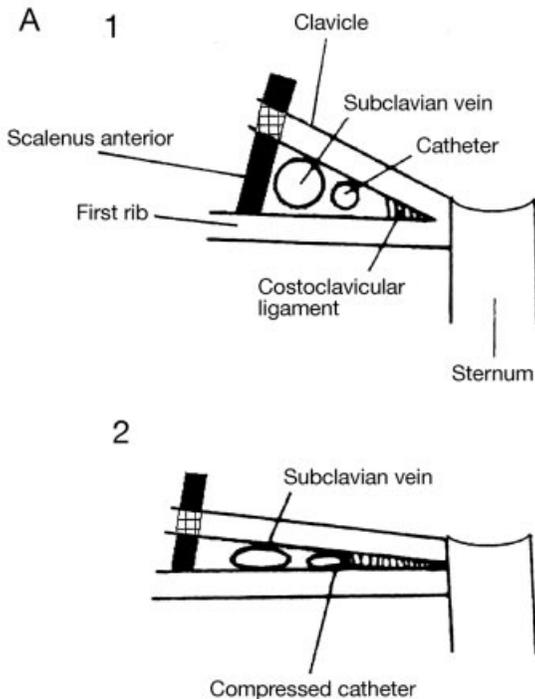
Fig 5 (A) Diagram to explain proposed mechanism of 'pinch-off'. At the time of catheter insertion the angle between the clavicle and the first rib is wide (1). In the upright position, the angle narrows and pinches the catheter (2). Adapted from Aitken *et al.* (1984)[3] with permission from Excerpta Medica. (B) Close-up view of left upper portion of chest X-ray. A single-lumen Hickman catheter has been inserted via the left subclavian route. The section of catheter lying under the first rib and clavicle (arrow) shows characteristic compression (scalloping) suggestive of pinch-off. Extravasation of infused fluid occurred and the damaged catheter required removal.

intuitive, there are reports of successful treatment using anticoagulation or thrombolysis with the catheter left *in situ*.[35 71]

Heparin-bonded coatings have been tried to attempt to delay catheter thrombosis, but are not widely used for longer-term catheters and their effectiveness has never been established. Many centres administer low-dose warfarin. A typical regime is a 10 mg loading dose and 1 mg daily thereafter. This has been shown to reduce the incidence of venous thrombosis from 37.5 to 9.5%. However, these small doses of warfarin may produce significant anticoagulation in susceptible patients with complications.[10] Low molecular weight heparin at a dose of 2500 IU per day has been shown to reduce the incidence of venous thrombosis from 62 to 6%, but with an incidence of significant haemorrhage of 6%.[69 88] Unfractionated heparins have been used similarly, in doses of 5000 units twice or four times daily, or 3 U per ml of parenteral nutrition.[88 99] There are few controlled trials to support such interventions and certainly not enough to distinguish which method should be recommended.

Catheter lumen blockage

Another aspect of catheter thrombosis is intraluminal thrombosis. This can usually be prevented by a heparin lock. Catheters are flushed with heparinized saline after use, or weekly. Various solutions and strategies have been used to aid unblocking of catheters. These include heparin, urokinase, streptokinase,[49] streptodornase and recombinant tissue plasminogen activator (rTPA).[7] Urokinase (a fibrinolytic drug) has been used with some success; typical doses would be 5000–10 000 U injected slowly,[8] or a low-dose infusion.[42] If the catheter is completely blocked, two techniques can be used to put the drug into the lumen. First, aspiration of air from the lumen using a small-volume syringe to create a vacuum, followed by connection to a syringe containing the fibrinolytic agent. Alternatively, simply connecting the syringe to the catheter and leaving for several hours will allow the enzyme to diffuse into the lumen and break down the thrombus. Trials with recombinant urokinase are currently under way, which look promising. These drugs should be used with caution, as they may lead to bleeding complications.

Catheter-related infection

The Department of Health, in its guidelines on catheter-related infection, suggests that tunnelled catheters should be used for patients likely to need vascular access for more than 30 days.[6 27] Infection is a major problem with long-term venous access, with reported rates between 3 and 60%.[40 43 92] These infections can be divided into three main groups, which may coexist: exit site infection; tunnel or pocket infection; and catheter sepsis or catheter-related bacteraemia. This is a complex area and readers are referred to other reviews for more information.[27 31 48 82]

Exit site infections

These are localized to the point at which a device exits through the skin. Most infections are due to *Staphylococcus epidermidis*.[56 83] Frequently, these can be managed with local wound care and antibiotics without resorting to catheter removal. However, if there is evidence of bacteraemia or a more virulent pathogen such as *Staphylococcus aureus*, such treatment will not be adequate.

Tunnel or pocket infection

This represents a process of suppuration or induration related to the subcutaneous tunnel (or pocket in the case of ports). Because of the presence of suppuration and a foreign body, these infections usually require the removal of the catheter as well as the use of antibiotics.

Catheter-related bacteraemia

This is the most serious type of infection. This occurs with 7–33% of catheters.[21 90] The larger value relates to patients receiving parenteral nutrition. The mortality is estimated at between 14 and 24%.[80] The usual presentation is a bacteraemia with no other obvious source of sepsis. This may be secondary to chronic colonization of the intravascular portion of the catheter from the exit site or external portions of the catheter. There is a strong correlation between thrombus formation and infection. The thrombus probably serves as a culture medium for bacteria. It is likely that any additional vessel wall damage (associated with traumatic insertion, for example), will predispose to infection. It has been shown that flushing the catheter with heparin,[88] use of oral anticoagulants[10] and the use of low molecular weight heparin[69] are associated with a reduction in rates of catheter-related infection. This only applies if the intervention is given before any thrombus has formed. Administration after thrombus formation may lead to septic emboli breaking off from the clot.

Correct diagnosis is important in order to avoid premature or unnecessary catheter removal. Successful treatment of catheter-related sepsis has been reported with the catheter left *in situ*.[15 43] However, this is dependant on the pathogen. *Staphylococcus aureus* bacteraemia and candidaemia have not been amenable to treatment without catheter removal.[24 29 30] This is because of the high rates of failure and also the risk of complications, including endocarditis. With the exception of these two situations, the decision regarding removal should be individualized and made according to the patient's response to antibiotics. Other factors, such as the potential ease of reinsertion, the fitness to undergo another procedure and the immediacy of need, should be considered.

Diagnosis of infection

This has been performed in a number of ways. Clinically, it should be suspected in any patient with features of sepsis, no obvious cause and a central venous catheter *in situ*. Patients will often develop rigors and a pyrexia on flushing or using the catheter. The roll plate method[66] has for many years

been the standard diagnostic test, and involves rolling the tip of the catheter on a culture plate. This only cultures organisms from the outside of the catheter and requires removal of the catheter. An alternative technique is the semiquantitative Cleri technique, which involves flushing the lumen of a catheter with a nutrient broth. This liquid is then cultured and colony-forming units are counted after a few days.[19] Sampling of blood through the catheter before it is removed can be used in the diagnostic process. Differences in time to positive blood cultures and colony counts collected through the catheter compared with similar-volume peripheral blood samples suggest likely catheter-related sepsis.[14 33] Alternatively, a small brush can be used to sample endoluminal organisms, without removal of the catheter.[55] There is, however, concern about bacterial embolization from this procedure, and results of this technique in an intensive care setting did not support its routine use.[63]

When should such devices be used in anaesthesia and intensive care?

Assuming such devices are working properly and are correctly placed, they could be used for induction of anaesthesia, infusion of fluids and blood products, monitoring of central venous pressure, or use of vasopressor agents. They may be particularly valuable in an emergency situation.

Provided adequate aseptic precautions are used when connecting such infusions, there should be minimal additional risk to the patient. The risk of any contamination of long-term access devices needs to be weighed against their suitability for the particular indication and the risk of difficulty in establishing alternative access. It should be noted that any patient who has had multiple long-term venous access devices may well have thrombosed central veins, with the potential to make further access difficult and dangerous (Figs 3 and 4). We have used such devices, often for prolonged periods, on the intensive care unit without serious sequelae.

Indwelling ports are probably less suited to use for a long period of anaesthesia or intensive care. This is because of the small diameter of the access needle limiting infusion rates and the risk that the needle may slip out. The technique for accessing the ports is simple. The area can be prepared in advance with anaesthetic cream or may have been denervated during surgical formation. When ready for access, the site is cleaned and the skin either side of the port is grasped firmly between two gloved fingers. The Huber needle is pushed through the skin and thick port membrane, which requires considerable force. There will be a palpable clunk as the needle hits the back wall of the device. Aspiration of blood confirms that the needle is in place and the port is working, and injection may then proceed.

Hickman and Broviac catheters simply require flushing before use. With Groshong catheters it is important to note that pressure is required to inject and aspirate through the catheter. Groshong lines cannot be used to monitor central venous pressure because of the valve function. It is also likely that, at low flow rates, the valve may produce intermittent boluses of fluid or drug, which may make these catheters inappropriate to use for inotropes or vasopressor infusions.

Summary

Long-term venous access devices are ubiquitous in hospital practice and will be regularly encountered in anaesthesia and intensive care medicine. Clinicians need to understand how the indications for and use of such devices differ from those for short-term access devices. There is an increased practice for anaesthetists to insert long-term access devices, with implications for training and accreditation in such procedures.

References

1 Adam A. Insertion of long term central venous catheters: time for a new look. *Br Med J* 1995; **311**: 341–2

2 Ahmed Z, Mohyuddin Z. Complications associated with different insertion techniques for Hickman catheters. *Postgrad Med J* 1998; **74**: 104–7

3 Aitken D, Minton J. The 'pinch-off sign': a warning of impending problems with permanent subclavian catheters. *Am J Surg* 1984; **148**: 633–6

4 Anderson A, Krasnow S, Boyer M, et al. Thrombosis: the major Hickman catheter complication in patients with solid tumor. *Chest* 1989; **95**: 71–5

5 Andris D, Krzywda E, Schulte W, Ausman R, Quebbeman E. Pinch-off syndrome: a rare etiology for central venous catheter occlusion. *J Parenter Enteral Nutr* 1999; **18**: 531–3

6 Anonymous. Managing bloodstream infections associated with intravascular catheters. *Drug Ther Bull* 2001; **39**: 75–80

7 Atkinson J, Bagnall H, Gomperts E. Investigational use of tissue plasminogen activator (t-PA) for occluded central venous catheters. *J Parenter Enteral Nutr* 1990; **14**: 310–1

8 Bagnall H, Gomperts E, Atkinson J. Continuous infusion of low-dose Urokinase in the treatment of central venous catheter thrombosis in infants and children. *Pediatrics* 1989; **83**: 963–6

9 Bennett J, Papadouris D, Rankin R, et al. Percutaneous inferior vena caval approach for long term central venous access. *J Vasc Interv Radiol* 1997; **8**: 851–5

10 Bern M, Lokich J, Wallace S, et al. Very low doses of warfarin can prevent thrombosis in central venous catheters. A randomised prospective trial. *Ann Intern Med* 1990; **112**: 423–8

11 Bernard R, Stahl W. Subclavian vein catheterizations: a prospective study. 1. Non infectious complications. *Ann Surg* 1971; **173**: 184–90

12 Bivins M, Callahan M. Position-dependent ventricular tachycardia related to a peripherally inserted central catheter. *Mayo Clin Proc* 2000; **75**: 414–6

13 Bjeletich J, Hickman R. The Hickman indwelling catheter. *Am J Nurs* 1980; **80**: 62–5

14 Blot F, Nitenberg G, Chachaty E. Diagnosis of catheter-related

bacteraemia: a prospective comparison of the time to positivity of hub-blood versus peripheral-blood cultures. *Lancet* 1999; **354**: 1071–7

15 Brar K, Murray D, Leader I. Central venous catheter infections in pediatric patients in a community hospital. *Infection* 1988; **16**: 86–90

16 Broviac J, Cole J, Scribner B. A silicone rubber right atrial catheter for prolonged parenteral alimentation. *Surg Gynecol Obstet* 1973; **136**: 602–6

17 Capaccioli L, Nistri M, Distante V, Rontini M, Manetti A, Stecco A. Insertion and management of long-term central venous devices: role of radiologic imaging techniques. *Radiol Med* 1998; **96**: 369–74

18 Chuter T, Starker P. Placement of Hickman–Broviac catheters in the cephalic vein. *Surg Gynecol Obstet* 1988; **166**: 163–4

19 Cleri D, Corrado M, Seligman S. Quantitative culture of intravenous catheters and other intravascular inserts. *J Infect Dis* 1980; **141**: 781–6

20 Coit D, Turnbull A. Long term central vascular access through the gonadal vein. *Surg Gynecol Obstet* 1992; **175**: 362–4

21 Curry C, Quie P. Fungal septicemia in patients receiving parenteral hyperalimentation. *N Engl J Med* 1971; **285**: 1221–5

22 Dailey R. Late vascular perforations by CVP catheters. *J Emerg Med* 1998; **146**: 487–90

23 Darouiche R, Raad I, Heard S, *et al*. A comparison of two antimicrobial-impregnated central venous catheters. *N Engl J Med* 1999; **340**: 1–8

24 Dato V, Dajani A. Candidemia in children with central venous catheters: role of catheter removal and amphotericin B therapy. *Pediatr Infect Dis J* 1990; **9**: 309–14

25 David S, Thompson J, Edney J. Insertion of Hickman catheters in total parenteral nutrition: a prospective study of 200 consecutive patients. *Am J Surg* 1984; **50**: 673–6

26 De Cicco M, Panarello G, Chiaradia V, *et al*. Source and route of microbial colonisation of parenteral nutrition catheters. *Lancet* 1989; **2**: 1258–61

27 Department of Health. Guidelines for preventing infections associated with the insertion and maintenance of central venous catheters. *J Hosp Infect* 2001; **47** (Suppl): 47–67

28 Duerksen D, Papineau N, Siemens J, Yaffe K. Peripherally inserted central catheters for parenteral nutrition: a comparison with centrally inserted catheters. *J Parenter Enteral Nutr* 1999; **23**: 85–9

29 Dugdale D, Ramsey P. *Staphylococcus aureus* bacteremia in patients with Hickman catheters. *Am J Med* 1990; **89**: 137–41

30 Eppes S, Troutman J, Gutman L. Outcome of treatment of candidemia in children whose central catheters were removed or retained. *Pediatr Infect Dis J* 1989; **8**: 99–104

31 Fletcher S, Bodenham A. Catheter-related sepsis: an overview-Part 1. *Br J Intensive Care* 1999; **9**: 46–53

32 Fletcher S, Bodenham A. Safe placement of central venous catheters: where should the tip of the catheter lie? *Br J Anaesth* 2000; **85**: 188–91

33 Flynn P, Shenep J, Stokes D, Barrett F. *In situ* management on confirmed central venous catheter-related bacteremia. *Pediatr Infect Dis J* 1987; **6**: 729–34

34 Forauer A, Glockner J. Importance of ultrasound findings in access planning during jugular vein haemodialysis catheter placements. *J Vasc Interv Radiol* 2000; **11**: 233–8

35 Fraschini G, Jadeja J, Lawson M, Holmes F, Carrasco H, Wallace S. Local infusion of Urokinase for the lysis of thrombosis associated with permanent central venous catheters in cancer patients. *J Clin Oncol* 1987; **5**: 672–8

36 Fukui S, Coggia M, Goeau-Brissonniere O, Robin A, Patel J.

Introducing an implantable central venous catheter via the right pudendal vein. *Presse Med* 1995; **24**: 1608–9

37 Galloway S, Bodenham A. Safe removal of long term cuffed Hickman type catheters. *Hosp Med* 2003; **64**: 20–3

38 Galloway S, Bodenham A. Ultrasound imaging of the axillary vein – anatomical basis for central venous access. *Br J Anaesth* 2003; **5**: 589–95

39 Gladwin M, Slonim A, Landucci D, Gutierrez D, Cunnion R. Cannulation of the internal jugular vein: is postprocedural chest radiography always necessary? *Crit Care Med* 1999; **27**: 1819–23

40 Greene F, Moore W, Strickland G, McFarland J. Comparison of a totally implantable access device for chemotherapy (Port-A-Cath) and long-term percutaneous catheterization (Broviac). *South Med J* 1988; **81**: 580–603

41 Groeger J, Lucas A, Coit D, *et al*. A prospective randomized evaluation of the effect of silver impregnated subcutaneous cuffs for preventing tunnelled chronic venous access catheter infections in cancer patients. *Ann Surg* 1993; **218**: 206–10

42 Haire W, Lieberman R. Thrombosed central venous catheters: restoring function with 6-hour urokinase infusion after failure of bolus urokinase. *J Parenter Enteral Nutr* 1992; **16**: 129–32

43 Hartman G, Shochat S. Management of septic complications associated with Silastic catheters in childhood malignancy. *Pediatr Infect Dis J* 1987; **6**: 1042–7

44 Hatfield A, Bodenham A. Portable ultrasound for difficult central venous access. *Br J Anaesth* 1999; **82**: 822–6

45 Heard S, Wagle M, Vijayakumar E, *et al*. Influence of triple-lumen central venous catheters coated with chlorhexidine and silver sulphadiazine on the incidence of catheter-related bacteremia. *Arch Intern Med* 1998; **158**: 81–7

46 Hickman R, Buckner C, Clift R, Sanders J, Stewart P, Thomas E. A modified right atrial catheter for access to the venous system in marrow transplant recipients. *Surg Gynecol Obstet* 1979; **148**: 871–5

47 Hoffer E, Borsa J, Santulli P, Bloch R, Fontaine A. Prospective randomized comparison of valved versus nonvalved peripherally inserted central vein catheters. *Am J Roentgenol* 1999; **173**: 1393–8

48 Hoch J. Management of the complications of long-term venous access. *Semin Vasc Surg* 1997; **10**: 135–43

49 Hurtubise M, Bottino J, Lawson M, McCredie K. Restoring patency of occluded central venous catheters. *Arch Surg* 1980; **115**: 212–3

50 Kalso E, Rosenberg P, Vuorialho M, Pietilä K. How much do arm movements displace cubital central venous catheters? *Acta Anaesthesiol Scand* 1982; **26**: 354–6

51 Kaufman J, Greenfield A, Fitzpatrick G. Transhepatic cannulation of the inferior vena cava. *J Vasc Interv Radiol* 1991; **2**: 331–5

52 Kearns P, Coleman S, Wehner J. Complications of long arm-catheters: a randomised trial of central versus peripheral tip location. *J Parenter Enteral Nutr* 1996; **20**: 20–4

53 Kenney P, Dorfman G, Denny D. Percutaneous inferior vena cava cannulation for long-term parenteral access. *Surgery* 1985; **97**: 602–5

54 Keohane P, Jones B, Attrill H, *et al*. Effect of catheter tunnelling and a nutrition nurse on catheter sepsis during parenteral nutrition. A controlled trial. *Lancet* 1983; **2**: 1388–90

55 Kite P, Dobbins B, Wilcox M, *et al*. Evaluation of a novel endoluminal brush method for *in situ* diagnosis of catheter related sepsis. *J Clin Pathol* 1997; **50**: 278–82

56 Krog M, Ekborn A, Nystrom-Rosander C, Rudberg C, Simonsson N. Central venous catheters in acute blood malignancies. *Cancer* 1987; **59**: 1358–61

57 Krog M, Gerdin B. An alternative placement of implantable central venous access systems. *J Parenter Enteral Nutr* 1989; **13**: 666–7

58 Latto IP. The external jugular vein. In: Latto IP, Ng WS, Jones PL, Jenkins BJ, eds. *Percutaneous Central Venous and Arterial Catheterisation*. Harcourt, London, 2000; 206–7

59 Levin N, Yang P, Hatch D, *et al.* New access device for haemodialysis. *ASAIO J* 1998; **44**: 529–31

60 Lucey B, Varghese J, Haslam P, Lee M. Routine chest radiographs after central line insertion: mandatory postprocedural evaluation or unnecessary waste of resources? *Cardiovasc Intervent Radiol* 1999; **22**: 381–4

61 MacDonald A, Master S, Moffitt E. A comparative study of peripherally inserted silicone catheters for parenteral nutrition. *Can Anaesth Soc*1977; **24**: 263–9

62 McBride K, Fisher R, Warnock N, *et al.* A comparative analysis of radiological and surgical placement of central venous catheters. *Cardiovasc Intervent Radiol* 1997; **20**: 17–22

63 McLure H, Juste R, Thomas M, Soni N, Roberts A, Azadian B. Endoluminal brushing for detection of central venous catheter colonization – a comparison of daily vs. single brushing on removal. *J Hosp Infect* 1997; **36**: 313–6

64 Maki D, Cobb L, Garman J, Shapiro J, Ringer M, Helgerson R. An attachable silver-impregnated cuff for prevention of infection with central venous catheters: a prospective randomized multicenter trial. *Am J Med* 1988; **85**: 307–14

65 Maki D, Stolz S, Wheeler S, Mermel L. Prevention of central venous catheter-related bloodstream infection by use of an antiseptic-impregnated catheter. *Ann Intern Med* 1997; **127**: 257–66

66 Maki D, Weise C, Sarafin H. A semiquantitative culture method for identifying intravenous catheter related infection. *N Engl J Med* 1977; **296**: 1305–9

67 Merrill S, Peatross B, Grossman M, Sullivan J, Harker W. Peripherally inserted central venous catheters. Low-risk alternatives for ongoing venous access. *West J Med* 1994; **160**: 25–30

68 Moller J, Reiss I, Schaible T. Vascular access in neonates and infants – indications, routes, techniques and devices, complications. *Intensive Care World* 1995; **12**: 48–53

69 Monreal M, Alastrue A, Rull M, *et al.* Upper extremity deep venous thrombosis in cancer patients with venous access devices-prophylaxis with a low molecular weight heparin (Fragmin). *Thromb Haemost* 1996; **75**: 251–3

70 Moorman D, Horattas M, Wright D, Kaufman K, Ruf W. Hickman catheter dislodgement due to pendulous breasts. *J Parenter Enteral Nutr* 1987; **11**: 502–4

71 Moss J, Wagman L, Riihimaki D, Terz J. Central venous thrombosis related to the Silastic Hickman–Broviac catheters in an oncologic population. *J Parenter Enteral Nutr* 1989; **13**: 397–400

72 Muhm M. Ultrasound guided central venous access. *BMJ* 2002; **325**: 1373–4

73 Nadroo A, Glass R, Lin J, Green R, Holzman I. Changes in upper extremity position cause migration of peripherally inserted central catheters in neonates. *Pediatrics* 2002; **110**: 131–6

74 Nazarian G, Bjarnason H, Dietz C, Bernadas C, Hunter D. Changes in tunnelled catheter tip position when a patient is upright. *J Vasc Interv Radiol* 1997; **8**: 437–41

75 Newman B, Cooney D, Karp M, Jewett T. The intercostal vein: an alternative route for central venous alimentation. *J Pediatr Surg* 1983; **18**: 732–3

76 Nixon S. Death after inserting Hickman line was probably avoidable. *BMJ* 2002; **324**: 739

77 O'Hara J, Brand M, Boutros A. Acute airway obstruction following placement of a subclavian Hickman catheter. *Can J Anaesth* 1994; **41**: 241–3

78 Pai M, Pendland S, Danziger L. Antimicrobial-coated/bonded and -impregnated intravascular catheters. *Ann Pharmacother* 2001; **35**: 1255–63

79 Patel N. Percutaneous translumbar placement of a Hickman catheter into the azygos vein. *Am J Roentgenol* 2000; **175**: 1302–4

80 Pittet D, Tarara D, Wenzel R. Nosocomial bloodstream infection in critically ill patients. Excess length of stay, extra costs and attributable mortality. *JAMA* 1994; **271**: 1598–601

81 Polderman K, Girbes A. Central venous catheter use. Part 1: Mechanical complications. *Intensive Care Med* 2002; **28**: 1–17

82 Polderman K, Girbes A. Central venous catheter use. Part 2: Infectious complications. *Intensive Care Med* 2002; **28**: 18–28

83 Press O, Ramsey P, Larson E, Fefer A, Hickman R. Hickman catheter infections in patients with malignancies. *Medicine (Baltimore)* 1984; **63**: 189–200

84 Puel V, Cudrey M, Le Metayer P, *et al.* Superior vena cava thrombosis related to catheter malposition in cancer chemotherapy given through implanted ports. *Cancer* 1993; **72**: 2248–52

85 Raad I, Darouiche R, Dupuis J, *et al.* Central venous catheters coated with minocycline and rifampicin for the prevention of catheter-related colonization and bloodstream infections. *Ann Intern Med* 1997; **127**: 267–74

86 Racadio J, Johnson N, Doellman D. Peripherally inserted central venous catheters: success of scalp-vein access in infants and newborns. *Radiology* 1999; **210**: 858–60

87 Ragasa J, Shah N, Watson R. Where antecubital catheters go: a study under fluoroscopic control. *Anesthesiology* 1989; **71**: 378–80

88 Randolph A, Cook D, Gonzales C, Andrew M. Benefit of heparin in central venous and pulmonary artery catheters. A meta-analysis of randomized controlled trials. *Chest* 1998; **113**: 165–71

89 Reed W, Newman K, Tenney J, Schimpff S. Autopsy findings after prolonged catheterization of the right atrium for chemotherapy in acute leukaemia. *Surg Gynecol Obstet* 1985; **160**: 417–90

90 Ryan J, Abel R, Abbott W, *et al.* Catheter complications in total parenteral nutrition: a prospective study of 2000 consecutive patients. *N Engl J Med* 1974; **290**: 757–61

91 Schuster M, Nave H, Piepenbrock S, Pabst R, Panning B. The carina as a landmark in central venous catheter placement. *Br J Anaesth* 2000; **85**: 192–4

92 Shaw J, Douglas R, Wilson T. Clinical performance of Hickman and Portacath atrial catheters. *Aust NZ J Surg* 1988; **58**: 657–9

93 Sheth N, Franson T, Rose H, Buckmire F, Cooper J, Sohnle P. Colonization of bacteria on polyvinyl chloride and Teflon intravascular catheters in hospitalized patients. *J Clin Microbiol* 1983; **18**: 1061–3

94 Simpson P. NICE Technology Appraisal Guidance no. 49. The use of ultrasound locating devices for placing central venous catheters. Bulletin 17, Royal College of Anaesthesists, London, 2003; 859

95 Stephens R, Mythen M, Kallis P, Davies D, Egner W, Rickards A. Two episodes of life-threatening anaphylaxis in same patient to a chlorhexidine–sulphadiazine-coated central venous catheter. *Br J Anaesth* 2001; **87**: 306–8

96 Tebbs S, Sawyer A, Elliot T. Influence of surface morphology on *in vitro* bacterial adherence to central venous catheters. *Br J Anaesth* 1994; **72**: 587–91

97 Veenstra D, Saint S, Saha S, Lumley T, Sullivan S. Efficacy of

antiseptic-impregnated central venous catheters in preventing catheter-related bloodstream infection. A meta-analysis. *JAMA* 1999; **281**: 261–7

98 Verdino R, Pacifico D, Tracy C. Supraventricular tachycardia precipitated by a peripherally inserted central catheter. *J Electrocardiol* 1996; **29**: 69–72

99 Wagman L, Kirkemo A, Johnston M. Venous access: a prospective randomised study of the Hickman catheter. *Surgery* 1984; **95**: 303–8

100 Wagman L, Neifeld J. Experience with the Hickman catheter: unusual complications and suggestions for their prevention. *J Parenter Enteral Nutr* 1986; **10**: 311–5