Pediatric Surgery International (2020) 36:551–562
https://doi.org/10.1007/s00383-020-04640-0

REVIEW ARTICLE

Long-term vascular access in differently resourced settings: a review of indications, devices, techniques, and complications

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Accepted: 5 March 2020 / Published online: 21 March 2020

Abstract
Central venous access is frequently essential for the management of many acute and chronic conditions in children. Millions of central venous access devices (CVADs) are placed each year. In this review article, we discuss the indications for long-term vascular access, the types of devices available, the state of the art of central venous cannulation and device placement, and the complications of long-term central venous access. We pay a special attention to the challenges of, and options for long-term central venous access, also those in developing countries, with limited financial, human, and material resources.

Keywords Central venous access device · Percutaneously inserted central catheter · Pediatric · Parenteral nutrition · Chemotherapy port · Developing country · Low resource

Introduction

Central venous access is frequently essential to the management of many acute and chronic conditions in children. Millions of central venous access devices (CVADs) are placed every year [1]. There are numerous CVAD types and access options in terms of site and technique. CVADs are associated with both short- and long-term complications. Low- and middle-income countries with limited financial, human, and material resources may face unique challenges when it comes to central venous access.

Indications

Administration of parenteral nutrition

Parenteral nutrition (PN) is indicated in children and infants who are unable to meet their caloric demands through enteral feeds. Although parenteral nutrition can be delivered through a peripheral cannula [2, 3], its high osmolarity may cause phlebitis and extravasation injuries [4]. Additionally, peripheral cannulas are associated with frequent loss of access and the need for multiple cannulations [2]. It is thus recommended that PN be delivered through a catheter placed in a central vein [5]. Children on PN also require regular blood sampling for monitoring purposes [3]. This can be done atraumatically via a CVAD.

Frequently, there is limited access to PN in low-income (LIC) and low-to-middle-income countries (LMIC). High costs along with limited medical and nursing expertise make the preparation and administration of PN difficult [6, 7]. A recent survey of pediatric oncology units in 31 African countries found that 42% of units did not have access to PN [8].

Administration of chemotherapeutic agents, antibiotics, and other drugs

CVADs are used in pediatric oncology to administer fluids, parenteral nutrition, chemotherapeutic agents, antibiotics, and blood products, and also to allow for blood sampling

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[9–11]. Children who require prolonged or repeated courses of intravenous antibiotics for conditions, such as cystic fibrosis or congenital cardiac disease, may also benefit from long-term CVADs [12–14] Peripheral cannulas can be used for these purposes, but repeated 'needling' can result in significant trauma. Extravasation of certain chemotherapeutic agents and vasoactive drugs can lead to skin ulceration and necrosis [11].

Renal replacement therapy (RRT)

Although vascular access via an arterio-venous fistula (AVF) is recommended in children requiring long-term haemodialysis [15], many children will receive hemodialysis via CVADs [16, 17].

RRT, and specifically, hemodialysis, presents unique challenges in developing countries [18, 19]. Therefore, in areas where RRT is feasible, peritoneal dialysis tends to be favored [20]. Hemodialysis is more expensive [21], which is not feasible in places with irregular power and water supply [19], where lack of transport precludes frequent hospital visits [22], and where there is lack of expertise regarding access. That said, hemodialysis can be safely and effectively implemented in pediatric dialysis units when there is investment in staff training and when funding for equipment and supplies can be secured [22].

Devices

Broadly speaking, there are three categories of CVADs: non-tunneled devices [such as peripherally inserted central catheters (PICCs) and non-tunneled central venous catheters (CVCs)], tunneled CVCs, and totally implantable venous access devices (TIVADs) [23–25], also referred to as implantable ports.

Catheters are usually made from either silicone or polyurethane [26–28] and may be impregnated or coated with anti-infective agents such as antibiotics, antiseptics, anti-metabolites, or silver [29, 30]. CVADs may have single or multiple lumens and are available in multiple diameter sizes. They can be as small as 1 French in the case of certain PICC lines [24]. The lengths of catheters are also variable and in certain tunneled lines, catheters can be trimmed to achieve a satisfactory tip position. Hemodialysis catheter tips are designed so as to minimize recirculation of blood during dialysis, usually by separating the openings of the two lumens through split catheter design or using a staggered tip [30]. Stocking a variety of catheter types, lengths, and sizes can be challenging in low-resource settings [31], and units where this is not possible should determine which device sizes are most frequently needed. Cuffed, tunneled catheters, as small as 4.2 French can be inserted in neonates [32]. They are also large enough to be useful in older children.

Tunneled CVADs with external access ports usually have a cuff which allows tissue ingrowth to anchor the line in place [5, 24, 30]. The cuff also separates the skin entry site from the point at which the catheter enters the vein [5, 23–25, 30].

TIVADs have a reservoir which is implanted subcutaneously. The hub of the reservoir is made of titanium, plastic (polyoxymethylene), or a mixture of both [33]. The reservoir is covered by a self-sealing silicone septum which faces the skin. To access the reservoir, the skin over the septum and then the septum itself are punctured. It is of extreme importance to use a "Huber" non-coring needle as this allows the silicone septum to self-seal. This allows the process to be repeated several hundred to several thousand times per port [34].

Device selection is usually dependent on the indication for the central venous access and the duration for which access is likely to be required. Non-tunneled catheters and PICCs are suitable for short-term access, for days to weeks. Where medium-term access of up to 3 months is required, PICCs and tunneled catheters are suitable. For long-term central venous access, i.e., for longer than 3 months, tunneled CVADs or TIVADs are indicated. The choice between a tunneled line with an external access port and a TIVAD depends on many factors including patient comfort and activity, nursing experience, and the frequency at which venous access is required [23]. There is evidence that PICCs can be used to provide long-term access in children with malignancies [11] and in children requiring TPN for IF [35].

The cost of CVADs can be a prohibitive in settings with low resources. There is a significant cost difference between a non-tunneled CVC or PICC, and a tunneled CVAD or TIVAD [31, 36], meaning that in many instances, non-tunneled lines will be more readily available, and a more practical option. There have been reports of reusing discarded or unused 'parts' from pre-packaged CVAD packs in an effort to reduce costs, with no significant difference in infectious complications [37].

Device placement

Depending on the type of device and the method of placement, insertion can be performed by a nurse [13] or specialist intravenous access team [25], a neonatologist or pediatrician, a surgeon, or an interventional radiologist. PICC lines can be placed at the bedside [11, 13, 35], but tunneled CVADs are placed in the operating room or interventional radiology suite.

Site selection

CVADs are most commonly inserted via the internal jugular (IJV), subclavian (SCV), or femoral veins (FV) [5, 25, 38]. PICC lines are threaded into these central veins via peripheral access points on the upper or lower limbs or scalp [39]. Veins commonly accessed on the upper limbs include the cephalic, basilic, and median cubital veins [11, 25, 35]. In the lower limb, the saphenous vein can be used as an access point [11, 12, 35, 40]. In neonates, the umbilical vein can be used for the short-term administration of intravenous therapies [5].

Percutaneous insertion

Percutaneous insertion of a CVAD is achieved by puncturing the skin and the desired central vein with a needle. Entry into the vein is confirmed by backflow of venous blood through the needle. A guidewire is passed through the needle into the right atrium, and the needle is removed. The catheter is tunneled from the desired skin entry site and trimmed to its desired length. A dilator with a peel-away sheath is passed over the guidewire using the Seldinger technique, the guidewire and dilator are removed, and the catheter is passed through the peel-away sheath which is then also removed [41].

Open cut-down techniques

Open cut-down placement of a CVAD involves a skin incision over the desired vein and placement of the catheter through a venotomy. In the neck, the IJV is accessed via a transverse supraclavicular incision a finger's breadth above the mid-portion of the clavicle. The IJV is identified by blunt dissection between the heads of the sternocleidomastoid muscle, and vessel loops are passed proximally and distally to the planned venotomy site, to achieve vascular control prior to performing the venotomy [32]. The venotomy may be closed around the catheter with interrupted sutures if necessary [32, 41].

Percutaneous techniques are as effective as cut-downs and may carry less risk of complications [41, 42], but in general, cut-downs are safe [32] and are useful where percutaneous attempts at access have failed [5], and in settings where clinicians lack experience with percutaneous techniques [31].

The landmark method

'The landmark method' is the technique by which percutaneous central vein puncture is achieved using anatomical landmarks only [43] and can be used in settings where there is limited access to ultrasound equipment [44].

To access the IJV using the landmark method, the patient is positioned with a roll beneath the shoulders and the head turned slightly to the contralateral side. Venipuncture is performed at the level of the cricoid ring, between the heads of the sternocleidomastoid muscle, and just lateral to the pulsation of the carotid artery. The needle is advanced latero-caudally and an angle of 30–40° to the skin, in the direction of the ipsilateral nipple [45].

To access the SCV, the skin is punctured just below and lateral to the mid-point of the clavicle. The needle tip is then aimed 1–1.5 cm above the sternal notch, with the needle at an angle of around 45° to the skin, to allow the needle to pass below the clavicle. Once the needle is below the clavicle, the angle should be dropped to 15–20°, to allow it to pass over the first rib. The needle should then be advanced in a straight line with minimal aspiration pressure on the syringe, until blood is aspirated [46].

The FV passes deep to the medial third of the inguinal ligament and can be accessed just medial to the femoral artery [47].

Use of ultrasound (US)

Real-time US is now commonly used to facilitate the placement of CVADs. The sterile probe can be placed to observe the needle and, subsequently, the guidewire entering the lumen of the target vessel [25]. Although some studies have shown that utilizing US results in improved first-attempt success rates, fewer passes, and faster cannulations in infants and children [43, 48, 49], a meta-analysis of ultrasound-guided IJV cannulation showed no differences in success rates and complications [44]. Barriers to the use of US include a lack of training or comfort with an US machine, as well as lack of availability of materials such as sterile US probe sheaths and machines themselves [31, 50] (Fig. 1).

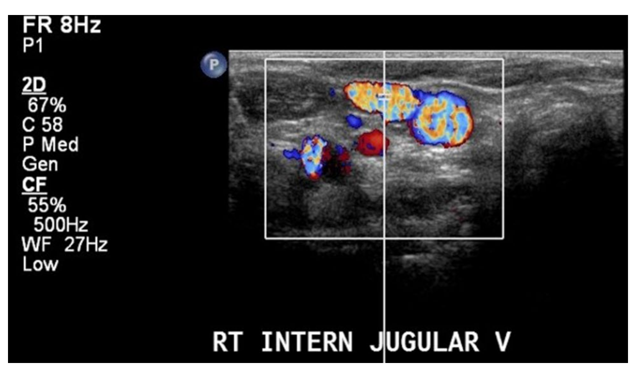

Fig. 1 Doppler view of the internal and external jugular veins

Use of fluoroscopy

Intra-procedural fluoroscopy during placement of a CVAD is useful to confirm that the guide wire has passed into the superior vena cava (SVC) prior to inserting the catheter, to monitor for complications such as pneumo- and hemothorax, cardiac tamponade, and myocardial perforation during the placement of the dilator or line [41], and to confirm the position of the catheter tip prior completing the procedure [5, 25, 51, 52]. Disadvantages to fluoroscopy include prolonging of procedural time, particularly if there is a delay caused by radiographer unavailability [41]. The radiation dose received is probably equivalent to that of a chest radiograph or a trans-Atlantic flight, with patient weight of < 10 kg and left IJV cannulation predisposing to higher doses [51]. Extremely narrow catheters may not be clearly visible on fluoroscopy. In this situation, water soluble contrast can be injected via the line to determine the tip position.

If no intra-procedural imaging is available, the presence of ventricular ectopic beats on the anesthetic ECG helps to confirm that the guidewire is within the heart. The line can be trimmed at the third intercostal space on the right which correlates with the junction of the SVC and the RA on chest radiograph [52] and the position confirmed radiologically post-operatively. Where available, ECG leads can be placed onto the guidewire or on a needle placed into a line flushed with sodium bicarbonate, and p waves monitored as the line is advanced, to determine the ideal position. The authors recommend examining the literature for a detailed description of this technique [52, 53].

Confirmation of catheter tip position

Many guidelines recommend that the tip of the catheter inserted via the neck veins should rest in the lower third of the SVC, near to the junction of the SVC and the right atrium (RA) [52]. Some recommend simply that the tip should be outside of the pericardial sac [5]. In the case of long-term hemodialysis catheters, recommendations do state that the tip should rest within the right atrium, because the beveled openings of these particular catheters may rest against the wall of the SVC lumen, which may interfere with the flows needed for successful dialysis [30, 52]. The tip of a catheter inserted via the femoral vein should rest above the renal vein (at the level of the first lumbar vertebra) [5].

Confirmation of catheter tip position is achieved most commonly by plain chest radiograph or using intra-operative fluoroscopy. If the tip lies at the level of the carina or above, then it is most likely in the distal SVC [5, 52]. US and echocardiography are also useful in confirming CVAD catheter tip positions without exposing the patient to further radiation, and have the advantage of providing information about the tip position in real time, while the patient is moving [52] (Fig. 2).

Complications

Complications associated with CVADs generally fall into one of the following categories:

1. Infection.
2. Device occlusion and deep vein thrombosis (DVT).
3. Cannulation-related complications.
4. Device damage breakage, and embolism.
5. Accidental removal.

Infectious complications

Infections are possibly the most common serious complication related to CVLs and CVADs. 'Catheter Related Blood Stream Infection' (CRBSI) is the term used when a colonized CVC or CVAD is proven to be the source of a systemic infection. The criteria for this are that a specific organism must be cultured from blood samples drawn both from the CVAD and from a peripherally drawn venous sample. The

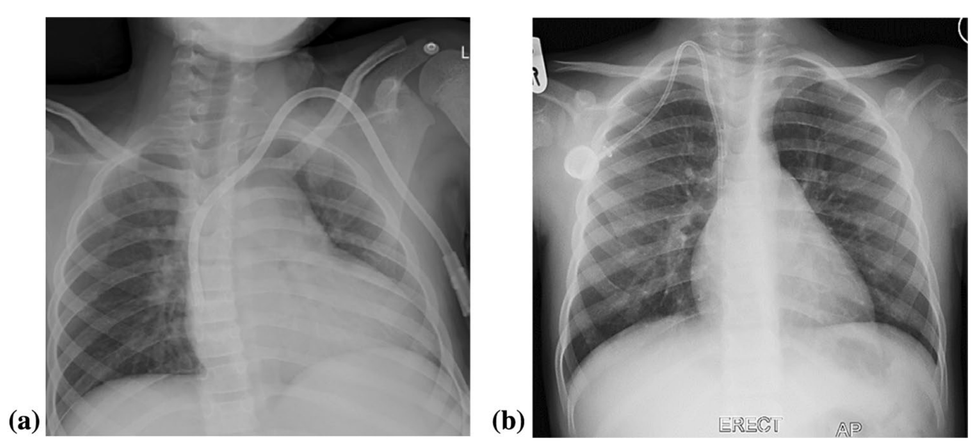

Fig. 2 **a** Chest radiograph demonstrating CVAD with a tip that is too deep. The ideal position for the tip is at the junction of the SVC and the RA as shown in **b**. Also, note the wide curve of the line in the neck area avoiding any chance of kinking

CVAD-derived sample should have a colony count at least three times higher than that grown from the peripherally drawn blood sample [54, 55]. Gram-positive staphylococci, both coagulase-negative and coagulase positive (15%) as well as Gram-negative bacteria, contribute greatly to catheter-related infections, while fungi and polymicrobial infections amount to a smaller number [56, 57].

CRBSI have a reported incidence of between 3.8 and 11.3 infections per 1000 catheter days [3, 58]. Data on the incidence of CRBSI in resource constrained settings are limited; however, there are reports of the incidence being as high as 60 infections per 1000 catheter days in some areas [59]. Infections are a significant cause of morbidity and mortality in children who require CVADs [3].

Numerous risk factors for CRBSI have been identified. These include prematurity, malignancy, non-operative cardiovascular disease, previous abdominal surgery, the presence of an enterostomy or gastrostomy tube, lack of enteral nutrition, the use of the catheter for PN and bloods transfusions, and prolonged access [3, 60–63]. In low-income settings, problems such as understaffing and overcrowding, lack of regulated infection control programs and poor compliance with infection control practices, as well as lack of access to materials such as alcohol hand rub, barrier equipment, and sterile dressings likely contribute to high CRBSI rates [59, 63].

Both groin and neck sites offer the potential for contamination of a CVAD. In small children, catheters placed in the femoral vein lie within the diaper area where fecal soiling makes the area difficult to keep clean. In the neck, proximity to oral secretions and spilled feeds may present opportunity for line contamination. Some adult studies show that FV placement presents a higher risk for CRBSI [64, 65], and some pediatric studies have similar findings [62]. Yet, other studies find that the risk of infectious complications in children is higher when CVLs are placed in the neck area [66]. Recommendations suggest that ultimately, both the groin and neck are acceptable sites in terms of infectious risk [5].

Prevention of CRBSIs focuses on reducing the risk of line contamination during initial insertion and subsequent access of lines, as well as when the line is not in use. The use of sterile barriers (drapes, masks, gloves, caps, and gowns) during insertion and access of catheters is of paramount importance [1, 59, 67]. Clean skin should be prepared with 2% chlorhexidine solution in 70% isopropyl alcohol, and be allowed to air-dry prior to skin puncture for insertion or port usage, and this solution should also be used to prepare line caps and hubs prior to access [5, 67]. The use of suture-free catheter fixation devices, chlorhexidine impregnated sponge dressings, and reduced frequency of dressing changes for unsoiled dressings all reduce the incidence of CRBSI [5, 68, 69]. Antimicrobial lock therapy (ALT) involves locking lines with a highly concentrated antimicrobial solution, sometimes in combination with heparin, while they are not in use as both prophylaxis and treatment of CRBSI [70]. Antimicrobials used include ethanol solutions [71, 72], vancomycin-based solutions, tetracycline-based solutions, and taurolidine [70]. All of these solutions have demonstrated a beneficial effect in terms of reducing the incidence of CRBSI in CAVDs in children [70]. Establishing dedicated infusion therapy teams is also of value [1, 67, 68], as are education sessions targeted at staff involved in the care of CVLs [73]. Instituting 'Care Bundles' has also been shown to reduce infection rates and other catheter-related complications [74, 75]. Catheters coated with chlorhexidine or silver sulfadiazine or impregnated with antimicrobials may reduce the incidence of CRBSIs in certain settings [29, 76], but are more costly and thus may not be available in low-income settings.

Treatment of CRBSI usually involves removal of the CVL, along with administration of appropriate systemic antibiotics [23, 77]. In cases of uncomplicated infections, ALT in addition to appropriate antibiotics may be used to salvage long-term CVADs and preserve vessels [23].

Device occlusion and deep vein thrombosis

Device occlusion is a well-described complication in CVADs [78], and its incidence is up to 3.37 per 1000 catheter days [3]. Catheter occlusion becomes evident when blood can no longer be drawn from the lumen or when infusions can no longer be administered. Occlusions can be divided into non-thrombotic and thrombotic occlusions.

Non-thrombotic occlusions

Mechanical Catheter kinking can occur anywhere along the path of the CVAD, at the insertion site or under the dressing. The fixation device may pinch the catheter if not applied correctly. Prevention of kinking at the time of insertion can be aided by avoidance of rotation of the line as well as creation of a sufficient subcutaneous pocket for the line to curve from neck insertion site to the vein entrance. Kinking can be recognized at the time of CVAD placement by the inability to withdraw blood or infuse saline immediately after insertion, or on control fluoroscopy. Late kinking is also possible and should be considered in CVADs that suddenly become occluded (Fig. 3).

Catheter tips can become occluded by becoming 'stuck' against a vessel wall. This problem can be mitigated against by proper catheter placement and positioning [79], and by confirming satisfactory catheter tip position with intra-procedural control fluoroscopy [80].

"Pinch-off syndrome", caused by repeated compression between clavicle and first rib, is related to catheters placed in the subclavian vein [79, 81]. This results in either

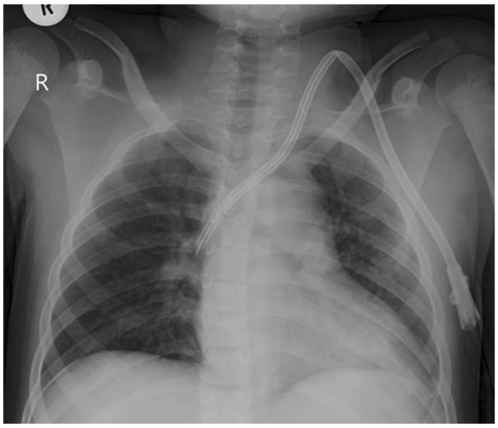

Fig. 3 Chest radiograph showing CVAD kinked at the insertion site in the neck, causing occlusion. When inserting the line, care should be taken to ensure an easy curve, which allows for unrestricted flow

blockage and occlusion or injury to the catheter and subsequent leakage.

Precipitation Precipitation of components of PN as well as the infusion of incompatible drugs are known causes of non-thrombotic occlusions. When a CVAD becomes blocked due to a crystalized alkaline infusion, the CVAD may be salvaged by instilling Sodium Bicarbonate ($NaHCO_3$). This will raise the intraluminal pH and possibly cause the blockage to liquefy again. Similarly, acidic medications that have crystalized may be liquefied by lowering the luminal pH with hydrochloric acid [82–85]. Lipid precipitations can be resolved with 70% ethyl alcohol. Lipid precipitations are common in silicone catheters as the lipid emulsions adhere to silicone [86].

Thrombotic occlusion and CVAD-associated deep vein thrombosis (DVT)

Thrombotic catheter occlusion refers to a thrombus that has formed in either the tip or the entire lumen of the intravenous catheter. DVT refers to thrombosis within the lumen of the catheterized vessel [87]. DVT may render the relevant vessel permanently occluded and unavailable for future CVAD placement, and successive thromboses may lead to complete venous occlusion of the veins draining a region, leading to regional symptoms. A further consequence may be complete loss of central venous access for all sites. The true incidence of central vein catheter-related thrombosis is difficult to establish due to diagnostic and reporting discrepancies. Whilst some reports find that the incidence of catheter-related DVT is 3.5 per 10,000 hospital admissions [88] and that most DVTs occur in the upper venous system, other authors have found that femoral vein catheters have a higher incidence of thrombotic complications [89] (Fig. 4).

Fig. 4 Venogram demonstrating occluded external iliac vein after placement of femoral CVL

Many CVAD-related thromboses may initially have no symptoms. If symptomatic, DVT classically presents with swelling in dependent tissues. Severe head and neck swelling and pleural effusion may be present with Superior Vena Cava thrombus. Pulmonary embolism has been reported as a consequence of CVAD-related DVT [90]. Ultrasound and echocardiography are most frequently used for diagnosis [88].

Inability to flush the catheter or draw back blood may hint at thrombosis. Establishing that thrombosis is the cause of the catheter occlusion relies on imaging, either via US or venogram. These imaging modalities may not be readily available in some resource-limited settings, and if other causes for occlusion such as device kinking have been excluded, empirically treating for thrombosis is an option.

A number of therapies have been applied to unblock clotted catheters. The most efficient agents are fibrinolytic/thrombolytic drugs. Early efforts involved streptokinase and urokinase while more recently tissue plasminogen activator has been used with even greater success. The safe use of alteplase was demonstrated in the "COOL" and "COOL-2" trials, with patency restored in up to 74% of occluded catheters [91, 92]. Even higher rates of restored patency were found in the CATHFLo ACTIVASE trail. Of note is that there were no intracranial hemorrhage or other major bleeding events [93]. Newer thrombolytics/fibrinolytics such as reteplase, tenecteplase, and alfimeprase may become relevant, as they may have higher efficacy and shorter dwell times [92, 94].

Catheter-related DVT requires a different approach as the thrombosis is located within the vein itself. Initial therapy (sometimes called the 'attack') aims to prevent thrombus extension and pulmonary embolization. Typically, anticoagulants such as low-molecular-weight heparin (LMWH) or intravenous unfractionated heparin (UFH) are used [3, 95, 96]. LMWH requires no additional IV access and is thus a simpler drug to administer [95, 96]. Maintenance anti-coagulation therapy should be continued at treatment dose for 3 months, and then at prophylactic dose until the device is removed [3].

Thrombolysis is only indicated if there is major vessel occlusion causing critical compromise of an organ or limbs [3] if no further access were possible if the affected vein was lost, or in the case of pulmonary embolism [97, 98]. The risk of major bleeding is greater with thrombolysis than with anti-coagulation alone. If thrombolysis is required, tPA is preferred. Interventional strategies including balloon angioplasty or endovascular re-cannulations have been described, although this requires advanced endovascular procedural skills and very costly technology [99].

Despite the fact that CVAD-related thrombosis is a significant problem, routine thrombo-prophylaxis is not recommended [84] as there is insufficient evidence to support its use [5].

Table 1 is adapted from Giordano et al. [84] and details the recommended therapy of venous thromboembolism in children.

Cannulation-related complications

Pneumothorax, caused by accidental pleural puncture during vessel cannulation, is a well-described complication. Cannulation of the SCV is associated with a higher incidence of pneumothorax than cannulation of the IJV [5, 100, 101]. Other risk factors for pneumothorax include physician inexperience, the emergent setting, and a high number of needle passes [100].

Pneumothorax should be suspected in cases where there were several failed attempts at vessel cannulation, and in patients who become hypoxic or difficult to ventilate. Typically, pneumothorax is diagnosed radiographically with CXR, but US is also effective when the operator is experienced, and carries a lower radiation burden [100]. Small pneumothoraces in asymptomatic patients can usually be treated with observation alone, with follow-up chest imaging to confirm improvement. Larger or symptomatic pneumothoraces can be managed with a pigtail drain with a Heimlich valve, and tube thoracostomies can be performed in refractory cases or in the emergent setting [100].

Unrecognized pleural puncture with placement of the catheter tip into the pleural space, and subsequent infusion of PN and other fluids can lead to pleural effusions (Fig. 5).

Accidental arterial puncture occurs more commonly when the landmark technique is used during femoral and internal jugular vein catheterization [102, 103]. Arterial puncture can be recognized by back flow of bright red blood, which may be pulsatile. Arterial puncture can usually be managed by removal of the needle or cannula, and compression of the vessel, although significant bleeding may cause a large hematoma or hemothorax. Unrecognized arterial placement of CVCs could result in arterial spasm, ischemia, and arterio-venous fistulae.

When placing lines that are particularly firm or large, tearing of the vein can occur, which can result in catastrophic bleeding.

Cardiac tamponade is a severe complication of CVLs and CVADs. When this occurs acutely or within hours of line placement, direct cardiac perforation from malpositioning is the most likely cause. Pericardial effusions that develop some time after catheter placement may be due to adhesion of the line to the myocardium with diffusion into the pericardial space, and osmotic erosion of the wall of the heart [104].

Venous air embolism is a very rare but potentially fatal complication which may occur during placement of a CVL. Typically, this occurs after the guidewire is removed from the dilator, but before the line is passed through the

Table 1 Therapy of venous thromboembolism in children [84]

Scenario	Characteristics	Attack	Maintenance
Venous thrombosis (first episode)	CVC related	UFH or LMWH for 5–10 days	OA or LMWH × 3 months then a prophylactic dose of OAT or LMWH for as long as CVC remains in place
Massive venous thrombosis	With organ failure	Thrombolytic therapy for 6–72 h onset within 14 days combined with UFH or LMWH, to be prolonged for 10 days	OA or LMWH × 6 months
Pulmonary embolism	Without circulatory impairment	UFH or LMWH for 5–10 days	OA or LMWH × 6 months
	With circulatory impairment	Thrombolytic therapy for 6–72 h combined with UFH or LMWH which may be prolonged for 10 days	OA or LMWH × 6 months

UFH unfractionated heparin, *LMWH* low-molecular-weight heparin, *OA* oral anti-coagulation

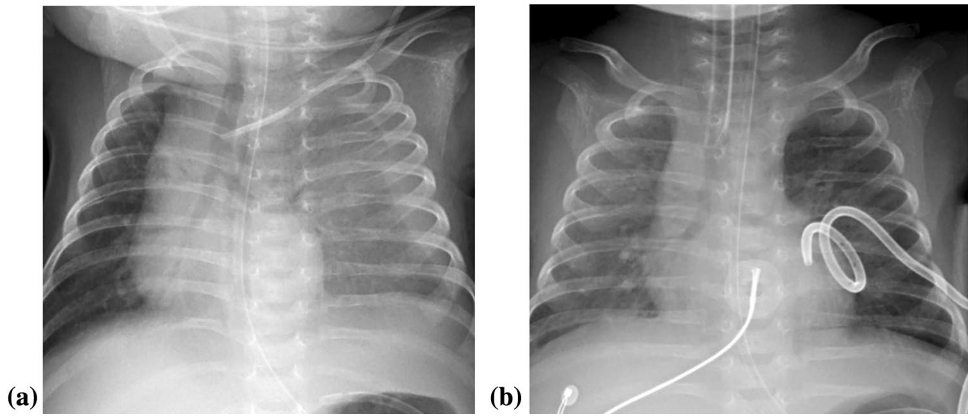

Fig. 5 **a** Left-sided pleural effusion secondary to malpositioned CVL. **b** Pigtail catheter in situ with resolution of the effusion in the same patient

peel-away sheath. A sudden drop in intra-thoracic pressure can cause air to be sucked into the cannulated vessel. Embolized air causes obstruction of flow through the pulmonary arteries and outflow tract, and the patient will become hypoxic, bradycardic, hemodynamically unstable, and may go into cardiac arrest. The likelihood of air embolism can be reduced by keeping the patient in slight Trendelenberg position during the procedure, while the anesthetist provides positive inspiratory pressure during placement of the dilator. Trans-esophageal echocardiography and precordial Doppler are both sensitive for diagnosis, but once this condition has occurred, time is of the essence and steps should immediately be taken to correct the problem. The patient should be ventilated with 100% oxygen and moved into the left lateral decubitus position, so that the air can move to the apices of the right atrium and ventricle, and away from the pulmonary artery and ventricular outflow tract. If possible, the line should be passed rapidly through the dilator into the atrium, and aspirated in an attempt to remove air [105].

Device damage and breakage

Catheters can fracture at intra- and extra-corporeal sites. Intra-corporeally, pinch-off syndrome, excessive movement, and acute angulation may lead to fracture. Extra-corporeally, the catheter may break at hinge points, such as where the catheter exits from below the dressing, or where it joins the hub. Many extra-corporeal fractures can be remedied using salvage repair kits [24]. Intra-corporeal fractures may lead to catheter embolization, although this is a rare occurrence [106]. Catheter fragment embolization can have serious consequences and it is recommended that where feasible, the fragment should be retrieved. Currently, endovascular techniques are available to retrieve catheter fragments [107], but frequently retrieval is not possible despite best efforts. Some series from the literature do report conservative management of retained fragments with observation, without complications [108].

Signs of fracture or damage include local pain and swelling, leakage from the insertion site, and resistance to injection or slow flow on withdrawing blood.

Extravasation describes the leakage of the infusate into surrounding tissue. Serious extravasations into the pleura and pericardium have been described and can be life threatening [104, 109]. Erosion through the vessel wall will also lead to leak and extravasation with consequent pleural and pericardial effusions and possible tamponade or exsanguination [110].

Accidental removal

In the authors' experience, accidental removal or dislodgement is one of the most common complications associated with CVADs, and is a well-described and common problem in all settings [31, 37, 66, 78, 106]. Using TIVADs or tunneled catheters reduces the incidence of accidental removal [5, 34], as well as taking care to coil lines below dressings, taking care to promptly change dressings as they start to peel off, and to vigilantly monitor for and address tension on lines. The importance of educating staff and caregivers who are handling lines and caring for the children in whom they dwell cannot be overstated (Fig. 6).

Conclusion

Central venous access is essential to the management of multiple medical and surgical conditions in infants and children, and options for devices, access sites, and techniques are numerous. The placement and care of CVADs requires an understanding of the potential complications associated with these devices, and an institutional commitment to caring for these devices and the patients benefitting from them. CVADs tend to be expensive, but hospitals with limited resources can opt to stock a narrow range of products that will benefit a wide range of patients. Although devices can be placed using minimally invasive techniques with

Fig. 6 Dislodged CVL. Note the poorly applied dressing that is wrinkling and falling off, which is also a risk factor for CVL contamination and CRBSI. Accidental removal or dislodgement is a common complication, and can be partially avoided by careful line handling and meticulous attention to dressings

radiological support, clinicians without access to these tools and services should not be discouraged from device placement as landmark and open cut-down techniques are safe and effective. Complications are numerous and of marked clinical significance, and the incidence can be particularly high in institutions that are poorly resourced or staffed. Here, low-cost efforts such as enforcing infection control policies and investing in the ongoing training of staff members can help to reduce adverse events.

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