

## **Long-term venous access devices and anaesthesiologists**

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### **KEY WORDS**

Vascular access devices, implanted ports, port-a-cath, indwelling catheters, Hickman catheter, complications, catheter-associated infections, catheter obstruction

### **ABSTRACT**

The use of long-term venous access devices is increasing. Anaesthesiologists frequently encounter patients, within and outside the operating room, with long-term venous access. It is important that anaesthesiologists are well informed about these devices, their indications, techniques for implantation and use, and maintenance. In this narrative review, we discuss two commonly used long-term venous access devices: implantable ports and tunnelled catheters. We discuss the indications and contraindications, our technique for placement, maintenance protocols and anticipated complications associated with implanted ports and tunnelled catheters. A goal of this review is to encourage anaesthesiologists to become more involved in placement and maintenance care of these devices.

### **INTRODUCTION**

Long-term venous access is required for many patients who need prolonged intravenous therapy to more reliably provide chemotherapy, parenteral nutrition, antibiotics or fluid replacement therapies. Long-term venous access is also indicated in patients needing high osmolar, irritant or vesicant drugs for an anticipated duration of more than 3 months, those requiring frequent blood draws and patients with poor venous access. Implanted port and tunnelled catheters are very commonly used as long-term venous access devices. Dialysis catheters and peripherally inserted central venous catheters are excluded from this review as the

former is used only in a special patient population and the latter is considered an intermediate-term access technique.<sup>1</sup>

As an increasing number of patients are managed with these devices, the anaesthesiologist needs to be well versed in their care. Long-term venous access devices have traditionally been placed by interventional radiologists, surgeons or oncologists. Anaesthesiologists have the prerequisite skill set for placing central lines. Long-term venous access requires some modification of the placement procedures: tunnelling or creating a subcutaneous pocket for ports. Hence, anaesthesiologists can become increasingly involved in establishing these lines and maintaining their use in patient care. Anaesthesiologists can take the lead in forming a hospital-based 'vascular access team'. This review describes the types of long-term venous access devices and associated indications, placement techniques, precautions, anticipated complications and maintenance care.

### **TYPES OF LONG-TERM VENOUS ACCESS DEVICES**

The two broad categories of long-term venous access are ports and tunnelled catheters. Table 1 compares the characteristic features, advantages and disadvantages of both. Use of multi-lumen catheters allows simultaneous administration of non-compatible medications. The material of the catheter determines its longevity and durability. Newer silicone and polyurethane catheters are biocompatible and have a lower thrombogenic potential than polyethylene and polyvinylchloride devices. Recent studies have revealed polyurethane catheters to be more durable but also more thrombogenic and susceptible to infections than silicone catheters.<sup>2</sup> Antibiotic and antiseptic coatings have been used on catheters in an attempt to reduce catheter-related sepsis but there is not enough evidence to support widespread practice.

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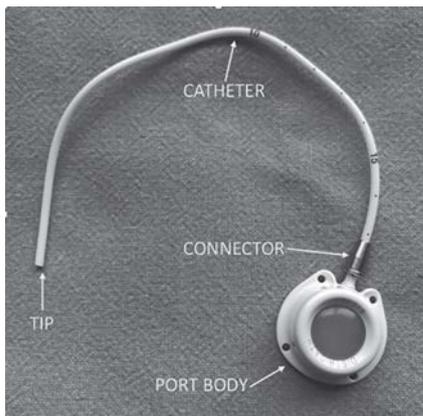
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**Table 1.** Basic features of and comparison between implanted ports and tunnelled catheters

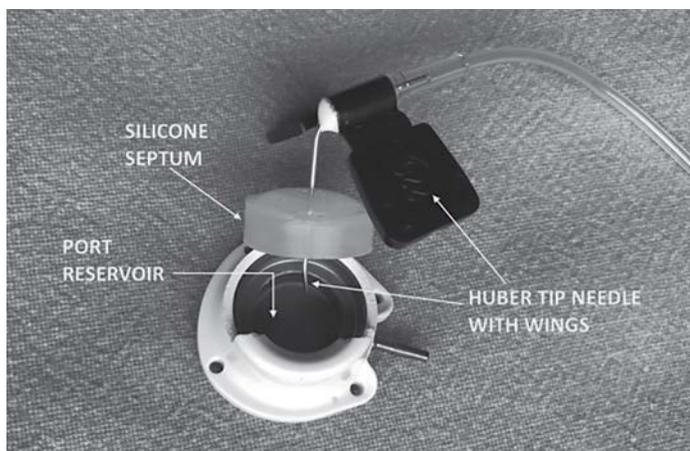
Basic feature	Implanted ports	Tunnelled catheters
Characteristic for reducing infections	Implanted into subcutaneous tissue pocket	Tunnelled underneath the skin and has a Dacron cuff
Number of lumens available	Single- and dual-body devices	Single-, double- or triple-lumen catheters
Advantages	Lower infection risk, cosmetically appealing, can perform activities such as showering and swimming	Bigger lumen size allows better flows needed for apheresis
Disadvantages	More expensive, needs more technical expertise to place and remove	Needs more maintenance; home care such as flushing the line is needed

## IMPLANTED PORTS

Since the first placement of an implanted port more than 25 years ago,<sup>3</sup> there have been many modifications to the device structure and material. The port has a body, a catheter and a connector (Figure 1). The port body has a reservoir with a self-sealing silicone septum on its roof. The silicone septum can withstand more than 1000 punctures with a Huber tip needle. Huber tip needles are special non-coring devices that cause minimal damage to the septum (Figure 2). Port



**Figure 1.** The parts of an implantable port: port body, connector, catheter and tip.



**Figure 2.** The structure inside the body of a port with a Huber needle inserted. This disassembled port reservoir displays the Huber needle piercing the silicone septum.

catheter tips can be open- or close-ended with a valve. The valve tip catheters were developed with the intention of reducing the incidence of thrombosis, but recent literature does not show that they provide any significant advantage.<sup>4</sup> Ports are manufactured by multiple companies worldwide and there can be significant variation in the size, shape and material used (Table 2). Selection of the most appropriate port depends on patient factors, treatment requirements and the clinician's familiarity with the port (Table 3). Power-injectable devices and catheters were developed to safely tolerate higher pressures and flows (300 psi or 5 ml/s flow) required for computed tomography (CT) contrast procedures. Power-injectable ports are labelled 'CT', which is visible on chest radiographs, for ease of differentiation from regular ports.

## Indications

Implanted ports are preferred for intermittent rather than continuous therapy. They are commonly used in chemotherapy of solid organ malignancies, intestinal failure, cystic fibrosis, sickle cell anaemias, haemophilia and other genetic diseases.

## Contraindications

Implanted ports are contraindicated if there is infection at the site of insertion, previous thrombosis of the selected vein or deranged coagulation parameters and in septic or neutropenic patients. Port placement can be considered in patients with a platelet count of  $> 50,000/\mu\text{l}$ , an international normalised ratio of  $< 1.7$  and a white blood cell count of  $> 3000 \text{ cells}/\mu\text{l}$ .<sup>6</sup>

## Placement technique

Implanted ports are placed in the strict aseptic environment of the operating theatre, with patients sedated or under general anaesthesia. Routine antimicrobial prophylaxis is not recommended.<sup>7</sup> The most common site of port placement is the infra-clavicular area of the chest wall. The catheter may be placed into the subclavian or internal jugular vein under ultrasound guidance using the modified Seldinger technique. The direction and location of the tip of the catheter should be confirmed by fluoroscopy. The catheter is tunnelled under the skin up to the port pocket. The port is anchored to the pectoral fascia. The port pocket is closed in two layers with absorbable sutures, after securing haemostasis. Video 1 shows the implantable port placement

**Table 2.** Types and sizes of implanted ports from different manufacturers (in alphabetical order)

Company	Body	Catheter	Tip	Catheter size <sup>a</sup>	Lumen
AngioDynamics	Titanium, plastic	Silicone, polyurethane	Open-ended	5 Fr, 6.9 Fr, 7.5 Fr, 8.4 Fr, 9.6 Fr	Single, dual
Bard	Titanium, plastic	Silicone, polyurethane (attachable/pre-attached)	Open-ended, valved	6 Fr, 6.6 Fr, 7 Fr, 8 Fr, 9.5 Fr	Single, dual
B Braun	Titanium, epoxy, polysulfone	Silicone, polyurethane	Open-ended, valved	4.5 Fr, 5 Fr, 6.5 Fr, 8.5 Fr, 10 Fr	Single, dual
Cook Medical	Titanium, plastic	Silicone (attachable/pre-attached)	Open-ended	6.5 Fr, 7.5 Fr, 9.5 Fr	Single, dual
Districlass Médical	Titanium, polysulfone	Silicone, polyurethane	Open-ended	5 Fr, 6 Fr, 6.6 Fr, 8 Fr, 9.3 Fr	Single, dual
Isomed	Titanium, polyoxymethylene	Silicone	Open-ended	6 Fr, 7 Fr, 7.8 Fr, 9.6 Fr	Single
Lexel	Titanium	Silicone	Open-ended	5.5 Fr, 7 Fr, 9 Fr	Single
Medcomp	Titanium, plastic	Silicone, polyurethane (attachable/pre-attached)	Open-ended	5 Fr, 6.6 Fr, 8 Fr, 9 Fr, 9.6 Fr	Single, dual
Navilyst	Titanium, polysulfone	Polyurethane, silicone (attachable/pre-attached)	Open-ended, valved	6 Fr, 6.6 Fr, 7 Fr, 8 Fr, 9 Fr, 9.6 Fr, 10 Fr	Single, dual
PakuMed	Titanium	Silicone, polyurethane	Open-ended	1.9 Fr (fetal), 3 Fr, 5.1 Fr, 7.5 Fr, 9 Fr	Single
Smiths Medical	Titanium, polysulfone	Silicone, polyurethane (attachable/pre-attached)	Open-ended	6 Fr, 7 Fr, 8.5 Fr, 9 Fr, 11 Fr	Single, dual
Teleflex/Arrow Polysite	Titanium, plastic	Polyurethane	Open-ended	6 Fr, 7 Fr, 8 Fr	Single
VYGON	Titanium	Silicone (attachable/pre-attached)	Open-ended	4 Fr, 5.1 Fr, 6 Fr, 6.6 Fr, 8.4 Fr, 9.6 Fr	Single

**Table 3.** Components and characteristics of implantable ports

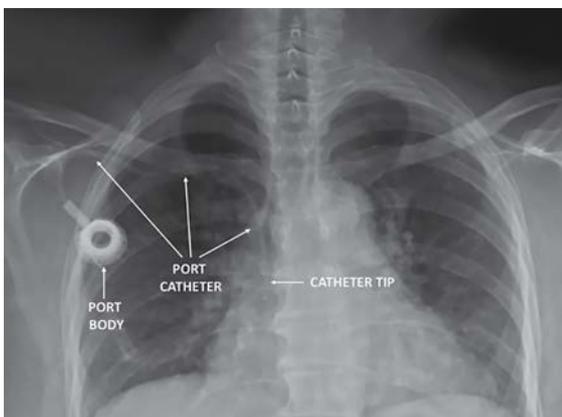
Component	Characteristic
<b>Port body</b>	
Titanium	MRI compatible <sup>a</sup> but can cause artefacts if the desired scanning area is within 40 cm <sup>2</sup> range of the port More longevity, less prone to fracture, preferred in treatments lasting for years
Plastic	MRI safe; preferred in patients with breast, chest wall and thoracic malignancies who may need repeated MRI scans Less durable, prone to fracture, posterior wall puncture with Huber needle <sup>5</sup>
<b>Catheter</b>	
Silicone	Biocompatible, least thrombogenic, lower material strength Smaller inner diameter with the same external diameter as polyurethane catheter
Polyurethane	Slightly higher incidence of thrombosis and infection than with silicone catheter Larger inner diameter allows better flow rate at the same external diameter; useful for apheresis and blood product transfusions
<b>Catheter tip</b>	
Open-ended	Easy backflow and forward-flow Needs heparin for flushing Flushing interval 28 days
Close-ended with valve	Slight resistance in back flow and forward flow causing difficulty transfusing blood Only requires saline flushing; useful in heparin allergy and heparin-induced thrombocytopenia Flushing interval 90 days; helpful in patients with poor visit compliance

MRI, magnetic resonance imaging.

<sup>a</sup>MRI compatible up to 3 tesla but could cause MRI-related heating of the port up to 1.9°C.



**Video 1.** Video showing the technique for implantable port placement.<sup>8</sup> <https://www.dropbox.com/s/2i3cknssigjzhmk/Video%201.mp4?dl=0>



**Figure 3.** A postoperative chest radiograph obtained after implantable port placement to confirm the final location and rule out pneumothorax.

technique.<sup>8</sup> Postoperative chest radiography is performed to confirm the final placement and rule out pneumothorax (Figure 3). The ideal position of the tip is the lower one-third of the superior vena cava. This correlates with the lower margin of the third costo-sternal junction or the sixth thoracic vertebral level (Figure 3). The port can be accessed immediately after the procedure if the Huber needle is placed during the procedure. It is advisable to start chemotherapy after a week, to allow for healing of the wound.

### Precautions during placement

- A Trendelenburg position of 10–15° and thumb over the open sheath should be practised to avoid air embolism.
- Care should be taken to place a wider loop while tunnelling from the insertion site to the port pocket to minimise kinking of the catheter.
- Good haemostasis is essential to avoid occurrence of port pocket haematoma.

### Complications

Complications during placement include arrhythmias, air embolism and inadvertent arterial injury. Early, delayed and late complications

are described in Box 1.<sup>4</sup> Infection is a common complication that can be intra-luminal or in the port pocket. The incidence of infection is higher in patients with haematological disease than in those with non-haematological disease.<sup>9</sup> Catheter occlusion can be treated with thrombolytic agents. Catheter-related vein thrombosis requires anticoagulation and may necessitate port removal. Catheter pinch-off syndrome is the pinching or fracture of the part of the catheter between the clavicle and the first rib (Figure 4). Catheter embolisation can be completely asymptomatic or a patient may complain of chest pain, palpitations, dyspnoea and cough.<sup>10</sup> The incidence of catheter pinch-off syndrome is believed to be 1% of subclavian vein port placements.<sup>11,12</sup> The incidence can be reduced or completely avoided by selecting a more lateral puncture site.

### Box 1. Complications of implantable ports<sup>4</sup>

- Early complications (procedure related)
  - haemorrhage
  - haemothorax
  - pneumothorax
- Delayed complications (procedure related)
  - delayed wound healing
  - port pocket haematoma
  - wound infections
- Late complications
  - catheter malposition
  - catheter occlusion
  - catheter pinch-off syndrome
  - catheter-related bloodstream infection (CLABSI)
  - extravasation
  - port fracture
  - vein thrombosis



**Figure 4.** Fluoroscopic image showing, on dye injection, a catheter break due to catheter pinch-off syndrome.

### Maintenance care

- It is recommended that there be a policy with respect to accessing and caring for long-term venous access ports developed by each local hospital and that these protocols be adhered to as well as the manufacturer's instructions.
- The port must be accessed using sterile technique. After cleaning the area over the port body, it is held and the Huber needle is inserted until loss of resistance is encountered. Backflow of blood confirms the correct position of the needle.
- Flushing is carried out with 10–20 ml of normal saline using a pulsatile technique.
- A syringe size of > 10 ml should not be used for flushing as it may generate higher pressures, predisposing to rupture of the catheter.<sup>13</sup> However, power ports tolerate higher pressures.
- The accessed port is covered with a sterile transparent dressing. The transparent dressing and the Huber needle should be replaced every 7 days.
- Aseptic non-touch technique is essential while using an accessed port. Port hubs should be scrubbed with alcohol or chlorhexidine for at least 15–30 seconds before connecting the medication.
- A port should be flushed with 10–20 ml of saline and locked with 5 ml of heparinised saline when not in use and before de-accessing the port (Table 4). Application of positive pressure during de-accessing the needle reduces the reflux of blood in the catheter tip and may prevent occlusion.<sup>14</sup>
- The port should be monitored for erythema, induration and signs

of infection. Any pain while injecting suggests extravasation or port fracture and should be evaluated immediately. The needle should be replaced if in doubt. Injection of dye into the port under fluoroscopy can be used to rule out extravasation.

### Device removal

The port is removed after completion of treatment. Premature removal may be needed when the port is infected, occluded or malpositioned. Port removal is commonly performed in the operating theatre under anaesthesia. A fibrous sheath forms around a long-standing implanted port. The sheath should be dissected and removed to prevent the formation of a potential space for serous fluid or haematoma collection. Once the port is removed it is visually inspected for completeness and integrity.

### TUNNELLED CUFFED CATHETERS

Tunnelled cuffed catheters were first introduced for prolonged parenteral nutrition in 1973. They were called Broviac catheters. They were made of silicone rubber and had an internal diameter of around 1.00 mm.<sup>15</sup> The Hickman catheter is another tunnelled catheter that was first used in marrow transplant recipients.<sup>16</sup> These catheters were characterised by the presence of a Dacron cuff.<sup>17</sup> The cuff provided a point on the catheter that can be used for anchorage

**Table 4.** Flushing protocols for long-term venous access

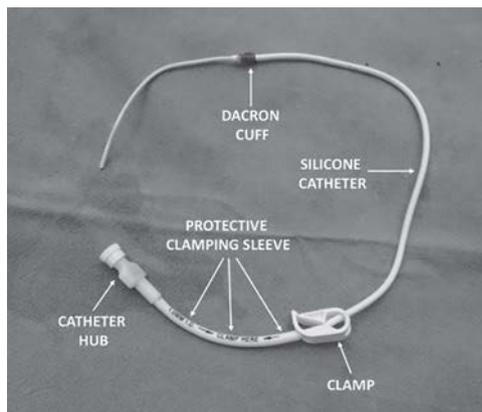
Procedure	Open-ended ports	Groshong tip ports	Tunnelled catheter
After each medication use	10 ml of saline followed by 5 ml of heparinised (10 U/ml) saline	10 ml of saline	3–10 ml of saline before and after medication use
After blood draw or transfusion of blood and viscous products	20 ml of saline followed by 5 ml of heparinised (10 U/ml) saline	20 ml of saline	10 ml of saline followed by 3 ml of heparinised (10 U/ml) saline
When not in use	5 ml of heparinised (100 U/ml) saline once a month	5 ml of saline once every 3 months	3 ml of heparinised (10 U/ml) saline once or twice weekly

Note: a minimum of twice the volume of the reservoir of long-term venous access should be used for flushing.

**Table 5.** Characteristics of tunnelled catheters

French size, number of lumens	Total catheter length (cm)	Lumen size OD/ID (mm), colour
BROVIAC® 4.2 Fr, single-lumen catheter with peel-apart introducer (paediatric)	71	1.4/0.7
BROVIAC® 6.6 Fr, single-lumen catheter with peel-apart introducer (paediatric)	90	2.2/1.0
HICKMAN® 9.6 Fr, single-lumen catheter with peel-apart introducer	90	3.2/1.6
HICKMAN® 7.0 Fr, dual-lumen catheter with peel-apart introducer	65	2.3/1.0 red; 2.3/0.8 white
HICKMAN® 9.0 Fr, dual-lumen catheter with peel-apart introducer	65	3.0/1.3 red; 3.0/0.7 white
HICKMAN® 9.0 Fr, dual-lumen catheter with peel-apart introducer	90	3.0/1.3 red; 3.0/0.7 white
HICKMAN® 12.0 Fr, dual-lumen catheter with peel-apart introducer	90	4.0/1.6 red; 4.0/1.6 white
HICKMAN® 10.0 Fr, triple-lumen catheter with peel-apart introducer	97	3.3/1.5 red; 3.3/0.8 white; 3.3/0.8 blue
HICKMAN® 12.5 Fr, triple-lumen catheter with peel-apart introducer	90	4.2/1.5 red; 4.2/1.0 white; 4.2/1.0 blue

ID, internal diameter; OD, outer diameter.



**Figure 5.** An explanted Broviac catheter showing the different parts: Dacron cuff, silicone catheter, protective clamping sleeve, clamp and catheter hub.

in the subcutaneous plane. It also forms a seal of fibrous tissue around the catheter. The cuff may also act as a microbial barrier, though the evidence for this is unclear.<sup>18,19</sup> The parts of a Broviac catheter are shown in Figure 5. Tunnelled catheters are available in various lengths and sizes (Table 5).

### Indications

Tunnelled catheters are indicated when longer duration intermittent or continuous therapy is anticipated. Typical indications include haematological malignancies, long-term antibiotic therapy, parenteral nutrition, apheresis treatments and repeated blood and blood product transfusions.

### Contraindications

Contraindications of tunnelled catheters are similar to those for implanted ports described earlier.

### Placement technique

Maximal barrier precautions and aseptic technique must be followed for placement of tunnelled catheters. The catheters are tunnelled in the subcutaneous plane and are secured at the exit site with sutures, usually on the anterior chest wall. Percutaneous insertion is preferred for the Hickman catheter as it is technically easier than the surgical cut-down technique.<sup>20</sup> Sites for cannulation include the internal jugular, subclavian or rarely the femoral vein. Ultrasound guidance and fluoroscopy is recommended for vein cannulation and catheter placement.

The vein is cannulated using the Seldinger technique. A skin incision of 0.5–1 cm is made at the chosen catheter exit site on the chest. Tunnelling is carried out in the subcutaneous tissue and the catheter is brought out just at the vein cannulation site, taking care not to dislodge the guidewire. It is recommended to keep the Dacron cuff around 5 cm from the exit site. The catheter is then cut to the desired length so that the tip lies in the lower one-third of the superior vena

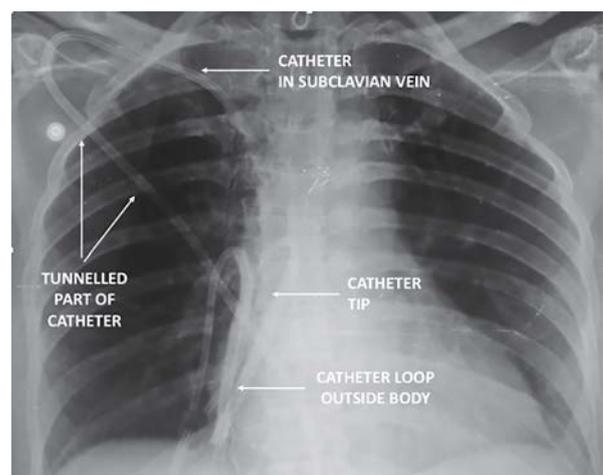


**Video 2.** Video showing the technique for Hickman catheter placement.<sup>21</sup> <https://www.dropbox.com/s/uwcv4lrnwq1cws/Video%202.mp4?dl=0>

cava. This cut end of the catheter is pushed into the vein while gently peeling off the sheath. Sterile dressings are applied to the percutaneous venous access and catheter exit sites. Video 2 shows placement of the Hickman catheter.<sup>21</sup>

### Precautions during placement

- Arrhythmias should be monitored for while passing the guidewire.
- The angled tip of the tunnelling rod has to be kept upwards at all times to prevent damage to the underlying structures and to ensure the correct direction while tunnelling.
- Wetting the Dacron cuff with normal saline prior to insertion aids fibrosis.
- In women with pendulous breasts, the catheter exit site is made near the sternal edge to avoid catheter displacement in the erect posture.
- A chest radiograph should be obtained after placement to check the catheter position and identify potential complications such as pneumothorax (Figure 6).



**Figure 6.** A postoperative chest radiograph taken after placement of a double-lumen Hickman catheter via the right subclavian vein. The tunnelled part of the catheter on the left (two arrows), the catheter loop outside the body at the bottom right (one arrow) and the catheter tip are seen.

## Complications

Procedure-related complications include arrhythmias, arterial puncture, kinking of the guidewire, bleeding, sheath or introducer kink/damage and pneumothorax.<sup>20,22,23</sup> Late complications are similar to those for ports and include infection, occlusion, thrombosis and extravasation. Catheter pinch-off can occur, although this is less common than in implanted ports.<sup>10</sup>

## Maintenance care

- Catheter access must be carried out using aseptic non-touch technique.
- The hub is scrubbed for at least 15–30 seconds using a 2% chlorhexidine- or 70% isopropyl alcohol-impregnated wipe and allowed to dry.
- The catheter is flushed as per protocol (see Table 4).
- Clamping is performed only over the protective clamping sleeve to avoid damage to the catheter.
- The site is monitored for erythema, tenderness, warmth and purulent discharge.
- The sterile transparent dressing is inspected every day and changed every 7 days or sooner if soiled or wet.
- If found to be damaged, the catheter can be repaired using a repair kit provided by the manufacturer.

## Device removal

Indications for removal of tunnelled catheters are similar to those for ports. Recently inserted catheters can be removed with traction alone, but catheters that have been in place for a prolonged time may require a cut-down technique under local or general anaesthesia at the cuff site. Gentle traction on the catheter reveals the cuff by palpation and it is essential to incise the fibrous sheath over the cuff to retrieve the catheter. Pressure needs to be applied over the vein puncture site to stop the bleeding. Skin closure with sutures and a sterile dressing are required.

## APPROACH TO A PATIENT WITH A LONG-TERM VENOUS ACCESS DEVICE

With an increase in the use of long-term venous access devices, it is likely that more patients with such devices will be encountered by anaesthesiologists. The devices may be used for administering anaesthesia, with appropriate vascular care during access using aseptic technique. The device patency and integrity can be checked with blood withdraw and flush. Any pain with catheter flushing should raise the suspicion of an infiltrated device, in which case it should be further evaluated prior to use. Additional peripheral intravenous access would be required for major procedures as ports are limited by flow rates. Ports could be used during cardiopulmonary resuscitation but may be inadequate for fluid resuscitation.

## SUMMARY

Knowledge of long-term venous access devices is essential as their indications and use are increasing. Familiarity with these devices and their handling protocols will enable anaesthesiologists to safely use long-term venous access. Insertion of these devices should be learnt under supervision. Anaesthesiologists should take the opportunity to lead the 'vascular access team', set protocols and train nurses, to provide safe care of patients with these devices.

## REFERENCES

1. Gallieni M, Pittiruti M, Biffi R. Vascular access in oncology patients. *CA Cancer J Clin* 2008; **58**: 323–46.
2. Wildgruber M, Lueg C, Borgmeyer S, Karimov I, Braun U, Kiechle M *et al*. Polyurethane versus silicone catheters for central venous port devices implanted at the forearm. *Eur J Cancer* 2016; **59**: 113–24.
3. Gyves J, Ensminger W, Niederhuber J, Liepman M, Cozzi E, Doan K *et al*. Totally implanted system for intravenous chemotherapy in patients with cancer. *Am J Med* 1982; **73**: 841–5.
4. Blanco-Guzman MO. Implanted vascular access device options: a focused review on safety and outcomes. *Transfusion* 2018; **58**: 558–68.
5. Dillon PA, Foglia RP. Complications associated with an implantable vascular access device. *J Pediatr Surg* 2006; **41**: 1582–7.
6. Bamba R, Lorenz JM, Lale AJ, Funaki BS, Zangan SM. Clinical predictors of port infections within the first 30 days of placement. *J Vasc Interv Radiol* 2014; **25**: 419–23.
7. Sousa B, Furlanetto J, Hutka M, Gouveia P, Wuerstlein R, Mariz JM *et al*. Central venous access in oncology: ESMO Clinical Practice Guidelines. *Ann Oncol* 2015; **26**: 152–68.
8. Zaghal A, Khalife M, Mukherji D, El Majzoub N, Shamseddine A, Hoballah J *et al*. Update on totally implantable venous access devices. *Surg Oncol* 2012; **21**: 207–15.
9. El Hammoumi M, El Ouazni M, Arsalane A, El Oueriachi F, Mansouri H, Kabiri El H. Incidents and complications of permanent venous central access systems: a series of 1,460 cases. *Korean J Thorac Cardiovasc Surg* 2014; **47**: 117–23.
10. Surov A, Wienke A, Carter JM, Stoevesandt D, Behrmann C, Spielmann RP *et al*. Intravascular embolization of venous catheter – causes, clinical signs, and management: a systematic review. *J Parenter Enteral Nutr* 2009; **33**: 677–85.
11. Fazeny-Dörner B, Wenzel C, Berzlanovich A, Sunder-Plassmann G, Greinix H, Marosi C *et al*. Central venous catheter pinch-off and fracture: recognition, prevention and management. *Bone Marrow Transplant* 2003; **31**: 927–30.
12. Mirza B, Vanek VW, Kupensky DT. Pinch-off syndrome: case report and collective review of the literature. *Am Surg* 2004; **70**: 635–44.
13. Gorski L. Infusion therapy standards of practice. *J Infus Nurs* 2016; **39** (Suppl. 1): S58.

14. Lapalu J, Losser MR, Albert O, Levert A, Villiers S, Faure P *et al*. Totally implantable port management: impact of positive pressure during needle withdrawal on catheter tip occlusion (an experimental study). *J Vasc Access* 2010; **11**: 46–51.
15. Broviac JW, Cole JJ, Scribner BH. A silicone rubber atrial catheter for prolonged parenteral alimentation. *Surg Gynecol Obstet* 1973; **136**: 602–6.
16. Hickman RO, Buckner CD, Clift RA, Sanders JE, Stewart P, Thomas ED. A modified right atrial catheter for access to the venous system in marrow transplant recipients. *Surg Gynecol Obstet* 1979; **148**: 871–5.
17. Galloway S, Bodenham A. Long-term central venous access. *Br J Anaesth* 2004; **92**: 722–34.
18. de Cicco M, Panarello G, Chiaradia V, Fracasso A, Veronesi A, Testa V *et al*. Source and route of microbial colonisation of parenteral nutrition catheters. *Lancet* 1989; **2**: 1258–61.
19. Keohane PP, Jones BJ, Attrill H, Cribb A, Northover J, Frost P *et al*. Effect of catheter tunnelling and a nutrition nurse on catheter sepsis during parenteral nutrition. A controlled trial. *Lancet* 1983; **2**: 1388–90.
20. Ahmed Z, Mohyuddin Z. Complications associated with different insertion techniques for Hickman catheters. *Postgrad Med J* 1998; **74**: 104–7.
21. Arul GS, Lewis N, Bromley P, Bennett J. Ultrasound-guided percutaneous insertion of Hickman lines in children. Prospective study of 500 consecutive procedures. *J Pediatr Surg* 2009; **44**: 1371–6.
22. Ray S, Stacey R, Imrie M, Filshie J. A review of 560 Hickman catheter insertions. *Anaesthesia* 1996; **51**: 981–5.
23. Ng F, Mastoroudes H, Paul E, Davies N, Tibballs J, Hochhauser D *et al*. A comparison of Hickman line- and Port-a-Cath-associated complications in patients with solid tumours undergoing chemotherapy. *Clin Oncol* 2007; **19**: 551–6.