Vascular Access

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1 Peripheral Vascular Catheters

1.1 Introduction

Peripheral access is achieved with peripheral intravenous catheters (PIVCs), midline catheters and peripherally inserted central lines (PICCs). Choosing among them depends on the specific indications, anticipated length of insertion and patient comorbidities.

Catheters are typically either derived from silicone or polyurethane with similar overall rates of complications for both in peripheral lines. The major difference noted between the two catheters is increased incidence of mechanical phlebitis in polyurethane catheters, given stiffer material [1]. These catheters come in different sizes depending on the outer diameter and the flow rate. The gauge system developed in Birmingham

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which was originally used for sizing the iron wires and later adapted for hollow needles and catheters is widely prevalent. Even though it does not correlate well with the outer diameter this system is commonly used in the peripheral vascular catheters. French system of catheter sizing is more systematic and simple. With the increase of one French unit, there is an increase of 0.33 mm in outer diameter. Most common vascular catheters range between 4 to 10 French in size. This system is commonly used for multi lumen catheters or speciality catheters (Table 1).

Table 1 Vascular catheters

Peripheral vascular catheters			
	Gauge size	Outside Diameters (mm)	
	12	2.64	
	14	2.03	
	16	1.62	
	19	1.22	
	18	1.02	
	20	0.91	Length varies from 3 to 5 cm
	21	0.81	
	22	0.71	
	23	0.61	
	24	0.56	
	25	0.5	
	26	0.45	

Table 1 (continued)

Midline catheters

Size (French)	Length (cm)	Number of lumens
4	8–20 cm	1–2
5	8–20 cm	1–2

PICC catheters

Size (French)	Length (cm)	Number of lumens	Gauge size	Flow rate (L/h)
5	50	Single	16	1.75
5	70	Single	16	1.3
5	50	Distal	18	0.58
		Proximal	20	0.16
5	70	Distal	18	0.44
		Proximal	20	0.12

Central venous catheters

Size (French)	Length (cm)	Number of lumens	Lumen size (Gauge)	Flow rate (L/h)
7	16	Distal	16	3.4
		Middle	18	1.8
		Proximal	18	1.9
7	20	Distal	16	3.1
		Middle	18	1.5
		Proximal	18	1.6
7	30	Distal	16	2.3
		Middle	18	1
		Proximal	18	1.1

(continued)

Table 1 (continued)

Hemodialysis catheters

Size (French)	Length (cm)	Number of Lumens	Lumen size	Flow rate (L/h)
12	16	Proximal	12	23.7
		Distal	12	17.4
12	20	Proximal	16	19.8
		Distal	12	15.5

It is essential to know that flow (Q) through a hollow rigid tube is directly proportional to the pressure gradient (ΔP) and inversely proportional to resistance. (Q = ΔP × 1/R). Also according to the Hagen-Poiseuille equation, flow (Q) is directly proportional to the fourth power of the inner radius of the tube (r^4) and inversely proportional to the length of the tube (L).

$$\text{Hagen Poiseuille equation}: Q = P \times \left(\pi r^4 / 8\,\mu L\right)$$

This equation influences the flow rate of the catheters. With increase in the inner radius of the catheters, the flow rate would increase significantly. It should also be noted that the flow in the 30 cm catheters would be less than half the flow rate in the 5 cm catheter.

Peripheral access catheters can be inserted using a direct visual approach or via visualization devices such as infra-red or ultrasound technology. Details of insertion will be discussed in the text below.

A. Peripherally Inserted Venous Catheters (PIVC) (Figs. 1, 2) The majority of hospitalized patients have at least one peripheral intravenous catheter (PIVC), making PIVC one of the most common clinical procedures. In the United States, over 300 million PIVCs are used for hospitalized patients

Figure 1 Peripheral vascular catheters

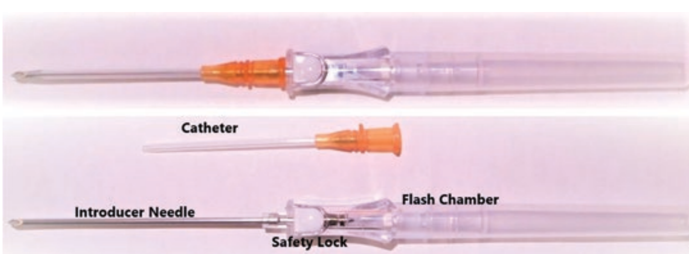

Figure 2 Peripheral catheters and its parts. Top: Catheter-over-needle device, Bottom: Parts of the peripheral vascular catheter

annually [2, 3]. These catheters are usually made up of polyethylene and provoke a strong inflammatory response on contact with blood vessels [1]. This limits the use of these catheters for prolonged duration. They are available in different lengths and diameters (Table 1).

Indications: Treatment with peripherally compatible solutions (less than 900 mOSm/liter, not vesicant or irritant) for less than 5 days [4, 5]. The larger bore catheters (14,16G) are used in rapid fluid resuscitation as in emergency situations like trauma or shock. Smaller bore catheters (20G) are most commonly used to cannulate the vein for most clinical conditions.

1.2 Method of Insertion [6]

1. Tourniquet should be applied in the arm to ensure adequate venous filling without causing patient discomfort or local ischemia.
2. Palpate and inspect the vein.
3. Clean area with alcohol swab or povidone-iodine solution.
4. Anchor the selected vein by applying gentle traction.
5. Insert catheter needle into the vessel at a 15-to-30° angle using the dominant hand. If using deeper veins, use a more obtuse (60°) angle.
6. Look for blood flash in the catheter hub, which suggests vessel penetration.
7. Further advance the catheter to the appropriate location. Withdraw the needle.
8. Remove tourniquet. To prevent hematoma formation, it is recommended to remove the tourniquet before needle removal and apply pressure on the area after needle removal.
9. Attach IV tube.
10. Secure catheter with tape and a sterile transparent dressing.
11. Assess catheter function and distal blood flow.

Advantages: Peripheral access is considered less invasive than central and has a lower risk of infection (0.5/1000 catheter days) [7, 8]. Cyclic or episodic chemotherapy management can also be considered when less than 3 months in duration with non-vesicant product infusion [9]. These catheters can be inserted in different locations like the neck (e.g., external jugular vein) or lower extremity (e.g., foot veins) in emergency situations [9].

Disadvantages: Access could be difficult in obese patients, patients without adequate veins, increased risk of infection and phlebitis in high risk patients (e.g., diabetics).

If repeated insertion attempts fail, it's appropriate to consider the designation of difficult intravenous access and explore the access site with ultrasound or other visualization technologies like using infrared rays [5]. Access through the distal portions of the upper extremity are preferred in patients with chronic kidney disease in order to preserve peripheral and central veins for hemodialysis, fistulas or grafts [10].

B. Midline Catheters (Fig. 3)
These catheters are inserted just like peripheral catheters, but they are of longer length (8–20 cm) compared to periph-

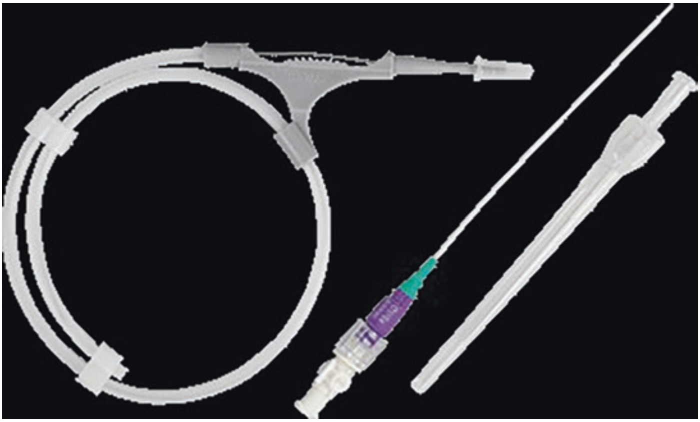

FIGURE 3 Bard Powerglide Midline Catheter 20G, 10 cm with guidewire

eral catheters (3–5 cm). These catheters can be single or dual lumen; however, a single-lumen catheter is typically preferred [9].

Indications:
When treatment is likely indicated for more than 6 days with up to 14 days being permissible. Patients with difficult intravenous access despite ultrasound-guided peripheral catheter attempts may also be considered for a midline catheter [9, 10].

Advantages:
Lower phlebitis rates than peripheral catheters and lower rates of infection compared to other central catheters [9].

Disadvantages:
Require more training and are more intensive than traditional PIVCs.

C. Peripherally Inserted Central Catheter (PICC) (Fig. 4)
PICC lines compromise more than half of all devices used to obtain central access [11]. These are long catheters inserted into the basilic or cephalic arm veins (above the antecubital fossa) and advanced into the superior vena cava. Because the basilic vein has a larger diameter compared to the cephalic vein and a straighter course in the arm, it is the preferred

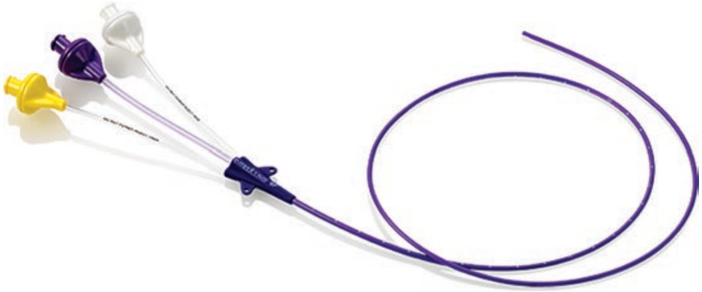

FIGURE 4 Medcomp triple-lumen PICC catheter

route for PICCs. PICCs are indicated in patients requiring intravenous access for more than 14 days or those necessitating continuous infusions of vesicant, parenteral nutrition, chemically irritating or peripherally incompatible solutions of any duration [10]. Cyclic chemotherapy of more than 3 months is another indication. PICCs may also be used in patients requiring frequent phlebotomy (e.g. every 8 h for more than 6 days). Burn patients, patients requiring chronic or lifelong access (e.g. sickle cell disease, cystic fibrosis or short gut) or those requiring frequent hospitalizations should also be considered for PICC insertion. PICC lines may also be used for cardiac monitoring or vasopressor administration in hemodynamically unstable patients [9]. Finally, using antimicrobial-coated PICC lines may help reduce significant reduction in risk of infections [12].

1.3 Technique [6, 13]

PICC lines are inserted under ultrasound guidance. The procedure is performed under strict aseptic precautions and the length of the catheter to be used is predetermined by measuring the distance from the antecubital fossa to the shoulder and then from shoulder to the right sternoclavicular joint, then down to the right 3rd intercostal space. After the basilic vein is located and cannulated, the catheter is advanced in the vein upto the lower third of the superior vena cava, just above the right atrium. The chest X-ray is performed to confirm the location of the catheter tip.

1.4 Pitfalls

General:

1. If having difficulty locating a vein, you can tap on the vein, ask the patient to grip and relax his/her hands repeatedly or apply a warm compress for at least 2–3 min. If still unable to isolate a vein, can also use ultrasound guidance.

Avoid venous access near sites of infection or injury. Also avoid using extremities with previous arteriovenous fistulas or grafts or lymph node dissections [6, 14].

2. When advancing the catheter after getting a blood flash, make sure further entry is smooth. If you meet resistance, withdraw the catheter as you may have penetrated the posterior wall of a vessel.
3. If you suspect that you pierced an artery, apply pressure at site.
4. If having difficulty securing the catheter, use multiple transparent dressings.
5. If induration, erythema or significant pain is reported at the insertion site, there may be concern for phlebitis or infection. Remove the catheter if infection is suspected and monitor for ongoing signs of sepsis.
6. If concerned for extravasation of fluids, apply compresses (e.g. using sterile gauze) and elevate the extremity [6].
7. Deep vein thrombosis is a potential complication of venous access. If this is a concern, evaluate using ultrasound.

PICC Related:

1. Venous air embolism: When advancing a catheter into the thorax, the negative intrathoracic pressure in spontaneously breathing patients can allow for air to enter the venous system if the catheter is open to the atmosphere. Presentation can range from dyspnea to R heart failure, pulmonary edema and embolic stroke. Prevention in such patients is by ensuring the patient is in Trendelenburg position [15].
2. Malposition seen on Chest Radiograph: A properly placed PICC should be in the SVC, with the tip 1–2 cm above the R atrium (near the tracheal carina) [16]. If the tip is below the carina, there is a concern for Right atrial entry and potential perforation; thus, retraction is recommended.

2 Central Vascular Catheters

2.1 Introduction

First described in 1929, central venous catheters (CVCs) have become an important part of hospital care. More than seven million units per year of central venous access devices are used in the United States; per 2016 data, the number increases to ten million worldwide [11].

Canalization sites include internal jugular (IJ), femoral and subclavian veins with advancement into the vena cava. Per CDC recommendations, to minimize infection risk, subclavian is preferred over jugular and femoral locations in adult patients when using non-tunneled CVC. No recommendation regarding anatomic preference is indicated for tunneled CVCs. Subclavian CVCs, however, should be avoided in hemodialysis patients and patients with chronic kidney disease to prevent subclavian vein stenosis. Additionally, when using IJ for canalization, the right side of the neck is preferred due to a vessel course [13, 17].

If ultrasound is available, the CDC recommends its use in placing CVCs to limit cannulation attempts and mechanical complications [17]. Complication rates increase with each additional attempt or percutaneous puncture [6].

2.2 Indications

2.2.1 Non-tunneled CVCs (Fig. 5)

Non-tunneled CVCs are indicated in patients requiring emergent care (i.e. unstable, requiring hemodynamic monitoring or large fluid infusions). They can also be used for parenteral nutrition. Typically, they are used for short-term access and are preferred over PICCs in patients requiring 14-day access. Additionally, they can be used to deliver parenteral nutrition and chemotherapy lasting more than 3 months [9].

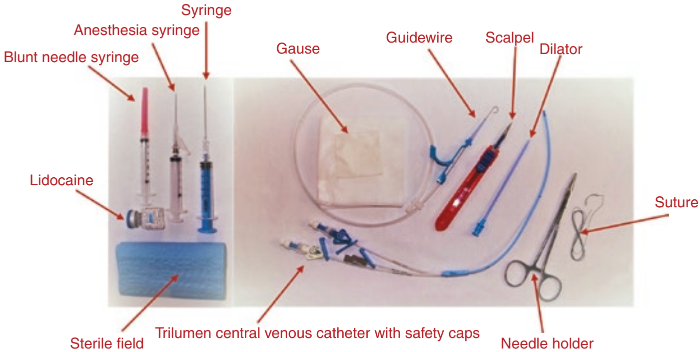

FIGURE 5 Central venous catheter kit

Their infection rate is similar to that of PICCS; antimicrobial coating agents are also used to reduce infection risk by 40% when access is required for more than 5 days [10]. Both chlorhexidine/silver sulfadiazine and minocycline/rifampin are available as antimicrobial coating agents [13, 18].

2.2.2 Tunneled CVCs

Tunneled CVCs are inserted using a subcutaneous tunnel in the mid-chest region. Such types of catheters are indicated in patients receiving treatment exceeding 31 days or those requiring multiple treatments over several months. They are used for delivery of vesicant, irritant, parenteral nutrition or chemotherapy medications (regardless of duration). Another consideration is for patients requiring more than 6 annual hospitalizations with each necessitating at least 15 days of therapy or those in whom a PICC is indicated but limited due to thrombosis risk [9].

2.3 *Technique of Insertion for Non-tunneled Catheters* [6, 13] (Fig. 6)

1. Maintain sterile precautions, including caps, masks, sterile gloves, sterile gowns and a sterile drape for the patient from head to toe [17].
2. Identify vessels using ultrasound. Hand hygiene before and after palpating the insertion site using an alcohol-based rub is recommended [17].

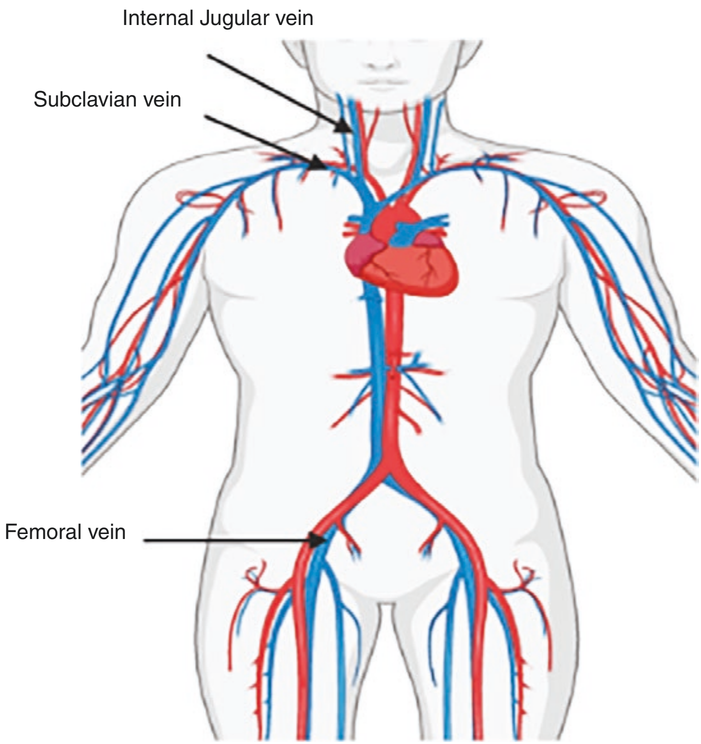

Figure 6 Sites of central venous access

A. Internal Jugular Vein (IJV): The IJV is located under the sternocleidomastoid (SCM) muscle and runs diagonally down the neck when a line is drawn from the pinna to the sternoclavicular joint. Insertion of the catheter can be done blindly by inserting the needle at the apex of the angle formed by the sternal and clavicular heads of the sternocleidomastoid muscle. Carotid artery is palpated on the lateral side of the sternal head of the sternocleidomastoid while the vein is superficial to it (about 1–2 cm depth from the skin usually). Care must be taken to point the needle to the ipsilateral nipple to avoid puncture of the carotid artery. Distance from the cannulation site to the right atrium is about 15 cm, so the shortest CVCs should be used. For left IJV, a 20 cm catheter may need to be considered. To identify the vessel, have the patient in Trendelenburg position and the head slightly turned to the opposite side to further straighten the venous course. Avoid turning the head beyond 30° because it can stretch the vessel and reduce diameter. Using US, place the probe at the triangle created by the two heads of the SCM. Right side IJV is preferred over left side due to the short and straight course to the heart.

B. Subclavian Approach: The subclavian courses underneath the clavicle and continues in the thoracic inlet. The vein is approached usually using landmarks with index finger at the sternal notch and thumb placed at the angle of the clavicle, two-thirds of the way lateral from the sternal notch.. The vessel may be difficult to identify using US because of the overlying clavicle; thus, surface landmarks are often used. To locate, identify the clavicular head of the SCM and the vein lies under the clavicle in this area. Cannulation can be done from above or below the clavicle.

C. Femoral Approach: The femoral vein is located in the femoral canal, along with its corresponding nerve and artery. At the level of the inguinal crease, the vein is medial to the artery and is easiest to cannulate with the hip abducted. The vein can be located by palpating the femoral artery pulse and US can be used to further locate the vein.

3. Apply chlorhexidine to the insertion site. Allot 2 min for it to dry.
4. Anesthetize insertion site by injecting 1–2% lidocaine in all conscious patients.
5. Using an 18-gauge introducer needle with an attached 10 ml syringe, introduce the needle into the skin and subcutaneous tissue until a flash of blood is seen in the hub. Perform this using your dominant hand.
6. Stabilize the needle with your nondominant hand.
7. Assure that the syringe has constant venous flow. If no flow is seen, withdraw the needle as you may have breached the posterior vessel wall.
8. Remove the attached syringe and occlude the catheter with your finger to prevent air entry.
9. Insert the guidewire through the needle, maintaining a firm grip on the guidewire.
10. Advance the guidewire. If you meet resistance, reposition the needle to assert proper needle position.
11. Remove the needle once the guidewire is inserted at least 10 cm into the vessel.
12. Make a small incision at the insertion site using a #11 scalpel blade to accommodate dilator/catheter. Do not cut the guidewire.
13. Advance the dilator/catheter over the guidewire with a gentle twisting motion.
14. Maintaining a grip on the guidewire, advance the catheter to its appropriate depth.
15. Remove the guidewire.
16. Aspirate and flush all ports to assert catheter function.
17. Secure the catheter with a suture and apply transparent dressing.
18. Obtain chest radiograph to confirm catheter placement in the superior vena cava.

2.4 Pitfalls

General

- If it is felt at any point that the sterile field is compromised, make sure to replace equipment.
- When preparing the insertion site, make sure to prep a wider region in case multiple cannulation attempts are required.
- Arterial puncture can occur in up to 15% of CVC placements, resulting in mediastinal hematoma, hemothorax, tracheal compression with possible asphyxiation and retroperitoneal hemorrhage [19–21]. A higher incidence is reported with internal jugular attempts [21–23] with carotid artery puncture being the most feared complication. Prevention includes using US guidance. If suspected, confirm with measurement of venous waveform; management includes either applying pressure at site to prevent further bleeding and removing the catheter slowly or leaving it in. Immediate removal may lead to more hemorrhage, pseudoaneurysm or fistula development, with a greater risk in patients on anticoagulant agents [24, 25].
- Make sure the guidewire passes easily when inserted. Do not force the guidewire. If it does not pass, then needle position may need to be adjusted.
- In the case of injury to the right atrium during canalization procedure (e.g. patient develops arrhythmias), Advanced Cardiac Life Support (ACLS) protocols should be followed. If perforation of the right atrium is suspected (e.g. potential cardiac tamponade), immediate assessment and pericardiocentesis may be indicated [24, 25].
- If the guidewire is lost at any point after insertion, make sure to obtain a chest radiograph to assess retention. Improper guidewire placement can lead to right atrial irritation and premature ventricular contractions or dysrhythmias.
- When advancing a catheter into the thorax, the negative intrathoracic pressure in spontaneously breathing patients

can allow for air to enter the venous system if the catheter is open to the atmosphere. Presentation can range from dyspnea to right heart failure, pulmonary edema and embolic stroke. Prevention in such patients is by ensuring the patient is in Trendelenburg position [15].

- Monitor patient for catheter-related infection (erythema at insertion site or fever, chills, hypotension without another confirmed source). Etiologies include skin flora, infection of catheter hub with repeated manipulation and hematogenous seeding from bacteremia. Prevention includes sterile technique, chlorhexidine application, avoidance of femoral line and removing unnecessary catheters [26, 27]. If a catheter-related infection is suspected, one should assess the need for continued catheter used and remove if possible. Blood cultures should be ordered with additional workup as indicated [28].
- If concerned for an occluded catheter (e.g. thrombosis, precipitation of medications), assess cause and consider re-insertion. Stenosis of subclavian veins is of greater concern than for other sites, which is the impetus for avoiding using this site in patients requiring an AV fistula for hemodialysis using the ipsilateral arm [29].
- If malposition of catheter is seen on chest radiograph, assess for pneumothorax and reposition catheter. Pneumothorax risk is minimal with IJ access because the veins are in the neck; however, risk increases with using surface landmarks as a guide [23].
- Lymphatic injuries (especially during internal jugular or subclavian vein canalization) can be seen. Treatment is with nitric oxide, thoracoscopic fibrin glue or percutaneous coiling [30].
- Tracheal injury due to accidental puncture is rarely reported; management is primarily surgical. Immediate consultation with an otorhinolaryngologist or a trauma surgeon is recommended [24].

3 Specialty Catheters

These catheters are used for a specific purpose only. Their long term use in hospital or intensive care settings is not indicated and alternative approaches should be performed if needed. They include hemodialysis catheters, introducer sheaths and pulmonary artery catheters. The Pulmonary artery Catheter is discussed in the next chapter while hemodialysis catheter and introducer sheath are discussed below.

3.1 Hemodialysis Catheters: (Fig. 7)

Hemodialysis requires direct access to the circulation, preferably via an atrioventricular fistula (AVF). In urgent cases or in patients with chronic renal failure requiring a bridge to AVF, atrioventricular graft or transplant therapy, dual-lumen dialysis catheters may be used. These catheters contain both an arterial and venous lumen that withdraws from and returns blood to the patient, respectively. They are placed into the internal jugular or femoral veins and may be tunneled or tunneled with subcutaneous cuffs. Typically, they are associated with a two- to three-fold increased risk of infection compared to AVF or AV grafts [31]. Flow rate is between 200 and 5000 mL/min [32].

Indicated in patients requiring urgent dialysis or in patients needing bridge therapy to an AVF, atrioventricular graft or transplantation.

3.2 Introducer Sheaths: (Fig. 8)

Catheter introducer sheaths facilitate percutaneous entry of intravascular devices, helping protect the vessel from injury as wires and catheters are introduced. Most have a 5- to-9-French inner diameter and vary in lengths depending on the intervention site. A one-way valve prevents bleeding through the sheath [33]. These catheters are indicated as part

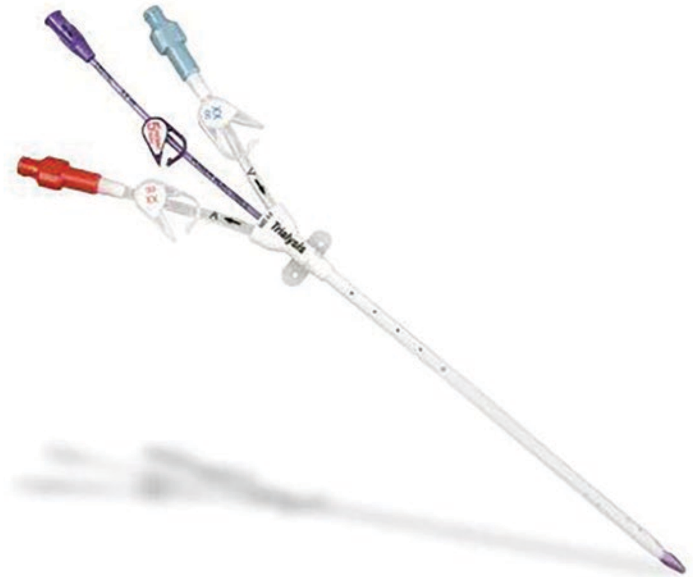

FIGURE 7 Bard power-triple lumen dialysis catheter 13 Fr × 20 cm

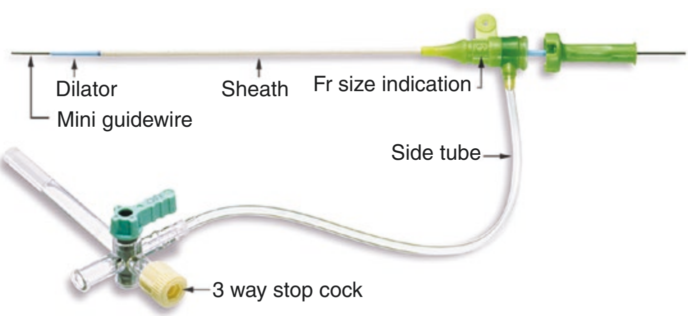

FIGURE 8 Radifocus introducer sheath

of endovascular catheterization devices to prevent blood vessel injury. Pulmonary artery catheters can also be introduced through the sheaths. They also can be used for rapid infusion of fluids or blood products during hemodynamic resuscitation. Along with the pressurized infusion system, the flow rates of 850 ml/min have been reported [34].

3.3 *Technique*

3.3.1 Hemodialysis Catheter

Insertion of hemodialysis catheter is similar to other forms of central venous access. The most important thing to consider during the procedure is to make a slightly bigger nick compared to the one for central line insertion. This helps as two dilation has to be done twice during this procedure. The smaller dilator primes the track for the bigger dilator. Dilator should be rotated clockwise holding it from the distal end (preferably with a gauze piece) for better grip. Each time, care should be taken to avoid pulling on the guidewire. Firm pressure should be applied with the gauze piece at the dilation site to avoid excess bleeding. The guidewire should always be moving freely within the dilator and the insertion should be smooth. If during the procedure significant resistance is felt, the position of the guidewire should be checked with should be placed at the site of the while introducing, summarized below. Further details as mentioned under "central venous access" [35].

3.3.2 Introducer Sheath [36]

The insertion requires identification of the target vessel, using ultrasound if necessary, introduction of micro-puncture needle into artery until a flash of blood appears, followed by guidewire insertion and introducer needle removal. The sheath with the accompanying dilator is threaded over the guidewire and eventually the dilator and guidewire is removed as a unit with the sheath left within the vessel.

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