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Chapter 6

ESTABLISHING VENOUS ACCESS

He who works with his hands is a laborer. He who works with his head and his hands is a craftsman.

St. Francis of Assisi

Establishing and maintaining access to the vascular system is one of the seminal tasks in critical care. This chapter presents some practical guidelines for the insertion of vascular catheters, and the next chapter describes the considerations involved in maintaining vascular access. The emphasis in this chapter is not the technique of catheter insertion (which must be mastered at the bedside) but the information that will allow you to make appropriate decisions about vascular cannulation in the individual patient (e.g., selecting the appropriate catheter and insertion site). The goal here is to follow the advice of Saint Francis of Assisi and teach you the craft of vascular cannulation.

PREPARING FOR VASCULAR CANNULATION

Hospital Staff

Anyone who inserts a vascular catheter must follow standard infection control practices in preparation for catheter insertion. Handwashing with an antimicrobial soap or gel is recommended for all vascular catheter insertions, including those involving small peripheral veins (0,2).

(Handwashing is described in detail in Chapter 3.) The hands should be decontaminated before donning gloves and again after the gloves are removed. Sterile gloves are recommended for insertion of central venous catheters and arterial catheters (1), while nonsterile disposable gloves can be used for cannulation of peripheral veins as long as the gloved hands do not touch the catheter (2). Full barrier precautions using masks, gowns, and sterile drapes are recommended for insertion of central venous catheters, including peripherally-inserted central catheters (PICCs) (1).

Catheter Insertion Site

The skin around the catheter insertion site should be decontaminated with an antiseptic agent (see Chapter 3 for information on antiseptic

agents). The Centers for Disease Control (CDC) recommends chlorhexidine because of its residual antimicrobial activity, which can last for 6 hours after one application (see Figure 3.1) (2). The clinical significance of this is, however, unproven, and other antiseptic agents like povidoneiodine (Betadine) and 70% alcohol are also acceptable (1). Remember that chlorhexidine and povidone-iodine should be allowed to dry on the skin and not wiped off to maximize their antibacterial effects (1).

VASCULAR CATHETERS

Vascular catheters are made of polymers impregnated with barium or tungsten salts to enhance radiopacity. Catheters designed for short-term cannulation (days) are usually made of polyurethane, a synthetic polymer known for its strength, durability, and moisture resistance. Catheters designed for prolonged use (weeks to months) are made of a silicone polymer that is more flexible and less thrombogenic than polyurethane. Because of their flexibility, silicone catheters must be inserted over a semi-rigid guidewire or through a surgically-created subcutaneous tunnel.

Catheter Size

The size of vascular catheters is expressed in terms of the outside diameter of the catheter. Two units of measurement are used to describe catheter size: a metric-based French size and a wire-based gauge size. The French size is a series of whole numbers that increases from zero in increments of 0.33 millimeters (e.g., a size 5 French catheter will have an outside diameter of $5 \times 0.33 = 1.65$ mm). The gauge size was introduced for solid wires and is an expression of how many wires can be placed side-by-side in a given space. The gauge size varies inversely with the diameter of the wire (or catheter). However, there is no simple relationship between gauge size and other units of measurement, and a table of reference values like Table 6.1 is needed.

Determinants of Flow Rate

The influence of catheter size on flow through the catheter is defined by the Hagen-Poiseuille equation, which is presented in detail in Chapter 1 (see Figure 1.6).

$$Q = \frac{\Delta P (\pi r^4)}{8\mu L} \quad (6.1)$$

Steady flow (Q) in a catheter is directly related to the pressure gradient along the catheter (ΔP) and the fourth power of the radius of the catheter (r^4) and is inversely related to the length of the catheter (L) and the viscosity of the fluid (μ). The principal determinant of flow in this equation is the radius of the catheter. The relationship between catheter diameter and flow rate is demonstrated in Figure 6.1. The data in this graph pertain to the gravity flow of blood through a catheter of constant length but varying diameter (3). As demonstrated, a given change in

TABLE 6.1 Catheter Size Chart

French Size	Gauge	Inner Diameter	Outer Diameter
1	27	0.007 in or 0.1 mm	0.016 in or 0.4 mm
2	23	0.012 in or 0.3 mm	0.025 in or 0.6 mm
3	20	0.020 in or 0.5 mm	0.037 in or 0.9 mm
4	18	0.025 in or 0.6 mm	0.047 in or 1.2 mm
5	16	0.030 in or 0.7 mm	0.065 in or 1.7 mm
7	13	0.050 in or 1.3 mm	0.095 in or 2.4 mm
9	11	0.062 in or 1.6 mm	1.25 in or 3.2 mm

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diameter resulted in a proportionately greater change in flow, reflecting the dependence of flow on a power function of catheter radius. The relationships in the Hagen-Poiseuille equation indicate that short catheters with large diameters are most appropriate for rapid infusion rates. Furthermore, catheter diameter takes precedence over

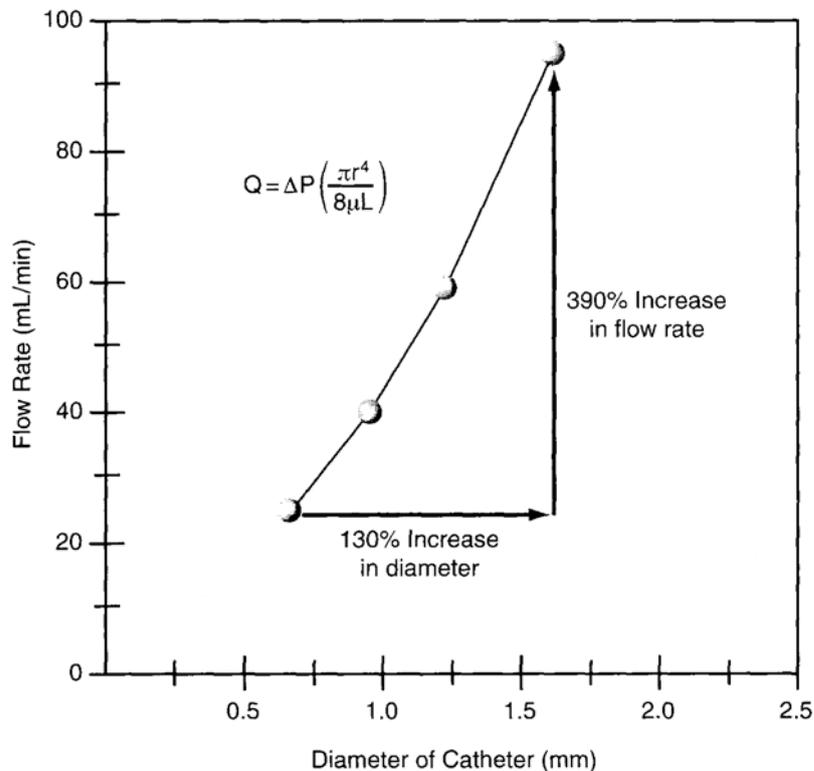


FIGURE 6.1 Relationship between flow rate and outside diameter of a catheter. (From de la Roche M, Gauthier L. Rapid transfusion of packed red blood cells: effects of dilution, pressure, and catheter size. *Ann Emerg Med* 1993;22:1551.)

catheter length when rapid infusions are needed. The performance of different sized catheters for volume resuscitation is described in more detail in Chapter 12.

Peripheral Venous Catheters

Catheters that are designed for cannulation of peripheral veins are typically short (usually 5 cm, or 2 inches in length) and about 18 to 22 gauge in diameter (see Table 6.2). These catheters are usually inserted using a catheter-over-needle device like the one shown in Figure 6.2. The catheter fits snugly over the needle, and has a tapered end to minimize damage to the catheter tip and soft tissues during insertion. The needle has a clear hub, called a flash chamber, which fills with blood when the tip of the needle enters the lumen of a blood vessel. The cap on the needle should be removed before insertion to facilitate the movement of blood into the flash chamber. When the tip of the needle enters the blood vessel (and blood fills the flash chamber), the catheter is advanced over the needle and into the lumen of the vessel.

Central Venous Catheters

The term *central venous catheter* refers to a catheter that is designed for cannulation of the subclavian vein, the internal jugular vein, or the

TABLE 6.2 Different Types of Vascular Catheters

Type of Catheter	Sizes	Lengths
Peripheral venous catheter	18 ga	5 em, 7 em
	22 ga	4 em, 5 em
Central venous catheter		
Single lumen	16 ga, 18 ga	15 em, 12 em
	20 ga	8em
Double lumen (18, 18 ga)	7.5 Fr	15 em, 20 em, 25
Triple lumen (18, 18, 16 ga)	7 Fr	15 em, 20 em, 25
Peripherally inserted central catheter (PICC)	3 Fr	50 em
	4 & 5 Fr	60 cm
Hemodialysis catheter	16 Fr	26 cm
Introducer catheter	9 Fr	10 em, 13 em
Radial artery catheter	20 ga, 21 ga	5 cm, 2.5 em, 5 em
Femoral artery catheter	18 ga, 20 ga	12cm,8cm

Catheter dimensions listed here are from one manufacturer (Cook Critical Care; Bloomington, IN) and may differ from those of other manufacturers.

Fr: French unit (one French unit = 0.33 mm): ga: gauge

femoral vein. As indicated in Table 6.2, these catheters are much longer than the catheters used to cannulate peripheral veins and are typically 15 to 25 cm (6 to 10 inches) in length. They also are available with two or three separate infusion channels, which is advantageous when multiple medications are required.

Seldinger Technique

Central venous catheters are placed by threading the catheter over a guidewire (a technique introduced in the early 1950s and called the *Seldinger technique* after its founder). This technique is illustrated in Figure 6.3. A small-bore needle (usually 20 gauge) is used to probe for the target vessel. When the tip of the needle enters the vessel, a long, thin wire with a flexible tip is passed through the needle and into the vessel lumen. The needle is then removed, and a catheter is advanced over the guidewire and into the blood vessel. When cannulating deep vessels, a rigid dilator catheter is first threaded over the guidewire to create a tract that facilitates insertion of the vascular catheter.

Introducer Catheters

The first catheter inserted in the large, central veins is usually a large-bore introducer catheter like the one shown in Figure 6.4 (see Table 6.2 for the dimensions of an introducer catheter). Once in place, these catheters are fixed to the skin with a single suture. A central venous catheter can then be threaded through the introducer catheter and advanced to the desired tip location. Introducer catheters allow central venous catheters to be inserted and removed repeatedly without a new venipuncture. A side-arm infusion port on the catheter provides an additional infusion line and also allows the introducer catheter to be used as a stand-alone infusion device (a rubber membrane on the hub of the catheter provides an effective seal when fluids are infusing through the side-arm port of the catheter). The large diameter of introducer catheters (9 French) makes them particularly valuable when rapid infusion rates are necessary (e.g., in hemorrhagic shock).

Multilumen Catheters

Central venous catheters are available with one, two, or three infusion channels (see Table 6.2). The multi lumen catheters are the most popular because they allow multiple infusions through a single venipuncture site. The popular triple-lumen catheter is shown in Figure 6.4. This catheter has an outside diameter of 2.3 mm (7 French) and houses one 16 gauge channel and two smaller 18 gauge channels. The distal opening of each channel is separated from the others by at least one centimeter to prevent mixing of infusate solutions. Although each channel of a multilumen catheter is a potential risk of infection (through breaks in the infusion lines connected to each channel), several clinical trials have failed to show a higher incidence of catheter-related infections with multilumen versus single lumen catheters (4).

Heparin-Bonded Catheters

The intravascular portion of a central venous catheter can serve as a nidus for thrombus formation, and this can be a prelude to thrombotic occlusion of the involved blood vessel as well as catheter-related septicemia. The link between thrombosis and infection may be the result

of microorganisms that become trapped and proliferate in the fibrin meshwork of a thrombus. The risk of catheter-related thrombosis varies with the site of venous cannulation. The incidence can be as high as 20% with femoral vein catheters and as low as 2% with subclavian vein catheters (5). Central venous and pulmonary artery catheters are now available with a heparin coating on the external surface to prevent thrombus formation. There is some evidence that heparin-bonded catheters can cause a small (2%) decrease in the incidence of catheter-related infections (6). However, the heparin coating is washed away by the flow of blood and can be completely lost in just a few hours after the catheter is placed (5). Furthermore, there are reports that heparin-bonded catheters can cause heparin-induced thrombocytopenia (7). Because the benefit of heparin-bonded catheters is small, while the risk of heparin-induced thrombocytopenia can be serious, it seems wise to avoid these catheters.

Antimicrobial-Impregnated Catheters

Central venous catheters are available with two types of antimicrobial coating: one uses a combination of chlorhexidine and silver sulfadiazine (available from Arrow International, Reading PA), and the other uses a combination of minocycline and rifampin (available from Cook Critical Care, Bloomington, IN). The earliest catheters used chlorhexidine and silver sulfadiazine on the outer catheter surface, and only 2 of 9 studies evaluating these catheters showed a significant reduction in catheter-related septicemia (6). A single multicenter study comparing both types of antimicrobial catheters showed superior results with the minocyclinerifampin catheters (1,8). These catheters have antimicrobial bonding on both (outer and inner) surfaces, and also show antimicrobial activity for up to 4 weeks, compared to one week for the chlorhexidine-silver sulfadiazine catheters (9). At the present time, it seems the minocyclinerifampin catheters are preferable, although newer chlorhexidine-silver sulfadiazine catheters are now available with antimicrobial bonding on both catheter surfaces. Antimicrobial-impregnated catheters should be considered if the rate of catheter-related septicemia in your ICU is higher than the national average (which is 3.8 to 5.3 infections per 1,000 catheter-days in medical-surgical ICUs) (1). They should also be considered in neutropenic patients and burn patients.

Peripherally Inserted Central Catheters

Long catheters (50 to 60 cm in length) can be inserted in the basilic vein or cephalic vein in the arm and advanced into the superior vena cava (see Figure 6.5) (10,11). These *peripherally inserted central catheters* (PICCs) offer one advantage over cannulation of the more centrally located subclavian and internal jugular veins: Le., there is no risk of pneumothorax. PICCs are made of soft silicone rubber, and a guidewire is required to insert these catheters. PICC insertion is described briefly in the next section.

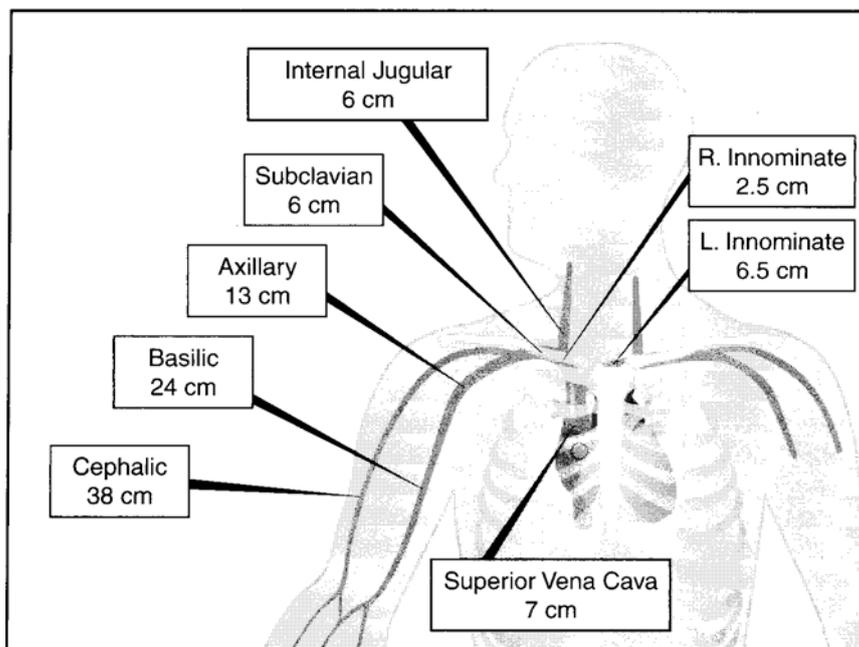


FIGURE 6.5 The length of venous segments involved in the insertion of peripherally inserted central catheters (PICCs) and central venous (i.e., subclavian and internal jugular vein) catheters. The circle in the third anterior intercostal space marks the junction of the superior vena cava and right atrium.

VENOUS ACCESS SITES

The following is a brief description of the common sites used for percutaneous cannulation of the venous system, including the advantages and disadvantages of each site, and the surface landmarks used to locate each target vessel.

The Upper Extremity

Cannulation of peripheral veins provides rapid and safe access to the systemic circulation. As mentioned earlier, the catheters used to cannulate peripheral veins are typically narrow (18 to 22 gauge) and short (5 cm or 2 inches) and are inserted using a catheter-over-needle device like the one in Figure 6.2. These peripheral venous catheters should be replaced every 3 to 4 days (using a new venipuncture) to limit the risk of phlebitis (1). The arms are preferred over the legs because of the higher incidence of venous thrombosis in the legs (1).

Comment

Cannulation of peripheral veins is best suited for rapid, short-term venous access (e.g., in the emergency department) and is advantageous

for acute volume resuscitation because the catheters are short. For most ICU patients, who are often clinically unstable or require prolonged venous access, cannulation of the large central veins is more appropriate. For the few ICU patients who are chronically stable and require prolonged infusion therapy, peripherally inserted central catheters (PICCs) should be considered.

Peripherally Inserted Central Catheters (PICCs)

PICCs are inserted percutaneously into the veins of the antecubital fossa and advanced into the superior vena cava. There are two veins that emerge from the antecubital fossa, as shown in Figure 6.5. The basilic vein runs up the medial aspect of the arm, and the cephalic vein runs up the lateral aspect of the arm. The basilic vein is preferred for PICC placement because it is slightly larger than the cephalic vein (8 mm vs. 6 mm in diameter), and it runs a straighter course up the arm.

POSITIONING THE CATHETERS. Once inserted, PICCs should be advanced into the lower third of the superior vena cava, just above the junction of the superior vena cava and right atrium. This can be done blindly or with the aid of fluoroscopy. For blind catheter placement, the measurements in Figure 6.5 (which apply to an average-sized adult) will help determine the appropriate length of catheter insertion. For cannulation of the right and left basilic veins, the distance to the right atrium is 52.5 cm and 56.5 cm, respectively. For cannulation of the right and left cephalic veins, the distance to the right atrium is 53.5 cm and 57.5 cm, respectively. These approximate measurements can be used to guide catheter placement, or a direct measurement can be made of the distance from the antecubital fossa to the right third intercostal space in individual patients. Without fluoroscopic guidance, malposition of PICCs is common (10,11).

Comment

PICCs can be left in place for 30 days or longer without an increased risk of catheter-related septicemia when compared with central venous catheters (10,11). However, thrombotic obstruction of these catheters can be problematic because of their narrow bore, and mechanical phlebitis can be a problem because of their long length (10). The only advantage of PICCs over central venous catheters is the absence of any risk of pneumothorax. However, as you will see, the risk of pneumothorax from central venous catheters is minimal if the procedure is performed by experienced personnel. Overall, PICCs offer few advantages over central venous catheters. They can be used for long-term (30 days or longer) infusion therapy in clinically stable patients, but they have no role in the care of acutely ill or unstable patients.

The Subclavian Vein

The subclavian vein is well suited for cannulation because it is a large vessel (with a diameter of 20 mm) that runs a fixed course. The major l

TABLE 6.3 Adverse Effects of Large-Vein Cannulation*

Adverse Effect	Complication Rates		
	Subclavian Vein	Internal Jugular Vein	Femoral Vein
Arterial puncture	1%-15%	3%	9% ^t
Major Bleeding	2%	1%	1%
Occlusive Thrombosis	1%	0	6% ^t
Pneumothorax	1%-3%	1%	–
Systemic sepsis	1%-4%	0-8%	2%-5%

^tCombined data from References 16-18. Rates shown here are rounded to the whole number.

^tIndicates a rate that is significantly different from the others.

concern with subclavian vein cannulation is the risk of pneumothorax, but, as demonstrated in Table 6.3 (12-14), this is not a common occurrence. Major bleeding is also uncommon, and the presence of a coagulopathy does not increase the risk of bleeding. In fact, the presence of a coagulation disorder is not a contraindication to placement of central venous catheters (15-17). Based on the information in Table 6.3, subclavian vein catheterization is a reasonably safe procedure when performed by experienced personnel.

Anatomy

The subclavian vein is a continuation of the axillary vein as it passes over the first rib (see Figure 6.5). It runs most of its course along the underside of the clavicle, and at some points is only 5 mm above the apical pleura of the lungs. The underside of the vein sits on the anterior scalene muscle, with the subclavian artery situated just deep to the muscle. Since the artery lies deep to the vein, avoiding deep penetration by the probe needle will limit the risk of subclavian artery puncture. The subclavian vein continues to the thoracic inlet, where it joins the internal jugular vein to form the innominate vein. The convergence of the right and left innominate veins forms the superior vena cava.

The average distance from cannulation sites in the subclavian (and internal jugular) vein to the right atrium can be inferred from the vein lengths in Figure 6.5. The average distance is 14.5 cm and 18.5 cm for right-sided and left-sided cannulations, respectively. Therefore to avoid placing catheters in the right side of the heart (which creates a risk of cardiac perforation), catheters used for subclavian and internal jugular vein cannulation should be no longer than 15 cm in length (18).

Locating the Vessel

The insertion points on the skin for subclavian vein cannulation are shown in Figure 6.6. To locate the subclavian vein, identify the sternocleidomastoid muscle, which is the large muscle that runs down the neck

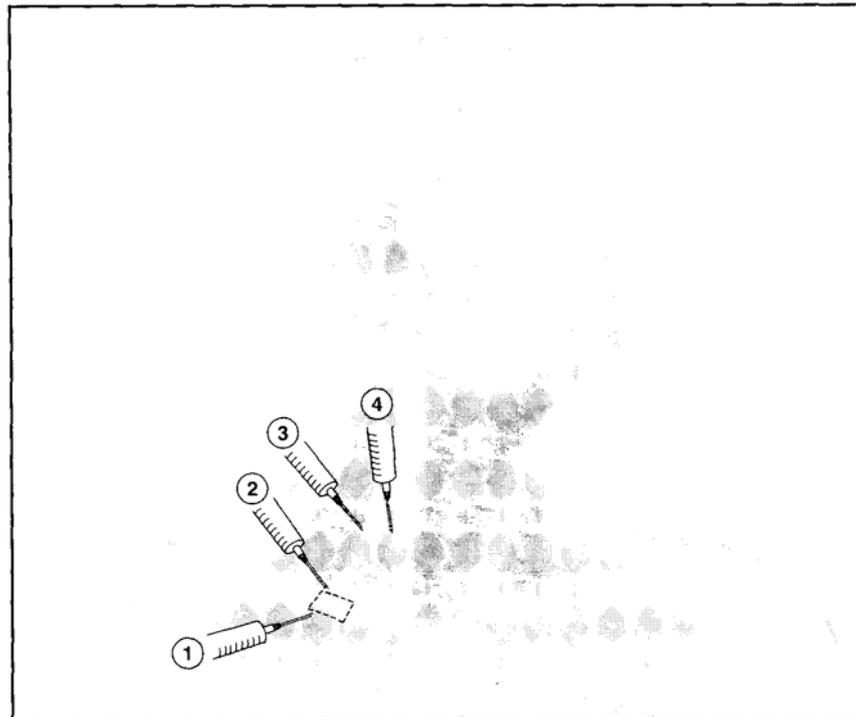


FIGURE 6.6 The points of entry and appropriate orientation of probe needles for cannulation of the subclavian vein (points 1 and 2) and internal jugular vein (points 3 and 4).

on either side of the midline. This muscle splits into a medial portion that inserts on the sternum and a lateral portion that inserts on the clavicle. Identify the lateral head of the muscle (by palpation if necessary), and note where the muscle inserts onto the clavicle. The subclavian vein lies just underneath the clavicle at this point. Mark the area of the clavicle that overlies the vein, as shown in Figure 6.6. The vein can be entered at this point from above or below the clavicle.

INFRACLAVICULAR APPROACH (NEEDLE POSITION 1 IN FIG. 6.6). The probe needle should enter the skin just below the clavicle and at the lateral boundary of the site marked on the clavicle. The bevel of the needle should be pointed upward (toward the ceiling) during insertion, and the needle should be advanced under the marked area on the clavicle. The needle will puncture the vein within a few centimeters of the surface. When the vein is entered, the bevel of the needle should be rotated to 3 o'clock so the guidewire threads in the direction of the superior vena cava. A common mistake made by the inexperienced is inserting the needle at the bend in the clavicle, which places the needle too far from the target vessel (probe needles are only a few inches in length, and might not reach the vein if the skin puncture is removed from the vein).

SUPRACLAVICULAR APPROACH (NEEDLE POSITION 2 IN FIG. 6.6).

This approach is the easier of the two. Identify the angle formed by the lateral margin of the sternocleidomastoid muscle and the clavicle. The probe needle is inserted so that it bisects this angle. Keep the bevel of the needle facing upward, and direct the needle under the clavicle in the direction of the opposite nipple. The vein should be entered at a distance of 1 to 2 cm from the skin surface (the subclavian vein is more superficial in the supraclavicular approach). When the vein is entered, turn the bevel of the needle to 9 o'clock so the guidewire threads in the direction of the superior vena cava.

Comment

The subclavian vein should be preferred for central venous cannulation because of the ease of insertion, the low complication rate, and the high degree of patient acceptance once the catheter is in place. The fear of pneumothorax is not justified, at least when experienced personnel are performing the procedure. Avoiding deep penetration of the probe needle should limit the risk of subclavian artery puncture and pneumothorax.

The Internal Jugular Vein

Cannulation of the internal jugular vein was popularized because of the assumption that this procedure, which is performed at the base of the neck, should eliminate the risk of pneumothorax. However, this is not the case, as demonstrated in Table 6.3. In fact, the incidence of pneumothorax is almost the same following cannulation of the internal jugular vein and subclavian vein. How can a puncture at the base of the neck cause a pneumothorax? Aside from poor technique, it is possible that the cupola of the lung protrudes into the base of the neck as a result of the high tidal volumes used during mechanical ventilation. In addition to the occasional pneumothorax, cannulation of the internal jugular vein has other disadvantages, such as carotid artery puncture and poor patient acceptance due to limitations in neck mobility.

Anatomy

The internal jugular vein is located under the sternocleidomastoid muscle in the neck and runs obliquely down the neck on a line from the pinna of the ear to the sternoclavicular joint. Turning the head to the opposite side will straighten the course of the vein. Near the base of the neck, the internal jugular vein lies just lateral to the carotid artery in the carotid sheath, and this position creates the risk of carotid artery puncture.

Locating the Vessel

The right internal jugular vein is preferred because the vessels run a straighter course to the right atrium. This is particularly advantageous for placing temporary transvenous pacemakers and to ensure adequate flow through hemodialysis catheters. The vein can be entered from an anterior or posterior approach.

THE ANTERIOR APPROACH (NEEDLE POSITION 4 IN FIG. 6.6). For the anterior approach, the operator must first identify a triangular area at the base of the neck created by the separation of the two heads of the sternocleidomastoid muscle. The carotid artery pulse is then palpated with the fingers of the left hand (for a right-sided approach), and the artery is retracted toward the midline. The probe needle is then inserted at the apex of the triangle with the bevel facing up, and the needle is advanced toward the ipsilateral nipple, at a 45° angle with the skin surface. If the vein is not entered by a depth of 5 cm, the needle is drawn back and advanced again in a more lateral direction. Two failed attempts should warrant abandoning this approach for the posterior approach.

THE POSTERIOR APPROACH (NEEDLE POSITION 3 IN FIG. 6.6). The insertion site for this approach is 1 centimeter superior to the point where the external jugular vein crosses over the lateral edge of the sternocleidomastoid muscle. The probe needle is inserted with the bevel positioned at 3 o'clock. The needle is advanced along the underbelly of the muscle in a direction pointing to the suprasternal notch. The internal jugular vein should be encountered 5 to 6 cm from the skin surface (19). The vein runs just lateral to the carotid artery in this region and can act as a shield for the carotid artery as long as the advancing needle is kept in the same plane as the internal jugular vein.

CAROTID ARTERY PUNCTURE. If the carotid artery has been punctured with a probing needle (as suggested by the return of pulsating bright red blood through the needle), the needle should be removed and pressure applied to the site for at least 5 minutes (double the compression time for patients with a coagulopathy). No further attempts should be made to cannulate the internal jugular vein on either side, to avoid puncture of both carotid arteries. If a catheter has been mistakenly placed in the carotid artery, do not remove the catheter because this could provoke serious hemorrhage. In this situation, get a vascular surgeon pronto.'

Comment

The internal jugular vein offers no advantages over the subclavian vein other than the occasional benefit for pacemaker catheters and hemodialysis catheters because of the straight course from the right internal jugular vein to the heart. The disadvantages of internal jugular vein cannulation (i.e., carotid artery puncture and poor patient acceptance) make this approach less desirable than subclavian vein cannulation.

The Femoral Vein

The femoral vein is the largest, easiest, and most problematic vein to cannulate. The problems with femoral vein cannulation include the risk for femoral artery puncture and a high rate of venous thrombosis (see Table 6.3). The risk of thrombosis may be overstated because most cases are clinically silent and without consequence (20). Earlier studies suggested a higher rate of infection with femoral vein catheters, but more recent observations (see Table 6.3) show no increase in infectious risk (14).

Anatomy

The femoral vein is the main conduit for venous drainage from the legs. In the proximal one-third of the thigh; the femoral vein runs next to the femoral artery. Both vessels are located in the medial portion of the femoral triangle (see Figure 6.7), with the femoral vein running just medial to the femoral artery. These blood vessels are within a few centimeters of the skin at the inguinal crease.

Locating the Vessel

The femoral vein can be located by palpating the femoral artery pulse just below the inguinal crease. The probe needle should be inserted (bevel up) 1 to 2 cm medial to the palpated pulse. The vein should be entered at a depth of 2 to 4 cm from the skin. If the femoral artery pulse is not palpable, draw an imaginary line from the anterior superior iliac crest to the pubic tubercle, and divide the line into three equal segments. The femoral artery should be just underneath the junction between the middle and medial segments, and the femoral vein should be 1 to 2 cm medial to this point. This method of locating the femoral vein results in successful cannulation in over 90% of cases (21).

Comment

The femoral vein is almost never recommended as a primary site for central venous cannulation because of the risk for venous thrombosis. Rather, it should be reserved for emergency cases where there is difficulty gaining venous access elsewhere. Some favor the femoral vein site during cardiopulmonary resuscitation because it does not disrupt resuscitation efforts in the chest (22). However, the American Heart Association discourages the use of leg veins in cardiac arrest because of a concern for delayed drug delivery (23). If femoral vein cannulation is necessary, the catheters should be removed as soon as possible to limit the risk of venous thrombosis.

Ultrasound Guidance

Two-dimensional ultrasound can be used to facilitate venous cannulation. An example of an ultrasound image obtained during cannulation of the internal jugular vein is shown in Figure 6.8. In this case, the ultrasound transducer is oriented along the long axis of the vein as the needle is advanced towards the vein. This type of real-time imaging (obtained while the procedure is performed) improves the success rate of cannulation and reduces the risk of accidental arterial puncture (22,24,25). Realtime ultrasound guidance has been used to facilitate cannulation of the large central veins (subclavian, internal jugular, and femoral veins) and

smaller peripheral veins in the arm (22,24-26). Most of the reported experience has been with the internal jugular vein, which is easy to visualize.

Comment

Ultrasound guidance for venous cannulation is expensive, time-consuming, and requires an experienced operator. As a result, this method is not used routinely but is reserved for situations where attempted central venous cannulation using anatomical landmarks has failed. Failed venous cannulation is most likely to occur when physicians with limited experience are attempting emergency venous cannulation, such as during cardiopulmonary resuscitation (27,28). Unfortunately, this situation is not well suited for the use of ultrasound because of the time required and the need for experienced personnel. Therefore ultrasound is rarely a useful adjunct for venous cannulation.

IMMEDIATE CONCERNS

Venous Air Embolism

Air entry into the venous circulation is one of the most feared complications of central venous cannulation in the chest. Fortunately, this complication can be prevented with attention to the measures described in the next section.

Preventive Measures

When the tip of a venous catheter is advanced into the thorax, the negative intrathoracic pressures generated during spontaneous breathing can draw air into the venous circulation through an open catheter and produce a venous air embolism. A pressure gradient of only 4 mm Hg along a 14-gauge catheter can entrain air at a rate of 90 mL/second and produce a fatal air embolus in one second (29). This highlights the importance of keeping the venous pressure higher than the atmospheric pressure to prevent venous air embolism. This is facilitated by placing the patient in the Trendelenburg position with the head 15° below the horizontal plane. Remember that the Trendelenburg position does not prevent venous air entry because patients still generate negative intrathoracic pressures while in the Trendelenburg position. When changing connections in a central venous line, a temporary positive pressure can be created by having the patient hum audibly. This not only produces a positive intrathoracic pressure but allows clinicians to hear when the intrathoracic pressure is positive. In ventilator-dependent patients, the nurse or respiratory therapist should initiate a mechanical lung inflation when changing connections.

Clinical Presentation

The usual presentation is acute onset of dyspnea that occurs during the procedure. Hypotension and cardiac arrest can develop rapidly. Air can pass across a patent foramen ovale and obstruct the cerebral circulation,

producing an acute ischemic stroke. A characteristic "mill wheel" murmur can be heard over the right heart, but this murmur may be fleeting.

Therapeutic Maneuvers

If a venous air embolism is suspected, a syringe should be attached to the hub of the catheter immediately (to prevent any further air entry), and you should attempt to aspirate air through the indwelling catheter. The patient can also be placed with the left side down, which presumably keeps air in the right side of the heart. In dire circumstances, a needle can be inserted through the anterior chest wall and into the right ventricle to aspirate the air. (This is accomplished by inserting a long needle in the fourth intercostal space just to the right of the sternum and advancing the needle under the sternum at a 45 degree angle until there is blood return.) Unfortunately, in severe cases of venous air embolism, the mortality is high despite any of the suggested therapeutic maneuvers.

Pneumothorax

Pneumothorax is a feared complication of subclavian vein cannulation but can also occur with jugular vein cannulation (2,30). The risk of pneumothorax is one of the principal reasons that postinsertion chest x-rays are recommended after central venous cannulation (or attempts). Postinsertion chest x-rays should be obtained in the upright position and during expiration, if possible. Films obtained during expiration will facilitate the detection of a small pneumothorax because expiration decreases the volume of air in the lungs but not the volume of air in the pleural space. Thus during expiration, the volume of air in the pleural space is a larger fraction of the total volume of the hemithorax, thereby magnifying the radiographic appearance of the pneumothorax (31).

Upright films are not always possible in ICU patients. When supine films are necessary, remember that pleural air does not collect at the apex of the lung when the patient is in the supine position (32,33). In this situation, pleural air tends to collect in the subpulmonic recess and along the anteromedial border of the mediastinum (see Chapter 26), which are the highest points in the thorax in the supine position.

Delayed Pneumothorax

A catheter-induced pneumothorax may not be radiographically evident until 24 to 48 hours after catheter insertion (31,33), which means that the absence of a pneumothorax on an immediate postinsertion chest film does not absolutely exclude the possibility of a catheter-induced pneumothorax. This is an important consideration only in patients who develop dyspnea or progressive hypoxemia in the first few days after central venous cannulation. For patients who remain asymptomatic after a central venous catheter is inserted, serial chest x-rays are not justified.

Catheter Tip Position

A properly placed subclavian or internal jugular vein catheter should run parallel to the shadow of the superior vena cava, and the tip of the

catheter should be at or slightly above the third anterior intercostal space (see Figure 6.5). The following catheter mal positions warrant corrective measures.

Tip Against the Wall of the Vena Cava

Catheters inserted from the left side must make an acute turn downward when they enter the superior vena cava from the left innominate vein. Catheters that do not make this turn can end up in a position like the one shown in Figure 6.9. The tip of this catheter is pointed directly at the lateral wall of the superior vena cava and can perforate the vessel (see Figure 7.1). Catheters in this position should either be withdrawn into the innominate vein or advanced further down the superior vena cava.

Tip in the Right Atrium

A catheter tip that extends below the third right anterior intercostal space is likely to be in the right side of the heart. These catheters are considered a risk for cardiac perforation (31). However, cardiac perforation is rare (35), even though over half of central venous catheters may be misplaced in the right atrium (35). Despite the low risk for cardiac perforation, placement of catheters in the right side of the heart should be avoided. This is best accomplished by using central venous catheters that are no longer than 15 cm in length, as mentioned earlier. If a catheter tip extends below the third anterior intercostal space, the catheter should be withdrawn until the tip is in the appropriate position. If the anterior portion of the third rib cannot be visualized, keep the catheter tip at or above the tracheal carina (i.e., the division of the trachea into the right and left main-stem bronchi)

Chapter 7

THE INDWELLING VASCULAR CATHETER

This chapter is a continuation of Chapter 6 and describes the routine care and adverse consequences of indwelling vascular catheters. Many of the recommendations in this chapter are taken from the clinical practice guidelines and reviews listed in the bibliography at the end of the chapter (0-4).

ROUTINE CATHETER CARE

The following practices are designed to prevent or limit complications of indwelling vascular catheters.

Protective Dressings

Catheter insertion sites on the skin are covered at all times as a standard antiseptic measure. Although sterile gauze is adequate (0), catheter insertion sites are often covered with costly adhesive dressings made of transparent, semipermeable polyurethane membranes (5-7). These dressings (e.g., Opsite, Tegaderm) partially block the escape of water vapor from the underlying skin and create a moist environment that is considered beneficial for wound healing. Although they allow inspection of the underlying catheter insertion site, occlusive polyurethane dressings do not reduce the incidence of catheter colonization or infection when compared to sterile gauze dressings (0,5-7). In fact, occlusive dressings can *increase* the risk of infection (5,6) because the enhanced moisture they create provides a favorable environment for the growth of microorganisms. Because of the added cost and minimal benefit provided by occlusive polyurethane dressings, sterile gauze should be the preferred dressing for most catheter insertion sites. Adhesive polyurethane dressings can be

reserved for catheter insertion sites that are close to a source of infectious secretions (e.g., internal jugular vein insertion sites that are close to a tracheostomy).

Antimicrobial Ointment

Antimicrobial ointments or gels are often applied to the insertion site of central venous catheters. These ointments are applied when the catheter is inserted and then re-applied each time the dressings are changed (which is usually every 48 hours). However, this practice does not reduce the incidence of catheter-related infections (3), and it can promote the development of antibiotic-resistant organisms (8). Therefore, it is wise to avoid the use of topical antimicrobial ointments on catheter insertion sites (0,3).

Replacing Catheters *Peripheral Venous Catheters*

The risk with peripheral vein cannulation is phlebitis (from the catheter or infusate), not septicemia. The incidence of phlebitis increases significantly after peripheral vein catheters are left in place longer than 72 hours (1), but the incidence does not change from 72 to 96 hours (9). Therefore, replacement of peripheral vein catheters (using a new venipuncture site) is recommended every 72 to 96 hours (0).

Central Venous Catheters

Septicemia from central venous catheters begins to appear after catheters have been in place for 3 days (0,10). This observation led to the common practice of replacing vascular catheters every few days to reduce the risk of infection. However, replacing vascular catheters at regular intervals, using either guidewire exchange or a new venipuncture site, does not reduce the incidence of catheter-related infections (1) and may actually increase the risk of complications (both mechanical and infectious) (2). This latter point deserves emphasis because there is a 7% complication rate associated with replacement of central venous catheters (3). The lack of benefit combined with the added risk is the reason that routine replacement of indwelling vascular catheters is not recommended (0,3,4).

Indications for Catheter Replacement

Vascular catheters should be replaced in the following situations:

When there is purulent drainage from the catheter insertion site.

Erythema around the insertion site of a central venous catheter is not absolute evidence of infection (3) and is not an indication for catheter replacement.

When a percutaneously inserted vascular catheter is suspected as a source of systemic sepsis and the patient has a prosthetic valve, is immunocompromised, or has severe sepsis or septic shock.

When a catheter has been placed emergently, without strict aseptic technique, and it can be replaced safely.

When a femoral vein catheter has been in place longer than 48 hours and it can be replaced safely. This will limit the risk of venous thrombosis from femoral vein catheters (see Table 6.3).

Flushing Catheters

Vascular catheters are flushed at regular intervals to prevent thrombotic obstruction, although this may not be necessary for peripheral catheters used for intermittent infusions (4). The standard flush solution is heparinized saline (with heparin concentrations ranging from 10 to 1,000 units/mL (1,15)). Catheter lumens that are used only intermittently are capped and filled with heparinized saline when idle. (The term *heparin lock* is used to describe this process because the cap that seals the catheter creates a partial vacuum that holds the flush solution in place.) Arterial catheters are flushed continuously at a rate of 3 mL/hour using a pressurized bag to drive the flush solution through the catheter (16).

Alternatives to Heparin

The use of heparin in catheter flush solutions has two disadvantages: the cost of the heparin (which can be substantial if you consider all the catheter flushes that are performed each day in a hospital), and the risk of heparin-induced thrombocytopenia (see Chapter 37). These disadvantages can be eliminated by using heparin-free flush solutions (see Table 7.1). Saline alone is as effective as heparinized saline for flushing venous catheters (5). This is not the case for arterial catheters (6), but 1.4% sodium citrate is a suitable alternative to heparinized saline for flushing arterial catheters (7).

TABLE 7.1 Alternatives to Heparinized Flushes

Vascular Device	Alternate Flush Technique	Indications
Central and peripheral venous catheters	Flush with 0.9% sodium chloride, using the same volume (1-5 mL) and time interval (every 8-12 hr) used with heparin (14)	Standard protocol for all venous catheters
Peripheral venous catheters	Flush with 0.9% sodium chloride (1-5 mL) only after drug administration (16)	Standard protocol for peripheral catheters
Arterial catheters	Flush with 1.4% sodium citrate, using a continuous-flow technique (17)	Heparin-induced thrombocytopenia

MECHANICAL COMPLICATIONS

The mechanical complications of indwelling catheters can be classified as occlusive (e.g., catheter or vascular occlusion) or erosive (e.g., vascular or cardiac perforation). The following are the more common or preventable mechanical complications.

Catheter Occlusion

Sources of catheter occlusion include sharp angles or kinks and localized indentations along the catheter (usually created during insertion), thrombosis (from backwash of blood into the catheter), insoluble precipitates in the infusates (from medications or inorganic salts), or lipid residues (from total parenteral nutrition). Thrombosis is the most common cause of catheter obstruction, and thrombotic occlusion is the most common complication of indwelling central venous catheters (4). Insoluble precipitates can be the result of drugs that have limited solubility in water (e.g., barbiturates, diazepam, digoxin, phenytoin, and trimethoprim-sulfa) or anioncation complexes (e.g., calcium phosphate and heparin-aminoglycoside complexes) precipitated by an acid or alkaline pH (8,19).

Signs of catheter occlusion include limited flow (partial occlusion), cessation of infusate (forward) flow but able to withdraw blood (partial occlusion), and total cessation of flow in both directions (complete occlusion).

Restoring Patency

Every effort should be made to relieve catheter occlusion and avoid replacing the catheter. Replacement over a guidewire is not advised because the guidewire can dislodge an obstructing mass and create an embolus, so a new venipuncture site is required to replace obstructed catheters.

THROMBOTIC OCCLUSION. Since thrombosis is the most common cause of catheter occlusion, the initial attempt to restore patency should involve the local instillation of a thrombolytic agent. Table 7.2 shows a regimen using alteplase (recombinant tissue plasminogen activator) that has proven 90% effective in restoring patency in partially and completely occluded vascular catheters (9-21). The total thrombolytic dose in this regimen (up to 4 mg) is too small to cause systemic thrombolysis, even if the entire dose is reaches the systemic circulation (9).

Non-Thrombotic Occlusion

Dilute acid will promote the solubility of calcium phosphate precipitates and some medications, and catheter occlusion refractory to thrombolytic agents will occasionally respond to instillation of 0.1N hydrochloric acid (22). If lipid residues are suspected as a cause of catheter occlusion (i.e., in patients receiving concentrated lipid infusions as part of a parenteral nutrition regimen), instillation of 70% ethanol (2 mL) can restore catheter patency (9).

TABLE 7.2 A Protocol for Restoring Patency in Occluded Vascular Catheters

Drug: Alteplase (recombinant tissue plasminogen activator)
Preparation: Reconstitute 50 mg vial of alteplase with 50 mL sterile water for a drug concentration of 1 mg/mL. Prepare 2 mL aliquots and freeze until needed.

Regimen:

1. Thaw two aliquots (2 mL each) of drug solution. (Drug must be used within 8 hr after thawing).
2. Draw 2 mL of drug solution (2 mg) into a 5 mL syringe and attach to hub of the occluded catheter.
3. Inject as much volume as possible (2 mL) into the lumen of the catheter and then cap the hub of the catheter.
4. Leave the drug solution in the catheter lumen for 2 hr (dwell time).
5. Attempt to flush the catheter with a saline solution. DO NOT use a tuberculin syringe to flush occluded catheters (the high velocities generated by these syringes can fracture the hub of a catheter).
6. If the catheter is still obstructed, repeat steps 1 up to 4.
7. If the catheter remains obstructed, consider using 0.1 N HCL (2 mL) for drug or calcium phosphate precipitates, or 70% ethanol (2 mL) if lipid residues are suspected. Otherwise, replace the catheter.

From References 19-22.

Venous Thrombosis

Thrombus formation around the catheter can occasionally extend to cause thrombotic obstruction of the surrounding vein. The following types of venous thrombosis can originate from an indwelling vascular catheter.

Upper Extremity Thrombosis

Clinically apparent thrombosis of the subclavian vein occurs in about 1 % of patients with subclavian vein catheters (see Table 6.3). The hallmark of subclavian vein thrombosis is unilateral arm swelling on the side of the catheter insertion (23). Symptomatic pulmonary embolism can occur, but the reported incidence varies from zero to 17% (23,24). On occasion, the thrombus can extend proximally into the superior vena cava (23), but complete occlusion of the superior vena cava with the resultant *superior vena cava syndrome* (swelling of neck and face, etc.) is rare (25).

Doppler ultrasound is often used to evaluate possible subclavian vein thrombosis, but the sensitivity and specificity of this test can be as low as 56% and 69%, respectively (26). Contrast venography is the gold standard but is rarely performed.

If a subclavian vein thrombosis is confirmed, the catheter should be removed. Systemic anticoagulation with heparin is a popular (but not standard) therapy for catheter-induced subclavian vein thrombosis

(23,24), but the efficacy of this treatment is unproven, and there are no guidelines regarding duration of treatment or the need for continued anticoagulation with coumadin.

Lower Extremity Thrombosis

As mentioned in the last chapter, the risk of venous thrombosis is higher with femoral catheters than subclavian or internal jugular vein catheters (see Table 6.3), and this is why the femoral vein is almost never used as a primary site for central venous cannulation. The diagnosis and treatment of deep vein thrombosis in the legs is described in detail in Chapter 5 and will not be repeated here.

Vascular Perforation

Catheter-induced perforations of the superior vena cava and right atrium are uncommon but avoidable complications of central venous cannulation, as described at the end of Chapter 6. Attention to proper catheter position is the most important measure for preventing perforation.

Superior Vena Cava Perforation

Perforation of the superior vena cava is most often caused by left-sided central venous catheters that cross the mediastinum and enter the superior vena cava but do not make the acute turn downward toward the heart (see Figures 6.9 and 7.1) (27). This complication has also been reported after guidewire exchange of left-sided catheters (28). Perforation can occur at any time in the life span of an indwelling catheter. Most occur in the first 7 days after catheter insertion, but perforations have been reported up to 2 months after catheter placement (27). The clinical symptoms (substernal chest pain, cough, and dyspnea) are nonspecific, and suspicion is usually raised by the sudden appearance of mediastinal widening or a pleural effusion on a chest x-ray (see Figure 7.1). The pleural effusions represent leakage of the infusion fluid, and they can be unilateral (right- or left-sided) or bilateral. The unexpected appearance of a pleural effusion in a patient with a central venous catheter should always raise suspicion of superior vena cava perforation.

DIAGNOSIS. Thoracentesis is required to confirm that the pleural fluid is similar in composition to the infusion fluid. Pleural fluid glucose levels are useful if the infusion fluid is a glucose-rich parenteral nutrition formula. The diagnosis can be confirmed by injecting radiocontrast dye through the catheter: the presence of dye in the mediastinum confirms the perforation.

MANAGEMENT. When vena cava perforation is first suspected, the infusion should be stopped immediately. If the diagnosis is confirmed, the catheter should be removed immediately (this does not provoke mediastinal bleeding) (27). Antibiotic therapy is not necessary (27) unless there

is evidence of infection in the pleural fluid. If the pleural effusion is a glucose-rich parenteral nutrition formula, it is wise to drain the effusion because the high glucose concentration provides a favorable medium for microbial proliferation.

Cardiac Tamponade

Cardiac perforation from a catheter misplaced in the right heart chambers is a rare but life-threatening complication of central venous cannulation. Perforation can lead to rapidly progressive cardiac tamponade and sudden cardiovascular collapse (29), and the diagnosis can be overlooked in the commotion of cardiopulmonary resuscitation. Immediate pericardiocentesis is necessary to confirm the diagnosis (the fluid will

have the same composition as the infusate) and to relieve the tamponade. Emergency thoracotomy may be necessary if there is a large tear in the wall of the heart. Repositioning catheters that extend below the right third anterior intercostal space (which marks the junction of the superior vena cava with the right atrium) should prevent this life-threatening complication.

INFECTIOUS COMPLICATIONS

Hospital-acquired (nosocomial) bloodstream infections occur 2 to 7 times more often in ICU patients than in other hospitalized patients (30), and indwelling vascular catheters are responsible for over half of these bloodstream infections (31). Catheter-related bloodstream infections add to the morbidity and mortality of the ICU stay (32).

Pathogenesis

Biofilms

Most microorganisms are not free-living but exist in protected colonies called *biofilms* that are found on moist environmental surfaces (the slippery material that covers rocks in a stream is a biofilm). Biofilm formation takes place in two stages: the attachment of the microbe to the object, and the production of an extracellular matrix (called a glycocalyx or *slime*) that surrounds the microbes and protects them from adverse environmental conditions. The protected environment of the biofilm allows microbes to thrive and proliferate (33).

Biofilms can also form on the surface of implanted medical devices, including urinary and vascular catheters (34). The biofilms that form on vascular catheters can shield the encased microbes from circulating antibiotics, and antibiotic concentrations must be 100 to 1,000 times greater to eradicate bacteria in biofilms than to kill free-flowing bacteria (2).

Staphylococci epidermidis, which is the organism most frequently involved in catheter-related bloodstream infections, shows a propensity for adhering to polymer surfaces and producing a protective biofilm (see Figure 7.2) (35). Understanding the behavior of biofilms has important implications for the prevention and management of infections arising from medical devices. For example, hydrogen peroxide has been shown to disrupt biofilms (36), and it is possible that such "biocides" will prove much more effective in eradicating catheter-related infections than conventional antimicrobial therapy. Biofilms deserve much more attention if we are to develop a more effective approach to infections involving indwelling medical devices.

Sources of Infection

The common sources of infection involving indwelling vascular catheters are shown in Figure 7.3. Each source is described below by using the corresponding numbers in Figure 7.3.

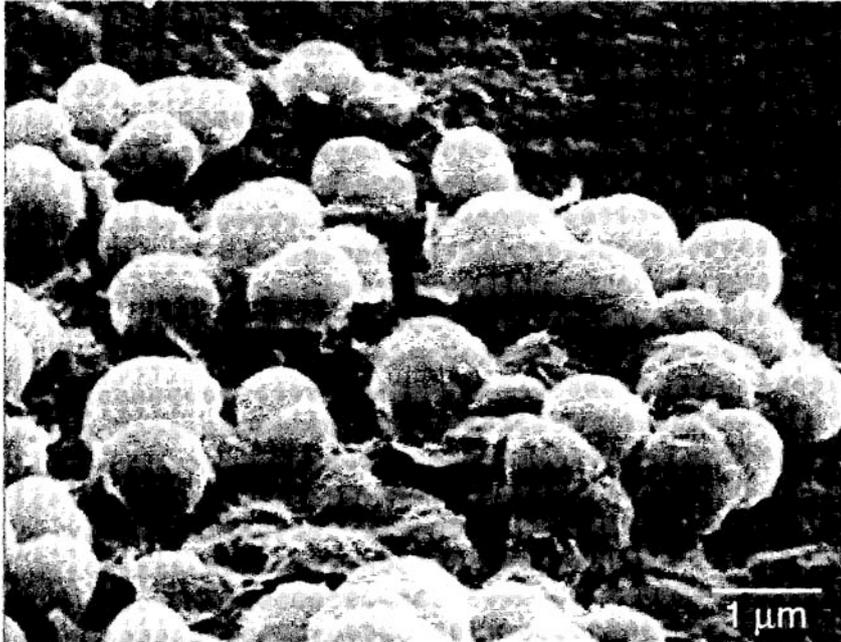


FIGURE 7.2 Electron micrograph of a biofilm formed by *Staphylococcus epidermidis*. The large, rounded tufts represent bacteria that are encased in an extracellular matrix. (Image courtesy of Jeanne M. Van Briesen, and Vanessa Dorn Briesen, Department of Biomedical Engineering Carnegie Mellon University.)

Microbes can gain access to the internal lumen of vascular catheters through break points in the infusion system, such as stopcocks and catheter hubs. This may be a prominent route of infection for long-term catheters inserted through a subcutaneous tunnel (2).

Microbes on the skin can migrate along the subcutaneous tract created by indwelling catheters. This is considered the principal route of infection for percutaneous (non-tunneled) catheters (2).

Microorganisms in circulating blood can attach directly to indwelling vascular catheters or can become trapped in the fibrin meshwork that surrounds indwelling catheters.

Definitions

The Centers for Disease Control and Prevention has identified the following infectious complications of indwelling vascular catheters (2).

Catheter colonization is characterized by significant growth of a microorganism on the catheter (the criteria for significant growth are presented later in the chapter) but no growth in blood cultures.

Exit-site infection is present when there is drainage from the catheter insertion site that grows a microorganism on culture. Blood cultures may be positive or negative.

Catheter-related septicemia is present when a blood culture taken from a site other than the catheter grows a microorganism and the same microorganism is isolated in significant numbers from the catheter or from blood withdrawn through the catheter.

Clinical Features

Catheter colonization is asymptomatic, while catheter-related septicemia is usually accompanied by non-specific signs of systemic inflammation (i.e., fever, leukocytosis, etc.). The diagnosis of catheter-related septicemia is not possible on clinical grounds (2). Purulent drainage from the catheter insertion site is uncommon and could indicate exit-site infection without septicemia, and the presence or absence of inflammation around the insertion site has no predictive value for the presence or absence of bloodstream infection (2,13). Catheter-related septicemia is usually suspected when a patient with a vascular catheter in place for longer than 48 hours has an unexplained fever. Confirmation requires identification of the same organism in blood and on the catheter.

Culture Methods

The following culture methods are useful for the diagnosis of catheter-related septicemia.

Quantitative Blood Cultures

This method requires two blood specimens (see Table 7.3): One specimen is withdrawn through the indwelling vascular catheter, and the other is drawn from a peripheral vein. The blood is processed by lysing the cells to release intracellular organisms then adding broth to the supernatant (Isolator System, Dupont, Wilmington, DE). This mixture is placed on an

TABLE 7.3 Diagnosis of Catheter-Related Septicemia using Quantitative Blood Cultures

Specimens: 10 mL blood withdrawn through the indwelling catheter and 10 mL blood drawn from a peripheral vein. Place blood specimens in evacuator tubes (e.g., Isolator System, Dupont Co.). DO NOT place blood specimens in routine culture bottles.

Criteria for catheter-related septicemia:

The same species of organism must be isolated from both blood specimens, and condition A or B must be satisfied

A. Blood from the catheter grows ~ 1 00 colony-forming units per mL (CFU/mL)

B. Colony count from catheter blood is ~5 times greater than colony count from peripheral blood

Test performance: Sensitivity = 40%-50%

Comment: This method does not require removal of the indwelling catheter, it has a low sensitivity because it does not detect infections arising from the outer surface of the catheter

All information in this table is taken from the clinical practice guideline in

agar plate and allowed to incubate for 24 hours. Growth is measured as the number of colony-forming units per milliliter (CPU / mL).

The criteria for the diagnosis of catheter-related septicemia are shown in Table 7.3. The same organism must be isolated from both blood samples (catheter and peripheral vein), *and* the colony count in blood from the catheter must be 100 CPU /mL or higher, or the colony count in catheter blood must be 5- to 10-fold higher than in peripheral blood (2). The comparative growth in a case of catheter-related septicemia is shown in Figure 7.4.

ADVANTAGES AND DISADVANTAGES. The major advantage of this culture method is that it obviates replacement of indwelling catheters. The major disadvantage is the inability to detect infections arising from the outer surface of the catheter, which may explain the low sensitivity (40 to 50%) of this method for detecting catheter-related septicemia (2).

Catheter Tip Cultures

The intravascular segment of the catheter can be cultured by removing the catheter and (using sterile technique) severing a 5 cm (2 inch) segment from the distal tip of the catheter. This is placed in a sterile culturette tube for transport to the microbiology laboratory. The following two culture methods are available (see Table 7.4).

SEMIQUANTITATIVE (ROLL-PLATE) CULTURE. The severed catheter segment is rolled directly over the surface of a blood agar plate, and the plate is incubated for 24 hours. Growth is measured as the number of colonyforming units (CPUs) on the agar plate after 24 hours, and significant growth is defined as ≥ 15 CFUs per catheter tip (2). This is the standard

method of culturing catheter tips, but it does not detect infections arising from the inner surface of the catheter.

QUANTITATIVE CULTURE. The catheter tip is placed in culture broth and vigorously stirred to release attached organisms. The broth is then subjected to serial dilutions and is placed on a blood agar plate. Significant growth is identified as ≥ 100 CFUs per catheter tip at 24 hours (2). This method can detect infections arising from both surfaces of a catheter, which explains why it has a higher sensitivity than the semiquantitative (roll plate) method for detecting catheter-related infections (see Table 7.4).

Which Method is Preferred?

The choice of culture method is dictated in part by the desirability of replacing the catheter. The quantitative blood culture method is preferred when replacement of indwelling catheters is not desirable. This situation arises when catheter replacement might not be necessary (e.g., for patients with isolated fever), when catheter replacement is not easily accomplished (i.e., for tunneled catheters, which must be surgically replaced), and when venous access is limited (e.g., chronic hemodialysis patients). Since over half of vascular catheters removed for suspected infection are sterile when cultured (2), the use of paired quantitative blood cultures will limit unnecessary catheter removal.

TABLE 7.4 Diagnosis of Catheter-related Septicemia using Catheter-Tip Cultures

Specimens:

1. The distal 5 cm of the catheter is severed and placed in a sterile culturette tube
2. One set of blood cultures is drawn from a peripheral vein

Culture methods:

Semiquantitative culture: The catheter tip is rolled across the surface of a blood agar plate, and the number of colony-forming units (CFUs) is recorded after 24 hr

Quantitative culture: The catheter tip is agitated in culture broth, and the broth is placed on a blood agar plate. Growth is recorded as the number of colony-forming units (CFUs) after 24 hr

Criteria for catheter-related septicemia:

The same species of organism must be isolated from the catheter tip and blood, and growth from the catheter tip should reveal the following:

- A. Semiquantitative culture: 2: 15 CFU
- B. Quantitative culture: 2:100 CFU

Test performance: Sensitivity of 60% for semiquantitative cultures and 80% for quantitative cultures

Comment: Semiquantitative cultures will miss infections arising from the inner surface of the catheter. Quantitative cultures are more sensitive for detecting catheter-related infections

All information in this table is taken from the clinical practice guideline in

Whenever catheter replacement is indicated (see earlier in the chapter), cultures of the catheter tip are essential. For catheter tip cultures, the quantitative method is preferred to the semiquantitative (roll-plate) method (2) because it can detect infection on both surfaces of the catheter and has a higher sensitivity for detecting catheter-related septicemia.

The Microbial Spectrum

A survey of 112 medical ICUs in the United States revealed the following microbial spectrum in primary hospital-acquired bacteremias (most caused by indwelling catheters) (37): coagulase-negative staphylococci, mostly *Staphylococcus epidermidis* (36%), enterococci (6%), gram-negative aerobic bacilli (*Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *E coli*, etc.) (6%), *Staphylococcus aureus* (3%), *Candida* species (11%), and other organisms (8%). About half of the infections involve staphylococci, and half involve organisms usually found in the bowel, including *Candida* organisms. This microbial spectrum is important to consider when selecting empiric antimicrobial therapy.

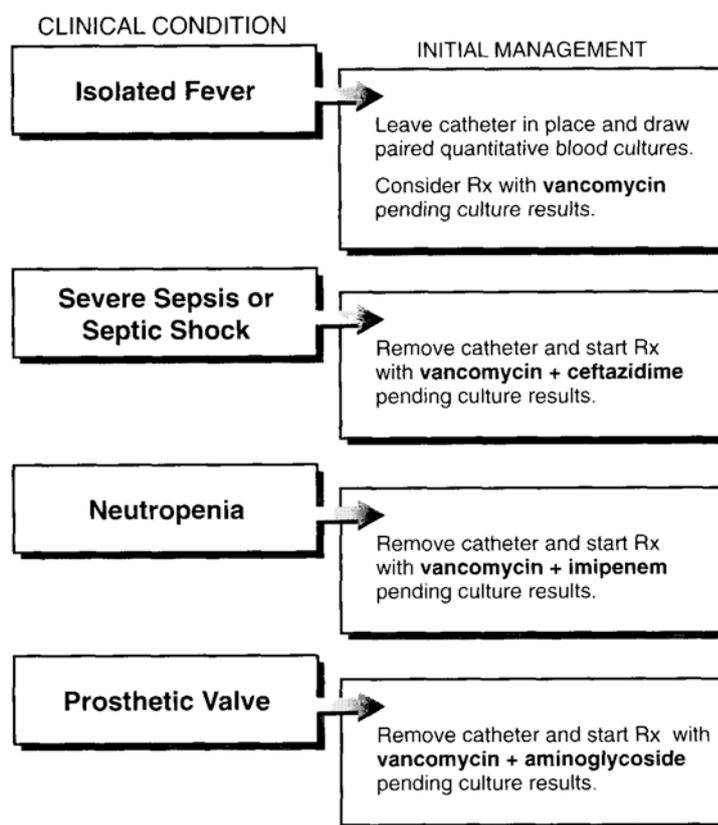


FIGURE 7.5 Recommendations for the initial management of suspected catheter-related septicemia. (From References 2 and 38.)

Management

The initial management of suspected catheter-related septicemia can be conducted as shown in Figure 7.5. In patients with isolated fever and no other signs of infection, catheters can be kept in place while performing paired, quantitative blood cultures. This approach is supported by studies showing that **up to 70%** of catheters removed for suspected catheter-related septicemia prove to be sterile (2). Removal of catheters is usually recommended for patients with the following: purulent drainage from the insertion site, severe sepsis, septic shock, neutropenia, or a prosthetic valve (2).

Empiric Antibiotic Therapy

Empiric antibiotic therapy is recommended for most patients with suspected catheter-related septicemia (2). Despite concern about vancomycin

TABLE 7.5 Directed Antimicrobial Therapy for Uncomplicated Cases of Catheter-Related Septicemia

Organism	Effective Antibiotics
Staphylococci	
Methicillin-sensitive	Nafcillin or oxacillin (2.9 g every 4 hr)
Methicillin-resistant (includes most strains of <i>S. epidermidis</i>)	Vancomycin (1 g every 12 hr)
Enterococci	
Ampicillin-sensitive	Ampicillin (2 g every 4-6 hr)
Ampicillin-resistant	Vancomycin (1 g every 12 hr)
Vancomycin-resistant	Linezolid (600 mg every 12 hr)
Gram-negative bacilli	Imipenem (500 mg every 6 hr) or
<i>E. coli</i>	Meropenem (1 g every 8 hr)
<i>Klebsiella</i> spp	
<i>Enterobacter</i> spp	For <i>P. aeruginosa</i> , some prefer
<i>P. aeruginosa</i>	Ceftazidime (2 g every 8 hr) or an Antipseudomonal penicillin
<i>Candida</i> organisms	Fluconazole (6 mg/kg/day) or Caspofungin (70 mg load, then 50 mg daily) Amphotericin B (0.7 mg/kg/day) is reserved for severe infections

Antibiotic recommendations from References 2 and 39.

resistance, this antibiotic is well-suited for suspected catheter-related infections because it is active against *Staph. epidermidis*, *Staph. aureus* (including methicillin-resistant strains), and most strains of enterococci (which together are responsible for over 50% of catheter-related infections). Gram-negative coverage with ceftazidime or cefepime (for antipseudomonal activity) can be added for patients with severe sepsis (i.e., sepsis plus dysfunction in 2 or more major organs) or septic shock, and for patients with neutropenia (neutrophil count $<500/\text{mm}^3$), a carbapenem (imipenem or meropenem) can be added to vancomycin (2,38). For patients with a prosthetic valve, an aminoglycoside should be added to vancomycin (the two agents can be synergistic for *Staph. epidermidis* endocarditis). The dosage of these antibiotics is shown in Table 7.5.

Directed Antibiotic Therapy

If the culture results confirm a catheter-related septicemia, directed antibiotic therapy can proceed using the antibiotics in Table 7.5 (2,39). For uncomplicated cases of catheter-related septicemia, 10 to 14 days of antibiotics is recommended, but only 5 to 7 days is sufficient for most cases of *Staph. epidermidis* septicemia (2). Antifungal therapy for

candidemia should continue for 14 days after blood cultures become sterile or signs of sepsis resolve (39). Catheters that have been left in place should be removed if cultures confirm the presence of catheter-related septicemia (2). There are two situations where catheters can be left in place if the patient shows a favorable response to antimicrobial therapy: when catheter removal is not easily accomplished (e.g., tunneled catheters), and when the responsible organism is *Staphylococcus epidermidis*. However, relapse after systemic antimicrobial therapy is higher when catheters have been left in place (40), and this relapse is less likely when *antibiotic lock therapy* is used (see next).

Antibiotic Lock Therapy

Antibiotic lock therapy involves the instillation of concentrated antibiotic solutions (usually 1 to 5 mg/mL) into the lumen of an infected catheter and leaving the solution in place for hours to days (2). This treatment is recommended only for infected catheters that have not been removed, and only when a lumen of the catheter is not used continuously for infusion therapy. It is best suited for tunneled catheters that have been in place for longer than 2 weeks, because these catheters are likely to have an intraluminal source of infection (2). The recommended duration of therapy is 2 weeks (2). This approach has had only limited success when *Candida* species are responsible for the infection (2).

Persistent Sepsis

Continued signs of sepsis after a few days of antibiotic therapy can signal the following conditions.

Suppurative Thrombosis

Thrombosis surrounding the catheter tip is a common finding in catheter-related septicemia (4), and if the thrombus becomes infected, it can transform into an intravascular abscess. When this occurs, there is persistent septicemia despite catheter removal and appropriate antimicrobial therapy. Purulent drainage from the catheter insertion site may or may not be evident (2), and thrombotic occlusion of the great central veins can result in ipsilateral arm swelling. Septic emboli in the lungs has also been reported in this condition (2). Catheter removal is mandatory in cases of suppurative thrombosis. Surgical incision and drainage is often required if peripheral vessels are involved. In the large central veins, antimicrobial therapy combined with heparin anticoagulation can produce satisfactory results in 50% of cases (41).

Endocarditis

Persistent septicemia despite antimicrobial therapy and catheter removal can also be a sign of infective endocarditis. Vascular catheters are the most common cause of nosocomial endocarditis, and *Staph. aureus* is the most common offending organism (2). Because of the risk of endocarditis, all

cases of *Staph. aureus* bacteremia should be evaluated for endocarditis (2). Transesophageal ultrasound is the procedure of choice. If vegetations are evident on ultrasound, 4 to 6 weeks of antimicrobial therapy is warranted (2).

Disseminated Candidiasis

Persistent candidemia or persistent sepsis despite broad spectrum antimicrobial therapy can be a sign of invasive candidiasis (42). The most common cause of this condition is vascular catheters, and patients at risk include those with abdominal surgery, burns, organ transplantation, human immunodeficiency virus infection, and those receiving cancer chemotherapy, long-term steroids, or broad-spectrum antimicrobial therapy (42). The diagnosis can be missed in over 50% of cases because blood cultures are often negative (43). Suspicion of this condition is often prompted by colonization of multiple sites with *Candida* organisms (e.g., urine, sputum, wounds, vascular catheters).

Clinical markers of disseminated candidiasis include candiduria in the absence of an indwelling urethral catheter and endophthalmitis. Heavy colonization of the urine in high-risk patients, even in the presence of an indwelling Foley catheter, can be used as an indication to initiate empiric antifungal therapy (44). Endophthalmitis can occur in up to one-third of patients with disseminated candidiasis (43) and can lead to permanent blindness. Because the consequences of this condition can be serious, all patients with persistent candidemia should have a detailed eye exam (43). The standard treatment for invasive candidiasis is amphotericin B (0.7 mg/kg/ day), which is now available in a special lipid formulation (liposomal amphotericin B, 3 mg/kg/ day) that produces less toxicity. The newer antifungal agent caspofungin (70 mg loading dose, followed by 50 mg/ day) has proven as effective as amphotericin for invasive candidiasis (45) and may become the preferred agent in this condition because of its safety profile. Unfortunately, satisfactory outcomes are achieved in only 60 to 70% of cases of invasive candidiasis despite our best efforts (45).

REFERENCES

